Middle East North Africa Sustainable ELECtricity Trajectories

Energy Pathways for Sustainable Development in the MENA Region

WORKING PAPER — Electricity Planning for Sustainable Development in the MENA Region

Criteria and indicators for conducting a sustainability assessment of different electricity generation technologies in Morocco, Jordan and Tunisia

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SUMMARY

The governments of Morocco, Jordan and Tunisia currently stand at a crossroads for new electricity pathways. While the deployment of renewable energies is receiving policy support across the region, fossil fuels—especially coal and natural gas—as well as nuclear power are prominent alternatives in the countries' development plans. This crossroads offers a unique opportunity to provide scientifically sound information on how to expand future electricity generation capacities in ways that are sensitive to the myriad of development challenges while avoiding a lock-in of the power sector in unsustainable pathways.

As electricity systems are not developed in isolation from society, but in a continuous interaction with social, economic, environmental, and political dimensions, this publication aims to develop a comprehensive database for the purpose of evaluating the complex trade-offs between different electricity generation technologies and sustainable development at the national and local level in Morocco, Jordan and Tunisia.

By shedding light on the intersection between electricity generation technologies, sustainable development and society, the results of this publication are intended to complement previous research on energy systems—that either focused on singular aspects of sustainable development, techno–economic aspects of electricity systems or on selected electricity technologies—with the "societal element" in electricity planning. Taken up by policymakers, project developers, civil society organization and researchers, the database of this document is furthermore envisioned to help in paving the way towards an energy system that is not only reliable, affordable and accessible but also socially robust and that contributes to sustainable development in Morocco, Jordan and Tunisia.

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ABREVIATIONS AND ACRONYMS

CO_2-eq	Carbon dioxide equivalents
CSP	Concentrated solar power
CSR	Corporate social responsibility
DLR	German Aerospace Center
DNI	Direct normal irradiation
GDP	Gross domestic product
ESIA	Environmental social impact assessment
FTE	Full time equivalent
GCC	Gulf Cooperation Council
GHG-	Greenhouse gas emission
GHI	Global horizontal irradiation
GIS	Geographic Information System
Ha/MW	Hectare per megawatt
HTFs	Heat transfer fluids
IEA	International Energy Agency
IFMEREE	Institute for Renewable Energy and Energy Efficiency in Morocco
INDC	Intended nationally determined contributions
IMC	Industrial Modernization Centre
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IRESEN	Institute of Research in Solar Energy and New Energies in Morocco
JEDI	Job and economic development model of NREL
KWh	Kilowatt hour
LCA	Life-cycle assessment
L/MWh	Litre per megawatt hour
LNG	Liquefied natural gas
LCOE	Levelized cost of electricity

MAD	Moroccan Dirham
MCDA	Multi-criteria decision analysis
MCI	Manufacturing, construction and installation
MDBs	Multilateral Development Banks
MENA	Middle East and North Africa
MEMEE	Ministry of Energy Morocco
Mtoe	Million tonnes of oil equivalent
MW	Megawatt
MWh	Megawatt hour
NERC	National Energy Research Center
NO_x	Nitrous oxides
NREL	National Renewable Energy Laboratory
OECD	Organisation for Economic Co-operation and Development
OM	Operation and maintenance
ONHYM	National Office of Hydrocarbons and Mines Morocco
PM	Particulate matter
PPA	Power purchase agreement
PV	Photovoltaics
RE	Renewable energy
R&D	Research & development
SME	Small and medium enterprises
SO_2	Sulphur dioxide
TPENI	Total primary energy net import
TPES	Total primary energy supplies
VAT	Value added tax
WRI	World Resource Institute

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1 INTRODUCTION

Middle Eastern and North African (MENA) countries are facing challenges from the convergence of rising needs for socio-economic development, environmental protection and political stability (UNDP, 2011). An important prerequisite for addressing these challenges are new electricity infrastructures as capacities to generate and distribute electric power are directly linked to development needs. In the MENA region the major part of electricity infrastructures necessary to respond to the increasing energy demands is still to be built. Hence, governments currently stand at a crossroads for new electricity policies. While the deployment of renewable energies (REs) is receiving policy support across the region, fossil fuels—especially coal and natural gas—as well as nuclear power are prominent alternatives in many MENA countries' development plans[1] (Mason & Kumetat, 2011).

This crossroads offers a unique opportunity to provide scientifically sound information on how to expand future electricity generation capacities in ways that are sensitive to the myriad of development challenges while avoiding a lock-in of the power sector in unsustainable pathways. Yet despite a broad public debate on energy, the scientific and political discussion about the future technology mix for supplying electricity in MENA countries has focused mainly on energy security objectives so far. As a consequence technological system optimization (reliable/uninterrupted supply), least-cost evaluation (affordable/competitive supply), and enabling framework conditions (accessible/available supply) tend to prevail in the energy decision-making of MENA countries (PWC, 2010; Dii, 2012; Dii, 2013; RCREEE, 2015; BETTER Project, 2015). Currently the questions about technological system optimization and the entire energy policy are dominated by experts' advice, developed through the application of the electricity system modelling. Only few existing research works focus on human factors, such as acceptance of new technologies, which play a role in the realization of the energy policy targets (Schinke et al., 2015).

Notwithstanding the importance of these aspects, their sole consideration in electricity planning cannot be regarded as sufficient. This is because electricity systems are not developed in isolation from society, but in a continuous interaction with social, economic, environmental, and political dimensions at the national and the local level (Oltra et al., 2014; Renn, 2015). The outcomes and processes of this

1 For details about the energy and electricity policies of the target countries see the MENA SELECT country fact sheets on Morocco (Schinke et al., 2016).

interaction are not only crucial for the integration of technologies into national electricity systems, but they also determine the attitudes and behaviours among the different members of a society and whether conditional supporters may turn into objectors towards the deployment of specific electricity technologies. Hence, the "societal element" in electricity planning is widely recognized as a key issue for achieving support among a wide range of stakeholder groups and for shaping the successful implementation of a country's energy future (Santoyo-Castelazo & Azapagic, 2014; Hadian & Madani, 2015).

1.1 Goal and Research Framework of Work Package 2

Although the main aim of electricity generation technologies is to assure secure, low-cost and accessible electricity supplies, interactions with sustainable development and considerations of societal preferences are increasingly recognized as equally important as techno–economic or regulatory issues for planning energy futures in MENA countries. Yet, at the intersection between electricity generation technologies, sustainable development and society, the determination of energy policies and the installation of electric facilities becomes a "messy, conflictual, and highly disjointed process" (Meadowcroft, 2009, p. 323). Shedding light on this process requires greater scientific and technological understanding, but also greater knowledge of peoples' responses.

In this spirit and building on the special edition of *Nature* on "Energy, Climate and Society" (2016) stating that "only through a multifaceted approach can we hope to find real and lasting solutions" (Sovacool, 2016, p. 1), the goal of Work Package 2 of the MENA SELECT project is defined as follows:

Building on the principles defined by the Brundtland Commission (United Nations, 1987) and reflecting on the Sustainable Development Goals adopted in 2015 (UN, 2015), the authors of this study understand sustainable development as a "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987, p. 43), which balances economic growth, environmental sustainability and social inclusion within planetary boundaries (Rockström et al., 2009) and is anchored to the equitable realization of Human Rights (UN, 1948; ICCPR, 1966; ICESCR, 1966). In light of this definition electricity is considered as a means to achieve sustainable economic growth, human wellbeing and a clean environment. Yet, this study does not intend to be comprehensive with respect to all these dimensions, but instead focuses on selected sustainable development objectives that are directly affected by the deployment of electricity generation technologies at national and local levels in the target countries.

To evaluate the multi-objective and value-biased complexity of future technology choices in the electricity sector of Morocco, Jordan and Tunisia against a) several sustainable development objectives and b) differing societal preferences, and thus the potential for stakeholder support or conflict.

Even though creating a better understanding of the interface between energy and society is not a panacea to achieving societal support for energy policies, it, however, may help in paving the way towards more socially robust energy systems in MENA countries. In order to do so Work Package 2 applies an interdisciplinary and stakeholder-based research framework that combines explorative qualitative and quantitative evaluation techniques within a multi-criteria decision analysis (MCDA). In contrast to single goal optimization, such as cost–benefit analyses (CBAs) that aggregate multiple criteria into a single monetary measure, MCDAs are integrative evaluation methods. They combine information about the performance of different alternatives across a range of criteria (scoring) with stakeholder preferences about the relative importance of the evaluation criteria (weighting). The result is a ranking of alternative electricity generation options with regard to their specific performance characteristics as assessed taking account of their sensitivity to subjective stakeholder preferences. Furthermore, participative MCDA methods enable to elicit differing narratives, attitudes and perceptions while opening up spaces for agreeing on "compromise solutions" from a number of alternatives based on mutual learning and cooperativeness among different stakeholder groups (Catrinu, 2006).

While MCDA methods have been applied extensively for the assessment of electricity generation options at the project, national, regional and global levels (Afgan & Carvalho, 2002; Chatzimouratidis & Pilavachi, 2008; NEEDS, 2009; Wilkens & Schmuck, 2012; Stein, 2013; Grafakos et al., 2015; Barros et al., 2015), a MENA-specific MCDA on electricity technologies has never been conducted[2]. Hence, Work Package 2 intends to complement previous research on energy systems in the MENA region—that either focused on singular aspects of sustainable development, techno–economic aspects of electricity systems or on selected electricity technologies—with the "societal element" in electricity planning (Dii, 2012; Dii, 2013; RCREEE, 2015; BETTER Project, 2015).

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[2] Brand & Missaoui (2014) conducted a MCDA on different electricity scenarios for Tunisia but did not assess the nexus of sustainable development and electricity generation technologies.

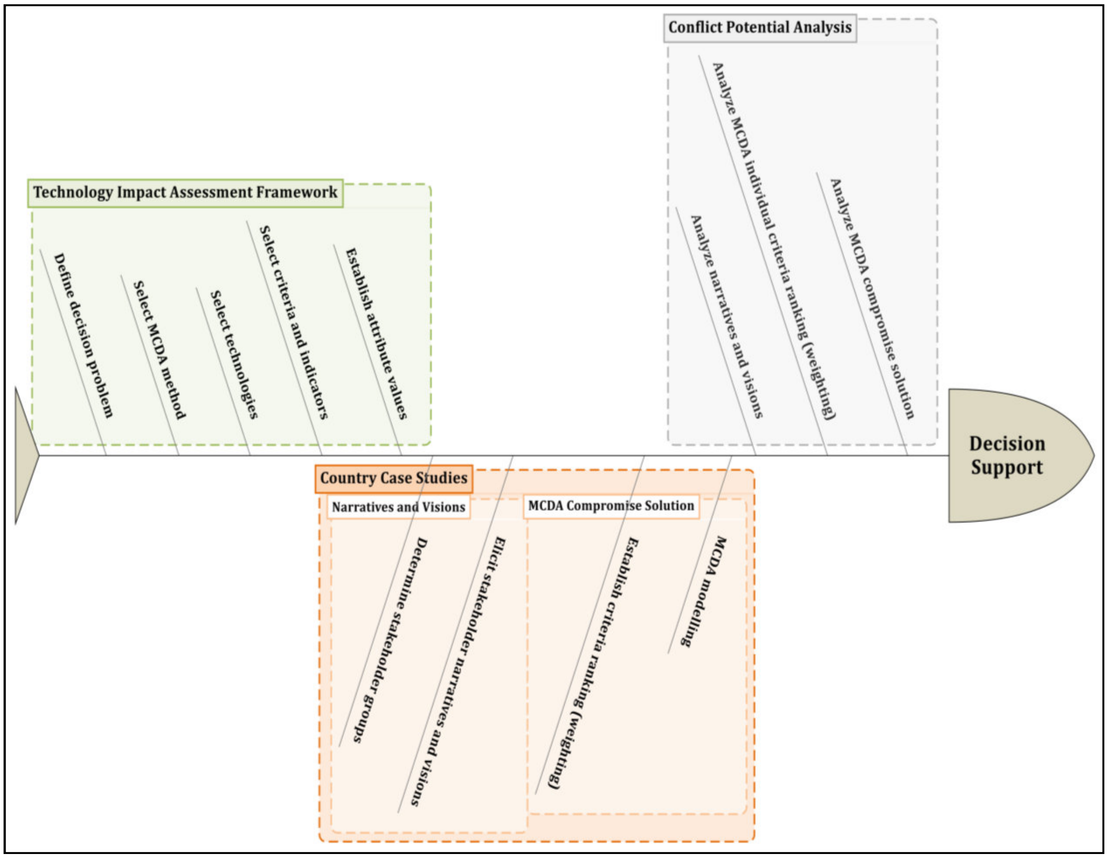

Figure 1: The research framework followed in Work Package 2 of the MENA SELECT project

Within the research framework of Work Package 2 four steps with different objectives are pursued (see also Figure 1).

1. *Technology impact assessment framework: Development of a comprehensive database for the purpose of evaluating the complex trade-offs between different electricity generation technologies and sustainable development at the national and local level (scoring) within the MCDA;*
2. *Country case studies:*

   2a) Elicit attitudes, perceptions and narratives of different stakeholder groups with regard to their envisioned energy future and technology choices;

   2b) Identify a MCDA "compromise solution" for the choice of different electricity generation technologies that has a high potential to be socially supported, based on their performance characteristics at the national and local level (scoring) and stakeholder preferences (weighting);

3. *Analysis of lines of contestation: Analyse the robustness of the "compromise solution" by identifying conflicting stakeholder attitudes, perceptions and preferences (weighting) towards different electricity generation technologies;*
4. *Decision support in electricity planning: Provision of results from 1 to 3 to inform policy on future technological pathways, as well as deliberative policy processes that appear to command wide stakeholder support whilst taking into account the need for procedural and distributive justice in electricity policy-making at the local level.*

1.2 The target audience

While the energy debate is of interest to the general public in the three countries under study, the results of this publication are particularly aimed at supporting the engagement of three stakeholder groups in energy decision-making:

\ **Public policymakers and project developers**: Provide policymakers (e.g., ministries, state agencies, electricity utilities) and project developers (e.g. private sector organizations and banks) concerned with the design and implementation of electricity policies with information for planning the future electricity mix of MENA countries in the most sustainable and socially supported way;

\ **Civil society**: Increase the knowledge of MENA stakeholder groups (e.g. national NGOs, local activist groups) for evaluating energy policies and understanding the possibilities, limitations and trade-offs between different electricity technologies and sustainable development;

\ **Researchers**: Establish a database for interdisciplinary research and teaching purposes (e.g. universities, research organizations) in the field of electricity planning and sustainable development.

1.3 The Technology Impact Assessment Framework

As a fundamental part of the technology impact assessment framework, this report contributes to the first objective of Work Package 2 by making available the database against which the different electricity generation technologies are evaluated within the MCDA (objective 2), lines of contestation among stakeholders are analysed (objective 3) and decision support is provided (objective 4). In order to develop the criteria set for the technology impact assessment framework several steps are followed.

\ **The decision problem:** Given that different electricity pathways could be selected within the target countries for fulfilling the growing energy needs, the decision problem is framed as follows: How do different electricity generation technologies perform during the construction and operation phase[3] in Morocco, Jordan and Tunisia a) against a set of criteria reflecting the contribution to national energy planning objectives as well as the local impact sensitivity and b) along different stakeholder preferences?

\ **The MCDA method:** As part of the multi attribute decision-making (MADM) toolbox, the state-of-the-art MCDA software DecideIT 2.82 is employed. In contrast to other regularly applied MCDA methods, DecideIT 2.82 follows the multi attribute utility theory (MAUT) approach based on the Delta method, which allows for the inclusion of uncertainties and imprecision (Ekenberg et al., 2011). The DecideIT 2.82 software has been successfully used in various contexts, e.g. long-term storage of nuclear waste, choice of computer systems, or the analysis of bio-energy systems (for more information: Danielson et al., 2003; Danielson, 2005; Danielson & Ekenberg, 2007; Danielson et al., 2007).

\ **The technologies[4]:** The eight technologies in this evaluation have been selected by reviewing the most prominent utility-scale[5] electricity technologies that are either widely applied or considered as viable options for the future electricity mix in the three target countries. Four of these are RE technologies, while the other half encompasses conventional power generation:

1. Utility-scale photovoltaic (PV);
2. Concentrated solar power (CSP);
3. Onshore wind;
4. Utility-scale hydro-electric power[6];

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3 The decommissioning phase was excluded from the assessment due to the absence of reliable data.

4 For a detailed description of the technologies and the configuration assumed in this study, please refer to the technology description in the Annex.

5 Although there is no common definition as to what size comprises "utility-scale", the authors understand it as projects that feed into the grid, are operated by a utility, have a Power Purchasing Agreement (PPA) in place, and are generally in the five to 1000 of megawatts (MW) range.

6 Hydro-electric power plants are distinguished according to their size (pico-hydro: < 5 kW; micro-hydro: 5 kW to 100 kW; mini-hydro 100 kW to 1 MW; small-hydro 1 MW to 20 MW; medium-hydro 20 MW to 100 MW; large-hydro > 100 MW). Utility-scale hydro-

5. Nuclear power;
6. Bituminous coal;
7. Natural gas;
8. Heavy fuel oil;

\ **The criteria:** All technologies are assessed against a set of 11 criteria, with a corresponding total of 20 indicators, of which nine are quantitative and 11 are qualitative[7]. The criteria were selected in a threefold process[8]:

- *Review of scientific literature*: The first step of the selection process was based on an extensive literature review of international peer-reviewed publications that applied MCDA methods and developed criteria relevant for assessing the performance of energy systems;
- *Screening of national policy frameworks in the target countries*: The second step involved the screening of existing policy frameworks in the three target countries and complemented the criteria set with nationally relevant development criteria (see for example Schinke et al., 2016).
- *Prioritization by the project team*: In the third step, each member of the project team evaluated each criterion according to its relevance ("high", "medium" and "low") within the MCDA. This process included several interactions and iterations that eventually narrowed down the provisional number of criteria from 32 to a final set of 11. Some of the provisional criteria are reflected on the indicator level. Key technical and economic criteria, which are prominently established in MCDAs on energy planning, were deliberately omitted as they are part of a different Work Package of the MENA Select project.

The criteria are divided into two levels, national and local. Both levels comprise factors that have an influence on societal support for a given technology by

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electric power plants are considered in this study to be all stations above the size of small-hydro that feed into the national grid.

[7] There is a range of other critical determinants in technology implementation, such as dispatchability and base load capacity, economic viability, or technology maturity. But because these elements are primarily technical they were excluded in this Work Package, but again included in Work Package 1 and 3 of the MENA SELECT project.

[8] Due to project-inherent constraints the envisioned validation and refinement of the criteria set by MENA stakeholders other than the MENA project partners were not possible.

covering its socio-economic, environmental and social impact dimensions of sustainable development in the context of technology planning and deployment (see Figure 2).

- *National level:* At the national level, expanding future electricity generation capacities in MENA countries is not only geared towards secure, low-cost and accessible power supplies but is envisioned to yield long-lasting development dividends. Five criteria have been selected as of predominant relevance with regard to their contribution to national energy planning objectives in the target countries: decreasing foreign resource independence, climate change mitigation, domestic industry development, technology and knowledge transfer, as well as affordable electricity system costs.
- *Local level:* Because electricity generation technologies are not only related to national planning objectives but can also have an impact on the livelihood of local communities in the vicinity of project sites, six locally relevant criteria aim to shed light on the local conflict sensitivity of certain electricity infrastructures. They encompass aspects of land and water resources, on-site job creation, air pollution and health, hazardous waste and safety issues. While these criteria also have national or even international relevance—nuclear waste or transnational water resource management for example—their immediate impacts take effect mostly at their source. They are therefore considered to be predominantly local.

In line with various authors (Wüstenhagen et al., 2007; Wolsink, 2007; Devine-Wright, 2008; Stern, 2014), these two elements are intended to give insights into whether the planning and implementation process of deploying certain technologies under the scheme of an established national electricity policy could receive societal support or might be confronted with resistance and opposition—at the national and local level. Although often used interchangeably (Ekins, 2004), the term "support" was chosen over "acceptance" as the latter has a passive connotation thereby perpetuating the normative top-down perspective on people's relations with energy infrastructures. In contrast, the term "support" explicitly entails that stakeholder actively approve of a decision and might participate in its implementation (Batel et al., 2013). Accordingly, societal support is herewith defined as: “the favourable or positive reaction towards the implementation or adoption of a proposed technology by the members (individuals and collective actors) of a given society... [at the national and local level]” (Oltra et al., 2014, p. 7).

\ **The indicators (attribute values)** [9]**:** The data collection that establishes the performance characteristics for each technology and each criterion was based on different sources and methods. The indicators—regularly also called "attribute values" in MCDAs—of the criteria set encompass both quantitative and qualitative data. Primary quantitative data sources involve remote sensing data and geographical information systems (GIS) maps. Secondary quantitative data sources include more than 200 regionally specific and international scientific peer-reviewed articles, official policy reports, industry reports, environmental and social impact assessments (ESIAs), and real project case studies. Additionally, expert surveys were conducted in the case countries to obtain qualitative indicators where no quantitative data could be found or developed. For this a purposive sampling was applied in order to consult a balanced diversity of experts with different fields of expertise and roles in society (see Annex). [10]

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9 The nine qualitative indicators of the 20 indicators require country-specific data, which is collected during the country case studies. Hence, country-specific data for the concerned indicators will be following in due course of Work Package 2's research progress. Responsibility for the country-specific data lies with the respective institutes conducting the case study (Germanwatch for Morocco, IIASA for Jordan and BICC for Tunisia).

10 The expert surveys were developed and conducted in collaboration with the respective local partners in each country. The local partners to Work Package 2 were Touria Barradi and Driss Zejli in Morocco.

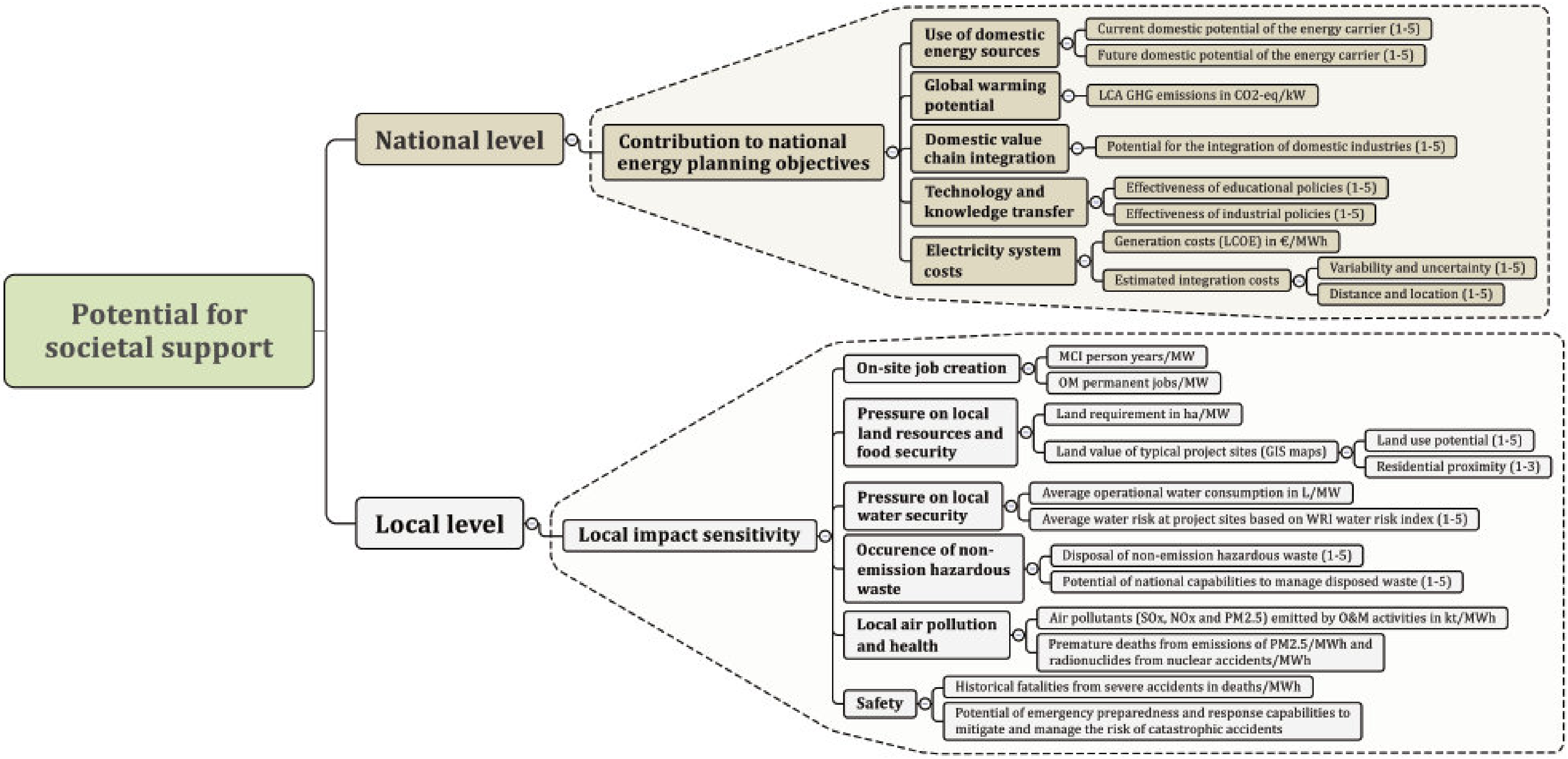

Figure 2: Criteria and indicators for evaluating the performance of different electricity generation technologies in Morocco, Jordan and Tunisia.

2 CONTRIBUTION TO NATIONAL ENERGY PLANNING OBJECTIVES

Investments into new electricity generation capacities are driven by national development goals throughout the world. This chapter discusses the contribution of different electricity technologies to national energy security objectives, climate change mitigation targets and sustainable socio-economic growth in Morocco, Jordan and Tunisia.

2.1 Criterion 1: Use of Domestic Energy Sources

Objective: *The technology should decrease the dependence on foreign energy imports by tapping into domestic resources that are either available today or could be exploited in the mid- to long-term*

Indicators (qualitative with a five-step descriptive scale, maximize):

\ Current domestic potential of each technology's energy carrier to decrease energy import dependence today;

\ Future domestic potential of each technology's energy carrier to decrease energy import dependence by 2040/50.

Unlike some of their neighbours, several countries along the southern and eastern coast of the Mediterranean Sea are net energy-importers with only marginal recoverable hydrocarbon sources yet. While energy exporting countries can rely on their foreign sales, the total primary energy supplies (TPES) of Morocco, Jordan and Tunisia for example are characterized by high total primary energy net import (TPENI) dependence rates. This is causing political vulnerability and high economic burdens as a result of import bills and subsidies (see for example Table 1).

			Current import dependence										
	TPES (Mtoe)	TPENI (Mtoe)	TPENI depen-dence (%)	Fiscal burden on GDP (%)	Share of TPENI (%)								
					Power	Utility PV	CSP	On-shore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
Morocco	18.80 (2012) *	18.07 (2012) *	96.12 (2012) *	-11.50 (2012) **	2.55 (2012) *	0.00 (2012) *	0.00 (2012) *	0.00 (2012) *	0.00 (2012) *	0.00 (2012) *	16.07 (2012) *	5.20 (2012) *	76.24 (2012) *

Table 1: Current import dependence of Morocco.

Sources: *IEA, 2015; **IMF, 2014, p. 18.

As energy import dependence (i.e. the extent to which a country depends on imports to meet its energy needs) raises concerns about future energy security, especially in times of rising energy demands, and as fossil fuel prices are projected to become more volatile and expensive, Morocco, Jordan and Tunisia are increasingly aiming to make use of domestically available energy sources. By taking into account this MENA-wide policy objective, the criterion *"Use of Domestic Energy Sources"* incorporates potential contributions of each technology to the independence from foreign energy imports by tapping into domestic energy sources. In this context, energy dependence can be decreased in two ways (assuming that an increase in demand is given and energy efficiency efforts correspond with a "business as usual scenario"):

\ Use the current energy infrastructures and substitute the formerly imported energy carriers with domestic energy carriers (e.g. replace the use of imported gas with domestic gas, nuclear or oil shale);

\ Build new energy infrastructures that run on the basis of domestically available energy carriers (e.g., build CSP power plants with storage capacities to replace dispatchable fossil-fired power plants);

Therefore, a technology has the potential to contribute to energy independence if the energy carrier needed is available domestically. This includes renewable and non-renewable sources that are either already available today or that could be exploited in the mid- to long-term.

In the MENA region, the RE potential is enormous, since solar radiation (direct normal irradiation (DNI) for CSP and global horizontal irradiation (GHI) for PV) ranges between 2000 and 2800 kWh/m^2/y and wind full load hours between 1100 and 3000/y. Especially in Morocco, Jordan and Tunisia solar radiation values and wind speeds are among the highest in the world, making these three countries suitable for utility-scale RE technologies, such as CSP, PV, on- and offshore wind farms (see Table 2).

Country	**GHI (kWh/m2/year**	**DNI (kWh/m2/year**	**Wind - Full load hours/year**
Algeria	1970	2700	1789
Jordan	2320	2700	1483
Kuwait	1900	2100	1605
Lebanon	1920	2000	1176
Morocco	2000	2600	2708
Saudi Arabia	2130	2500	1789
Tunisia	1980	2400	1789
UAE	2120	2200	1176

Table 2: RE potential in selected MENA countries.

Sources: IRENA, 2013b, p. 28.

Together with declining production cost, this potential has stimulated MENA countries to meet their growing electricity demands through domestic RE (IRENA, 2013b, pp. 25–27). Evidence that RE technologies are likely to be the preferred technologies in the foreseeable future can be found in the rapidly changing set of policies, targets and institutions, all aiming to increase the share of RE in the electricity mix across the MENA region (REN21, 2013, p. 9). All MENA countries now have RE targets, typically between 10 and 20 per cent that would result in 107 GW of installed capacity by 2030 and that already have led to a 6.5-fold increase in new investments in RE (REN21, 2013, p. 7). Especially solar and onshore wind projects have recently been fast-tracked in Morocco, Jordan and Tunisia and are expected to cover a significant share of electricity generation by 2020 and beyond (see Schinke et al., 2016 for Morocco).

However, the uptake of RE in MENA countries is yet challenged by another trend, which is currently being observed throughout the region. With the world's conventional hydrocarbon reserves declining, MENA countries are in parallel turning their attention to domestic unconventional fossil fuel deposits and progressively exploring the extraction of oil shale both on- and offshore[11]. Especially Jordan and Morocco are considered to possess significant reserves and resources of oil shale (see Box for the distinction between reserves and resources) that would outstrip other members of the Gulf Cooperation Council (GCC), if counted by the International Energy Agency (IEA) as oil. Assessments provided by Jordan's National Energy Research Center (NERC) estimate that Jordan might have the seventh largest oil shale accumulation in the world with more than 50 billion barrels of "proven and exploitable" crude oil (NERC, 2015). Similarly, the National Office of Hydrocarbons and Mines (ONHYM) in Morocco estimates the country's oil shale resources to be more than 50 billion barrels, a level which ranks the country also amongst the world leaders in respect of in-place oil shale (Bencherifa, 2010; WEC, 2010, p. 101 and 116). The Tunisian share of the exploitable oil shale reserves in the Gadhames Basin is estimated to be 1.5

Definition of reserves and resources

A distinction between reserves and resources is important to account for uncertainties, as it reflects the likelihood that fossil fuels will be brought to the market.

Reserves: The portion of energy resources which is known in detail and can be recovered economically using current technologies.

Resources: Either proven sources or sources that can be expected for geological reasons but that—at present—are not economically recoverable (BGR, 2010, p. 80).

[11] Oil shale is an organic-rich, sedimentary rock that contains kerogen. Therefore, it cannot be pumped like oil but needs to be drilled or mined. When kerogen is processed by retorting, shale oil and shale gas can be generated as basis for crude oil and natural gas.

million barrels (ARI, 2013, p. XVI-2)

Although it is yet too early to talk about actual new prospects because of uncertainties concerning the precise amount that could be recovered as well as technological challenges, Jordan and Morocco are pressing ahead with plans to unlock their domestic unconventional fossil potential. With high hopes to reduce their energy import dependence and create fiscal benefits from potential export markets in the future, both kingdoms have started drilling for oil and gas in their territories. They have also begun implementing new legal frameworks to attract developers and build corresponding infrastructures, such as terminals, pipelines and power plants. As a result, exploration contracts with major companies, such as Shell, BP, Chevron, Total and Petrobras have been signed, and an increasing number of other international corporations are now eyeing the unconventional potential in both countries (WEC, 2010, p. 116).

Against this background, different pathways for decreasing Morocco's and Jordan's energy import dependency by embarking on domestically available energy sources are possible. While RE sources are already increasingly tapped, and it is projected that this trend will continue, significant uncertainties remain about the future uptake of new hydrocarbon sources and the technological advancements needed to bring them to maturity. Yet, it should be noted that, until recently, shale gas and shale oil were considered to be both technically and economically unrecoverable, but today have developed into important elements of many countries' energy plans. Two indicators of the *"Use of Domestic Energy Sources"* criterion aim to address these uncertainties by covering both current and potential future contributions of different electricity generation technologies to increase import independence.

2.1.1 Indicators

The first indicator explores the current potential of each technology to satisfy the national energy demand when using domestically available energy carriers. It is defined as the *"Current domestic potential of each technology's energy carrier to decrease energy import dependence today"*. The second indicator takes into account the uncertainties about future discoveries and exploitation of renewable and non-renewable potentials. It considers whether the current domestic availability of each technology's energy carrier has a considerable potential to change in the mid- to long term (e.g. through technological advancements or the discovery of new energy reserves). Thereby, it could contribute to a decrease in national energy import dependence by 2040/50. It is defined as the *"Future domestic potential of each technology's energy carrier to decrease energy import dependence by 2040/50"*. For the purpose of the MCDA, it was assumed that the indicators had to be maximized.

Due to the lack of data and the high uncertainties associated with the exploitation of new energy sources, the attribute values for both indicators were obtained qualitatively by consulting national experts in each country. The question included in the expert consultation for obtaining the data of the first indicator was:

"If the country wants to decrease its energy import dependence, how high do you evaluate the existing potential of each energy source (e.g., solar resources for PV and CSP power plants, gas resources for natural gas power plants etc.) to contribute to this goal?"

The question for obtaining the data of the second indicator was:

"If the country wants to decrease its energy import dependence, how high do you evaluate the future potential of each energy source (e.g., solar resources for PV and CSP power plants, gas resources for natural gas power plants etc.) to contribute to this goal, by taking into account the abundance of proven non-renewable and renewable sources and the likelihood of the resources to be exploited and used for electricity generation until 2040/50?"

As with all expert consultations within this study, the provided scale ranged from 1 to 5 (1 = very low potential, 2 = low potential, 3 = moderate potential, 4 = high potential, 5 = very high potential).

2.1.2 Results

The results of the expert consultations in Morocco are illustrated in the figures below (for more details on the consulted experts see Figure 20 in the Annex).

Morocco

For Morocco, the expert judgements reflect the country's lack of fossil energy sources and its high solar and wind potential (see Figures 3 and 4 as well as Tables 3 and 4).

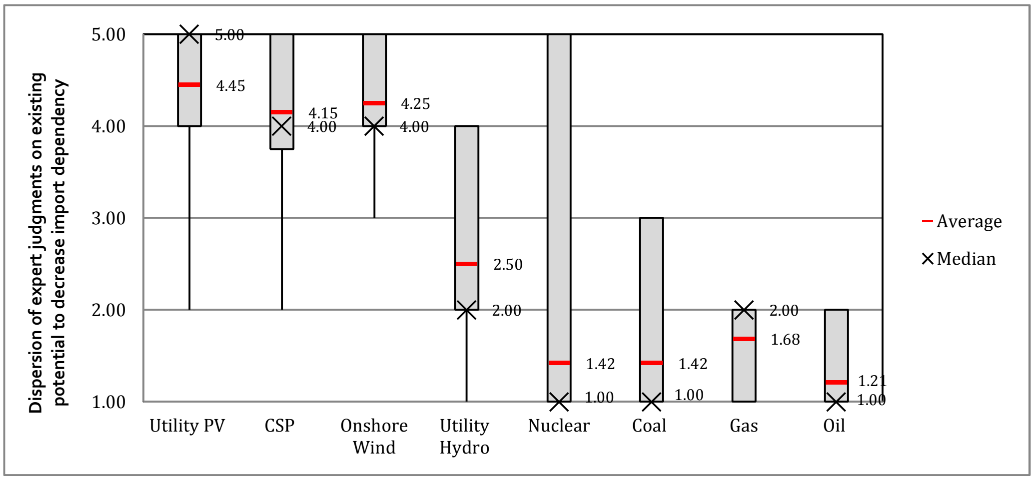

Figure 3: Dispersion of the expert judgement on the *"Current domestic potential of each technology's energy carrier to decrease energy import dependence today"* in Morocco.

Note: Whisker ends represent maxima and minima. Upper and lower ends of boxes represent 75th and 25th percentile, respectively.

	Utility PV	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
Quantile 1 (25%)	4.00	3.75	4.00	2.00	1.00	1.00	1.00	1.00
Min	2.00	2.00	3.00	1.00	1.00	1.00	1.00	1.00
Median	5.00	4.00	4.00	2.00	1.00	1.00	2.00	1.00
Average	4.45	4.15	4.25	2.50	1.42	1.42	1.68	1.21
Max	5.00	5.00	5.00	4.00	5.00	3.00	2.00	2.00
Quantile 3 (75%)	5.00	5.00	5.00	3.00	1.00	2.00	2.00	1.00

Table 3: Statistics of the expert judgement on the *"Current domestic potential of each technology's energy carrier to decrease energy import dependence today"* in Morocco.

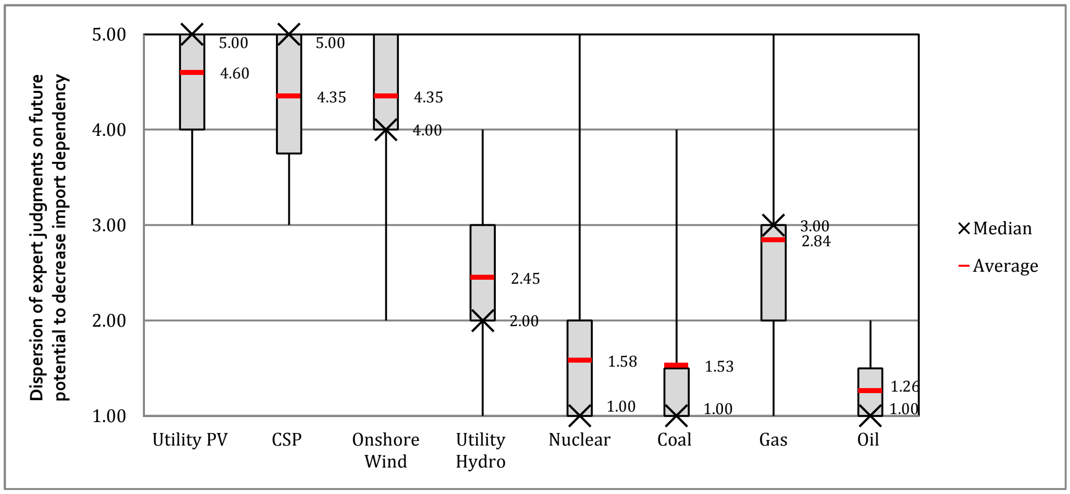

Figure 4: Dispersion of the expert judgement on the *"Future domestic potential of each technology's energy carrier to decrease energy import dependence by 2040/50"* in Morocco.

Note: Whisker ends represent maxima and minima. Upper and lower ends of boxes represent 75th and 25th percentile, respectively.

	Utility PV	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
Quantile 1 (25%)	4.00	3.75	4.00	2.00	1.00	1.00	2.00	1.00
Min	3.00	3.00	2.00	1.00	1.00	1.00	1.00	1.00
Median	5.00	5.00	4.00	2.00	1.00	1.00	3.00	1.00
Average	4.60	4.35	4.35	2.45	1.58	1.53	2.84	1.26
Max	5.00	5.00	5.00	4.00	5.00	4.00	5.00	2.00
Quantile 3 (75%)	5.00	5.00	5.00	3.00	2.00	1.50	3.00	1.50

Table 4: Statistics of the expert judgement on the *"Future domestic potential of each technology's energy carrier to decrease energy import dependence by 2040/50"* in Morocco.

With the exception of utility hydro-electric power plants, both indicators illustrate that all RE technologies are considered to have a "high" to "very high" potential to contribute to Morocco's policy objective of reducing its reliance on foreign energy imports in the short- and long term. The "low" and "moderate" values for hydro and natural gas mirror the limited capacities to increase the deployment of hydro-electric projects as well as the uncertainties about the future use of domestic gas. Nuclear, oil and coal are ranked with a "very low" potential due to the fact that Morocco is not endowed with any significant resources of neither one of these energy carriers.

2.2 Criterion 2: Global Warming Potential

Objective: *The technology should contribute to the mitigation of climate change*

Indicator (quantitative, minimize):

\ Total lifecycle GHG emissions (CO2-eq) per generated kWh

Measured throughout the entire lifecycle, all utility-scale electricity generation technologies emit greenhouse gases (GHG) and therefore contribute to climate change. It is widely recognized that GHG emissions resulting from the use of a particular technology need to be quantified over all stages of the technology and its fuel life-cycle. The criterion *"Global Warming Potential"* aims to address this through one indicator.

2.2.1 Indicator

The indicator of the *"Global Warming Potential"* criterion is defined as the *"Total lifecycle GHG emissions (CO_2-eq) per generated kWh"*. The attribute values for each technology not only include direct emissions stemming from power plant operation but also upstream (e.g. fuel exploration, mining, fuel transport) and downstream (infrastructure, decommissioning, waste management and disposal) emissions. For the purpose of the MCDA, it was assumed that the indicator had to be minimized.

2.2.2 Results

To date, a great variety of GHG Life-Cycle Assessments (LCA) of different power plants have been conducted. However, despite the large number of studies, they are characterized by significant discrepancies that can be attributed to differences in technology characteristics, local conditions and methodological aspects. As a result of these uncertainties, the attribute value for the criterion was drawn from a comprehensive literature review provided in the International Panel on Climate Change IPCC report (2012), which is subject to extensive review.

Notwithstanding significant ranges among each technology, the median values were used to determine CO_2-eq attribute values for all technologies. Figure 5 and Table 5 present all ranges and the median suggested by the IPCC (2012) for the criterion *"Global warming potential"* of the different technologies in the MCDA.

Together with nuclear power, all RE technologies have a significantly lower potential to contribute to climate change than the fossil-based alternatives. Utility hydro-electric power plants are found to be the most promising technology, closely followed by onshore wind, nuclear, CSP and utility PV. Coal, oil and natural gas rank at the bottom. The technology performance values were derived relatively to the highest and lowest average values and thus do not constitute an absolute evaluation.

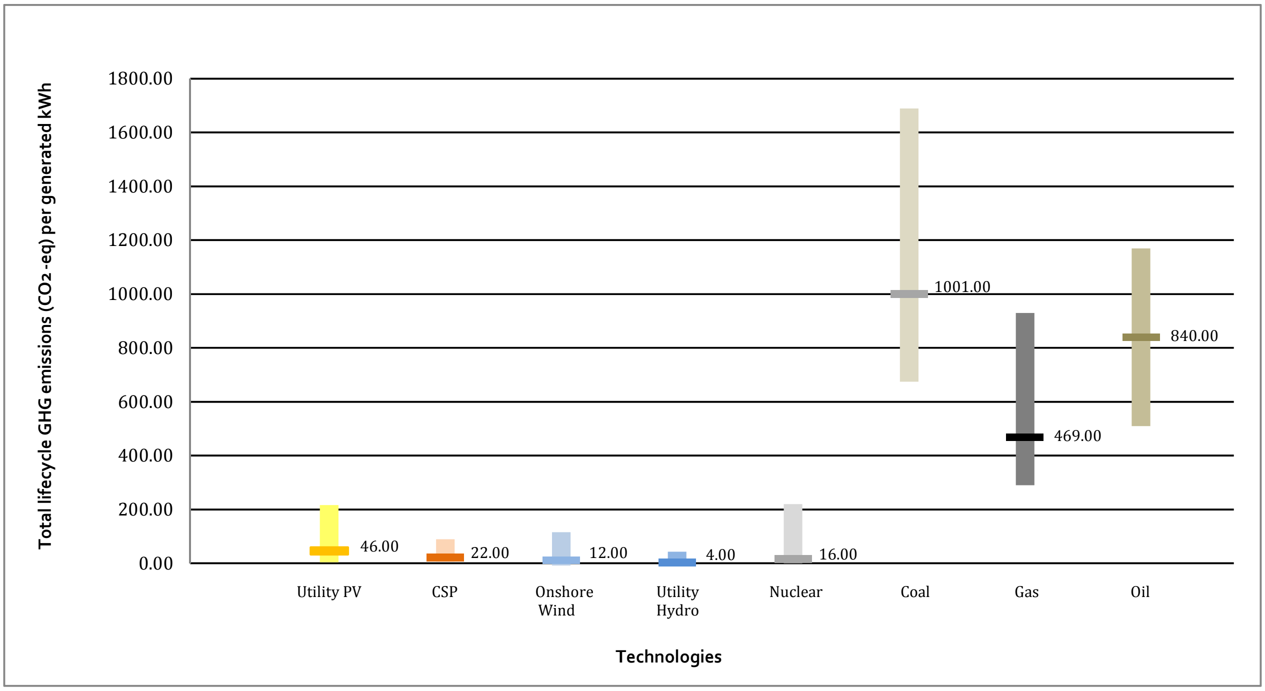

Figure 5: Total lifecycle GHG emissions (CO2-eq) per generated kWh of different electricity generation technologies at the global level.

Sources: IPCC, 2012.

Unit		Utility PV	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
CO2-eq/kWh	Min	4.00	7.00	2.00	0.00	1.00	675.00	290.00	510.00
	Average	46.00	22.00	12.00	4.00	16.00	1001.00	469.00	840.00
	Max	217.00	89.00	81.00	43.00	220.00	1689.00	930.00	1170.00

Table 5: Aggregated attribute values derived of a literature review on the criterion *"Global Warming Potential"* based on LCAs of GHG emissions from electricity generation technologies at a global level.

Sources: IPCC, 2012.

2.3 Criterion 3: Domestic Value Chain Integration

Objective: *The technology should have a high potential to use components and services provided by domestic industries throughout the entire value chain*

Indicator (qualitative with a 5-step descriptive scale, maximize):

\ Existing potential for the integration of domestic industries to manufacture a significant share of components and provide essential services during the manufacturing, construction and installation (MCI) and operation and maintenance (OM) phases of the technology

Notwithstanding the importance of direct employment, job creation can only sustain long-term socio-economic benefits in the context of expanding populations if the deployment of electricity generation technologies allows for the economic participation of domestic industries. For this a significant share of small-medium enterprises (SMEs) and large firms have to be involved and indirect employment be generated throughout the value chain of a power plant.

Indirect employment

Indirect employment is the employment in upstream industries that supply core activities of energy deployment. Usually, these workers do not consider themselves as working in energy; they produce steel, plastics or other materials, or they provide financial and other services (IRENA, 2013a, p. 22).

Typically, these multiplier effects stemming from direct or indirect employment and spurred investment can significantly outweigh direct on-site job creation and substantially increase overall job numbers. For example, a study conducted by Klein & Whalley (2015), using the Job and Economic Development (JEDI) model of NREL, derived the following indirect employment multipliers measured in FTE/GWh for different power technologies in the United States (see Table 6).

	Utility PV	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas
Indirect jobs in MCI	0.29	0.47	0.05	0.17	0.05	0.06	0.05
Indirect jobs in OM	0.22	0.42	0.07	0.08	0.07	0.18	0.17

Table 6: Indirect employment multipliers in FTE/GWh estimated for different power technologies in the United States.

Sources: Klein & Whalley, 2015, p. 148.

Based on this study the indirect employment effects of CSP during the MCI and OM phases are highest compared to all other technologies, followed by utility PV and utility hydro-electric power plants. Coal and gas are characterized by lower indirect job values but still higher than nuclear and onshore wind that rank equally in the US case.

Yet, industry localization is country specific and essentially depends on the absorptive capacities and technological capabilities of a country's economy. Power plant technologies are generally based on a technically-intensive and a highly specialized production (some examples of relevant components and services are provided in Table 7).

	Low-value	**Medium-value**	**High value**
Components	Steel, concrete, and cement	Electronics, mirrors, aluminium mounting structures, cables, and pipes	Heat exchangers, receivers, generators, turbines, modules, and inverters
Services	Groundwork (levelling, back filling, and construction), and surveillance	Electrical work, assembly, and installation	Maintenance, technical consultancy, and project management, financing

Table 7: Exemplary components and required services for the construction and operation of electricity generation technologies.

Thus, the more sizeable, qualified and equipped the domestic industry is, the more components and services or portions of overall project costs can be sourced from domestic suppliers and added value be generated along the value chain. On the other hand, if the industry sector is mostly made up of the labour-intensive production of low value-added goods, more components and services will have to be imported from abroad and less economic spill-over effects can be achieved. The criterion *"Domestic Value Chain Integration"* aims to address these issues through one indicator.

2.3.1 Indicator

The indicator of the *"Domestic Value Chain Integration"* criterion is defined as the *"Existing potential for the integration of domestic industries (SMEs) to manufacture a significant share of components and provide essential services during the MCI and OM phases of the technology"*. For the purpose of the MCDA, it was assumed that the indicator had to be maximized.

The attribute values for this indicator were obtained qualitatively by consulting with national experts in each country. The question included in the expert consultation was:

"How high would you assess the existing potential of the domestic industry to manufacture a significant share of components and provide essential services during the MCI and OM phases for each technology?"

As with all expert consultations within this study, the provided scale ranged from 1 to 5 (1 = very low potential, 2 = low potential, 3 = moderate potential, 4 = high potential, 5 = very high potential).

2.3.2 Results

The results of the expert consultations in Morocco are illustrated in the figures below (for more details on the consulted experts see Figure 20 in the Annex).

Morocco

For Morocco, the expert judgement illustrates that all RE technologies are believed to be more beneficial for local value chain integration than their fossil and nuclear alternatives, with CSP ranked highest and nuclear as well as oil ranked at the bottom (see Figure 6 and Table 8). With the exception of onshore wind, this judgement also reflects the findings of Klein & Whalley (2015) (see Table 6).

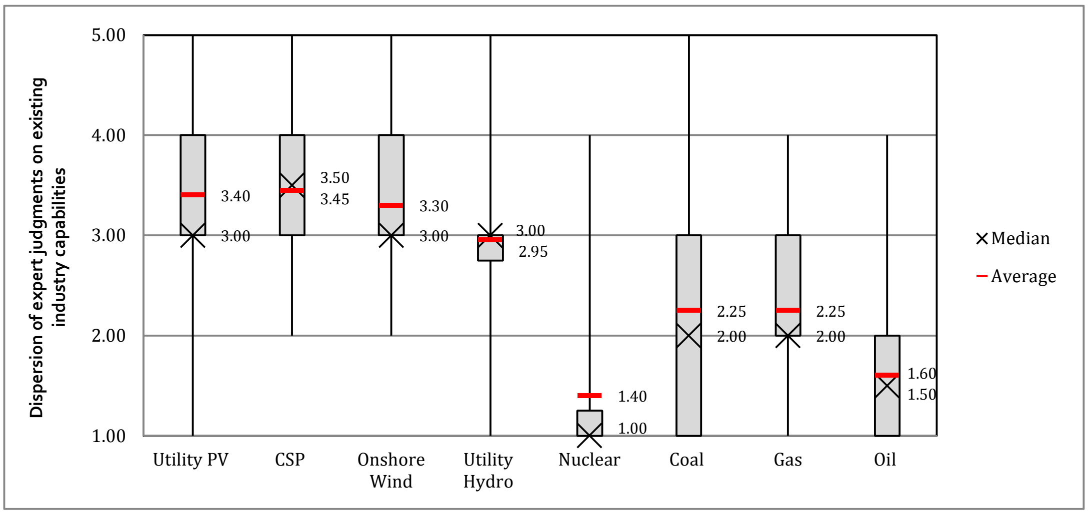

Figure 6: Dispersion of the expert judgement on the *"Existing potential for the integration of domestic industries (SMEs) to manufacture a significant share of components and provide essential services during the MCI and OM phases of the technology"* in Morocco.

Note: Whisker ends represent maxima and minima. Upper and lower ends of boxes represent 75th and 25th percentile, respectively.

	Utility PV	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
Quantile 1 (25%)	3.00	3.00	3.00	2.75	1.00	1.00	2.00	1.00
Min	1.00	2.00	2.00	1.00	1.00	1.00	1.00	1.00
Median	3.00	3.50	3.00	3.00	1.00	2.00	2.00	1.50
Average	3.40	3.45	3.30	2.95	1.40	2.25	2.25	1.60
Max	5.00	5.00	5.00	5.00	4.00	5.00	4.00	4.00
Quantile 3 (75%)	4.00	4.00	4.00	3.00	1.25	3.00	3.00	2.00

Table 8: Statistics of the expert judgement on the *"Existing potential for the integration of domestic industries (SMEs) to manufacture a significant share of components and provide essential services during the MCI and OM phases of the technology"* in Morocco.

2.4 Criterion 4: Technology and Knowledge Transfer

Objective: *Based on existing policies, the technology should have a high potential to benefit from technology and knowledge transfer in order to stimulate future domestic value-added in electricity generation*

Indicators (qualitative with a 5-step descriptive scale, maximize):

\ Effectiveness of educational policies to foster skill development and R&D

\ Effectiveness of industrial policies to enhance industry linkages between domestic and foreign firms geared towards horizontal technology transfer

It can neither be assumed that socio-economic benefits will be sustained automatically in the mid- to long-term as investments in electricity generation technologies pour in, nor that absorptive capacities and technological capabilities will be adequate as investors introduce new jobs and technologies. High value-added jobs (both direct and indirect) in power plant deployment are dominated by technical job profiles that require specific curricula and qualifications. As a consequence, countries in the MENA region will only be able to use the deployment of energy technologies as means for future, long-term job creation and industry development, if they have adequate technology-specific skills to absorb foreign technologies and know-how. Moreover, competencies are also required for innovation and entrepreneurship, as well as for adapting technologies to local contexts to establish a self-sustaining market. Yet, the lack of adequate human capital in technology-intensive activities, such as manufacturing, operating and maintaining technologies, is still a major barrier to increasing the economic participation of industries and workers in a knowledge- and technology-based economy in the MENA region. Millions of educated people, especially among the youth, will remain unemployed and their economic potential untapped, if the existing skill gap/mismatch—skill shortages and the deficiency in the quality of skills—between the labour force and labour market requirements of electricity generation technologies is not addressed properly (BI, 2016).

Thus, it is necessary to expand the knowledge base and strengthen the expertise and technological capabilities with respect to manufacturing, operation and innovation to match peoples' skills and allow for industrial upgrading through horizontal technology and knowledge transfer. In this regard, educational policies (e.g., by the Ministry of Higher Education) aligned within an industrial development strategy (e.g., by the Ministry of Finance or Industry) and developed in close cooperation with the private sector play an important role. The criterion *"Technology and Knowledge Transfer"* aims to address this through two indicators.

2.4.1 Indicators

The indicators of the *"Technology and Knowledge Transfer"* criterion are qualitative and encompass both skill development and industry linkages. The first indicator is defined as the *"Effectiveness of educational policies to foster skill development and R&D"* and reflects on measures such as the establishment of specific research institutions, vocational training and university programmes. The second indicator covers the industry linkages and is defined as the "*Effectiveness of industrial policies to enhance industry linkages between domestic and foreign firms geared towards horizontal technology transfer"*. For the purpose of the MCDA, it was assumed that the indicators had to be maximized.

Examples of an effective interplay between industrial and educational policies can be found in the following areas (see Table 9):

Education and training	**Industry linkages**
Research institutions, such as the Institute of Research in Solar Energy and New Energies *(*IRESEN*)* in Morocco or the Industrial Modernization Centre (IMC) in Egypt	Joint ventures and inter-company trainings between transnational corporations and domestic SMEs
Master and bachelor programmes designated at energy related curricula	Industry or excellence clusters of R&D and vocational training
International university exchange programmes	Science and technology parks
Training centres for technicians, such as the Institutes for RE and Energy Efficiency (IFMEREE) in Morocco	Local content regulations

Table 9: Areas of education, training and industry linkages in energy deployment.

The attribute values for each indicator were obtained qualitatively by consulting with national experts in each country. For the first indicator, the question included in the expert consultation was:

"How high would you assess the effectiveness of national policies and institutions to develop educational curricula through vocational training and university programs for the deployment and development of each technology?"

The question for obtaining the data of the second indicator was:

"How high would you assess the effectiveness of national policies and institutions to foster private sector linkages between domestic and foreign firms in order to benefit from knowledge and technology transfer for each technology?"

As with all expert consultations within this study, the provided scale ranged from 1 to 5 (1 = very low potential, 2 = low potential, 3 = moderate potential, 4 = high potential, 5 = very high potential).

2.4.2 Results

The results of the expert consultations in Morocco are illustrated in the figures below (for more details on the consulted experts see Figure 20 in the Annex).

Morocco

For Morocco, the expert judgements reflect the country's high efforts to align its RE ambition with corresponding educational and industry policies in order to foster skill development and domestic value chain integration, whereas all fossil and the nuclear alternatives are evaluated more pessimistically, with slightly better results for coal and gas (see Figure 7 and 8 as well as Table 10 and 11).

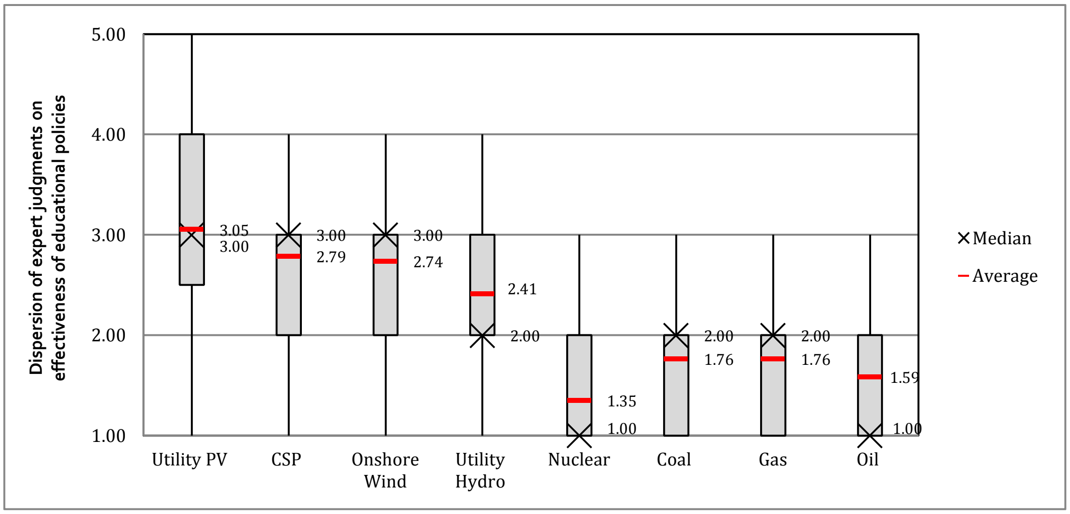

Figure 7: Dispersion of the expert judgement on the *"Effectiveness of educational policies to foster skill development and R&D"* in Morocco.

Note: Whisker ends represent maxima and minima. Upper and lower ends of boxes represent 75th and 25th percentile, respectively.

	Utility PV	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
Quantile 1 (25%)	2.50	2.00	2.00	2.00	1.00	1.00	1.00	1.00
Min	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Median	3.00	3.00	3.00	2.00	1.00	2.00	2.00	1.00
Average	3.05	2.79	2.74	2.41	1.35	1.76	1.76	1.59
Max	5.00	4.00	4.00	4.00	3.00	3.00	3.00	3.00
Quantile 3 (75%)	4.00	3.00	3.00	3.00	2.00	2.00	2.00	2.00

Table 10: Statistics of the expert judgement on the *"Effectiveness of educational policies to foster skill development and R&D"* in Morocco.

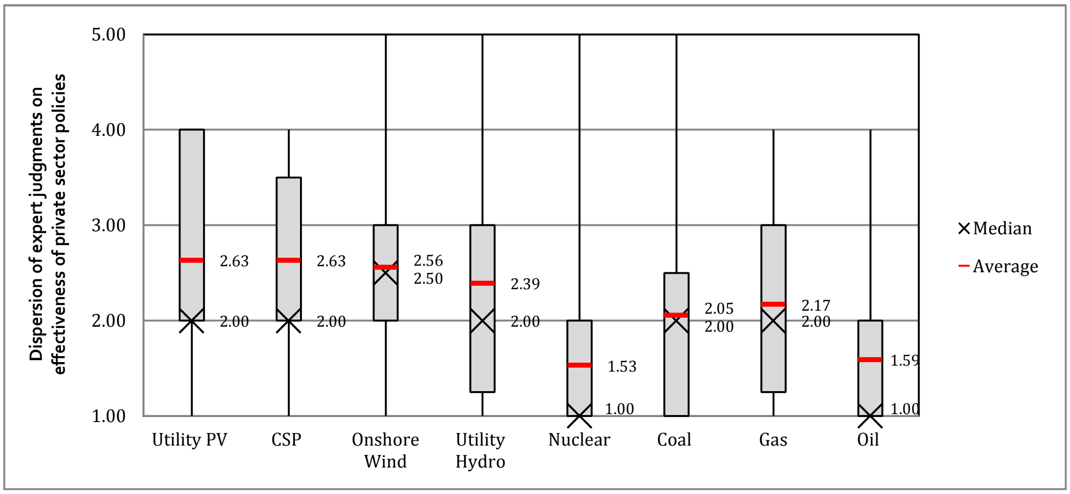

Figure 8: Dispersion of the expert judgement on the *"Effectiveness of industrial policies to enhance industry linkages between domestic and foreign firms geared towards horizontal technology transfer"* in Morocco.

Note: Whisker ends represent maxima and minima. Upper and lower ends of boxes represent 75th and 25th percentile, respectively.

	Utility PV	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
Quantile 1 (25%)	2.00	2.00	2.00	1.25	1.00	1.00	1.25	1.00
Min	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Median	2.00	2.00	2.50	2.00	1.00	2.00	2.00	1.00
Average	2.63	2.63	2.56	2.39	1.53	2.05	2.17	1.59
Max	4.00	4.00	5.00	5.00	5.00	5.00	4.00	4.00
Quantile 3 (75%)	4.00	3.50	3.00	3.00	2.00	2.50	3.00	2.00

Table 11: Statistics of the expert judgement on the *"Effectiveness of industrial policies to enhance industry linkages between domestic and foreign firms geared towards horizontal technology transfer"* in Morocco.

2.5 Criterion 5: Electricity System Costs

Objective: *The electricity system costs of the technology should be as low as possible in order to not constitute a burden for the countries overall budget*

Indicators (quantitative/qualitative with a 5-step descriptive scale, minimize):

\ Electricity generation costs measured as Levelized Costs of Electricity (LCOE) in € per generated MWh (quantitative);

\ Estimated additional integration costs at increasing penetration levels based on uncertainty/variability and distance/location (qualitative).

When evaluating and comparing the performance of different electricity generation technologies, associated costs are considered a key criterion in MCDA studies. The criterion *"Electricity System Costs"*, defined as "the total costs above power plant-level to supply electricity at a given load" (OECD, 2012, p. 4), aims to take this into account through two indicators. The first indicator considers the generation costs measured as Levelized Costs of Electricity (LCOE). Notwithstanding LCOE being a common metric for comparing electricity technologies, it does not take into account the temporal and spatial heterogeneity of different electricity generation technologies. Therefore, the second indicator addresses these shortcomings by considering integration costs that are expected to increase, in particular with growing shares of the relevant technologies. Yet, potential cost reductions from learning effects over time, future price uncertainties for fossil fuels and environmental externalities (e.g., CO_2 prices) are not considered.

2.5.1 Indicators

The first indicator is defined as *"Electricity generation costs measured as Levelized Costs of Electricity (LCOE) in €/MWh"* and includes “the life-cycle costs [during construction and operation] of a power generation technology per unit of electricity” (Ueckerdt et al., 2013, p. 61). Due to the calculation of the LCOE it is possible to compare the costs of producing one unit of electricity (typically 1 MWh or 1 KWh) for different electricity generation technologies that may have different cost structures (WEC, 2013, p. 6; Kost et al., 2013, p. 36). The LCOE is, therefore, considered to be the most transparent metric to electricity generation costs (Hearps & McConnel, 2011, p. 7). To put it simply, the idea behind the calculation of the LCOE is to sum up all costs for building and operating a power plant (e.g., fixed and variable operating costs as well as specific investment costs for development, construction and installation). This figure will be divided by the sum of the annual power generation, while also considering the lifetime of a power plant as well as financing parameters, such as the discount rate (Kost et al., 2013).

Because electricity generation technologies do not exist in isolation but in close interaction with another through the grid, electricity production generates costs beyond the perimeter of power plants. LCOEs do not take into account these "hidden costs" or "technical externalities" of system integration and thereby inherently overestimate the economic efficiency of variable RE and, to some extent, also nuclear and coal at increasing shares in particular. As a consequence, LCOE represents an imperfect measure for comparing the total economic attractiveness of conventional dispatchable and baseload generation with RE technologies and has been criticized by various authors (Singh & Singh, 2010; Joskow, 2011; Ueckerdt et al., 2013).

The second indicator *"Estimated additional integration costs at increasing penetration levels based on uncertainty/variability and distance/location"* recognizes this criticism by considering the additional costs that can occur in the power system should the share of technologies in the electricity mix increase. For the purpose of the MCDA, it was assumed that the indicators had to be minimized.

2.5.2 Results

In order to derive the attribute values for the indicator *"Electricity generation costs measured as Levelized Costs of Electricity (LCOE) in €/MWh"* a three-step literature review was conducted aiming at LCOEs for the different technologies:

\ First, national reports from industry, governments and multilateral development banks (MDBs) for Morocco, Jordan and Tunisia were screened for latest LCOE data on the technologies (see Table 37 in the Annex).

\ Second, where no national data could be found, three regional state-of-the-art meta-studies on North Africa[12] that used comparable site conditions with regard to the study's target countries for CSP, utility PV, onshore wind and oil were considered (Richts, 2012; Kost et al., 2013; IRENA, 2015). Based on these studies, the following LCOE values were selected where the authors were unable to obtain national data: For utility PV and CSP, the average based on the ranges

[12] The study by DLR (2005) has a regional MENA focus and covered all RE based technologies as well as oil, gas and coal, but not nuclear. However, because of technology advances, especially in the field of RE technologies, and shifting fuel prices that both have had a great influence on the LCOE, only studies that were published later than 2010 were considered.

stated by Kost et al. (2013) and Richts (2012). For onshore wind, the average based on the range stated by Kost et al. (2013). For utility hydro-electric power plants, an average between the weighted averages stated for Africa and the Middle East by IRENA (2015). For oil, the average based on Kost et al. (2013).

\ Third, gaps where neither national nor regional data could be obtained were filled with international meta-studies that conducted their LCOE estimations under comparable conditions to the surrogate plant locations assumed for the countries in this study. For example for fossil-fired technologies regional data are less available. Therefore, a meta-study (WEC, 2013) was considered that does not specifically focus on the target region, but gives ranges for LCOEs of the different technologies across several regions. The authors assumed that the LCOEs for fossil technologies in the countries under study range between the average and the bottom end of the ranges provided within the meta-study for two reasons: First, construction and operation costs are considered to be rather low in the MENA region due to relatively low unit labour cost. Second, countries as Morocco or Jordan do not yet pay a price for CO_2-certificates and environmental regulations that may also drive investment costs. These assumptions may furthermore be underpinned by examples given a) for other developing countries, where LCOEs lay at the bottom end of the global ranges, or b) for comparable regions, like the Middle East, where nuclear energy is at the bottom end of the range (WEC, 2013). For these reasons, a value for nuclear, coal and natural gas was chosen that lays 25% above the bottom end of the stated range.

Figure 9 below and Table 34 in the Annex summarize the results of the literature review.

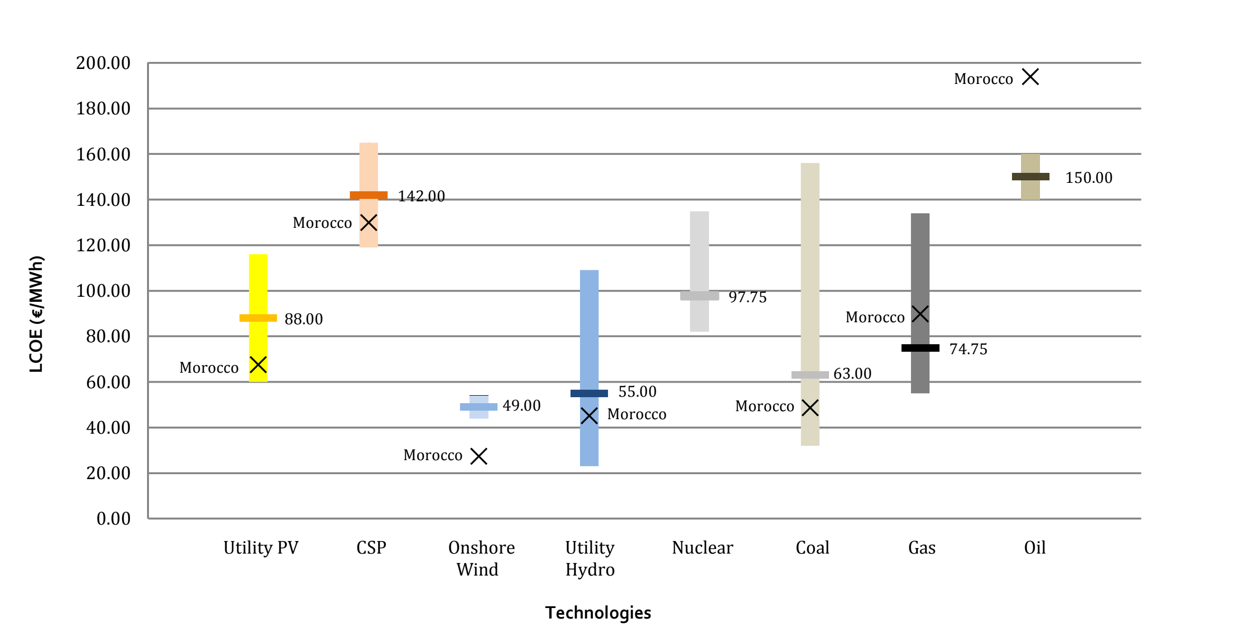

Figure 9: Ranges and averages of *"Electricity generation costs measured as Levelized Costs of Electricity (LCOE) in €/MWh".*

Sources: Based on the literature review for the different electricity technologies (Table 34 in the Annex).

As there is no universal agreement on methods for calculating integration costs and because of missing comparable system-level data for each technology in the countries under study, a quantitative evaluation of the second indicator was not possible. Instead, the authors derived it qualitatively by evaluating the system integration compatibility of each technology according to specific supply characteristics based on existing literature and their judgments (Milligan et al. 2011; Borenstein 2012; IPCC, 2012; OECD, 2012; Ueckerdt et al., 2013; and IRENA, 2015).

Although there are integration costs for every new power plant, the IPCC (2012) emphasizes in particular two supply characteristics that are of direct relevance to the integration into electrical power systems. They provide an indication for additional integration costs that can stem from higher shares of specific technologies in the electricity mix: a) variability and uncertainty, and b) distance and location (IPCC, 2012, p. 622). These characteristics relate to additional expenses required to respond to higher penetration shares by a) increased balancing capacities, such as more generation flexibility, new backup and storage capacities, and improved operational planning, and by b) strengthened or expanded grid infrastructure (OECD, 2012, p. 7). Diminishing cost savings in the non-RE system due to the penetration of RE, however, are excluded here due to their rather complex nature (see profile costs at Ueckerdt et al. (2013)).

\ *Variability and uncertainty:* The electricity supply of fossil-based generation technologies is characterized by very low variability and the ability to provide reliable baseload (coal, nuclear) and/or dispatchable (oil, gas) electricity by demand. However, if coal or nuclear plants were forced to ramp or cycle in case of newly added capacities to the grid (conventional or RE), their relative inflexibility in adjusting to the new circumstances would lead to economic losses when pushed to operate flexibly, or the plants' utilization rates were reduced (OECD, 2012, p. 8). Despite being affected by natural variations (e.g. cloud cover or seasonal precipitation patterns), CSP with storage and utility hydro-electric power plants can also provide dispatchability and predictable baseload and thereby help smoothening seasonal and inter-annual variability. With its storage component, CSP in particular can be reliably scheduled towards meeting late-day electricity demand in North Africa and thereby replace gas-fired power plants (Brand & Zingerle, 2011, p. 441–41). Yet, the electrical output of the intermittent utility PV and onshore wind varies nearly instantaneously with changes in weather conditions. Whereas the availability of electricity generated by onshore wind can differ significantly over the course of a day and thus makes the requirement of additional system storage and balancing capacities for higher shares costly, the electrical output of utility PV in North African countries offers opportunities to follow demand profiles at relevant time scales. This is because regional electricity demand patterns with daily and annual electricity demand peaks (especially for air conditioning given the hot climate) coincide with the maximum incident of solar radiation and utility PV peak load during day and summer time. Furthermore, the primary factors that affect PV generation in North Africa—cloud coverage and night—are more predictable (Griffiths, 2013, p. 125-131). While this, to some extent, could leverage conventional technologies aimed for peak load supply, at higher penetration rates new balancing capacities comparable to onshore wind would be required as well.

\ *Distance and location:* Conventional electricity generation generally is located near centres of demand or close to existing transportation infrastructure, such as ports or storage terminals from there it is transmitted to the electricity grid. Utility-scale hydro-electric power plants often fulfil multiple purposes, e.g. drinking and agricultural water supply, and thus are located relatively close to consumption centres and grid infrastructure. Onshore wind can be distributed along densely populated coastal areas, but also be located in remote areas where the extension of existing transmission infrastructure is required. Although both CSP and utility PV are generally sited in desert areas, CSP with storage and potentially in combination with gas-fired backup must be located closer to consumers due to its high maintenance and corresponding transportation requirements. Therefore, it does not require as extensive new transmission lines as utility PV plants that can be located in distant remote areas.

Although integration costs can be reduced by various measures, e.g., long-distance transmission or demand-side management, for the countries under study, these options are not expected to be implemented in the short- to medium-term. Despite that integration cost can be negative or modest at low (<10%) penetration for variable RE (IRENA, 2015, p. 14), the great ambition in North African countries to further increase their solar and wind penetration in the short- to mid-term suggests that higher shares of variable RE in the future electricity mix can be expected. Corresponding additional integration costs should, therefore, be considered (Morocco already aims to increase its installed capacity of solar and wind energy up to 14 per cent each by 2020, and 20 per cent each until 2030). Consequently, the interaction of these characteristics can guide the determination of the scale of the system integration challenge as an indication of the potential for additional integration costs in a given electricity system at increasing penetration levels.

	Variability/ Uncertainty	Distance/ Location
Utility PV	Moderate	Very high
CSP	Low	High
Onshore Wind	Very high	Moderate
Utility Hydro	Low	Low
Nuclear	Low	Very low
Coal	Low	Very low
Gas	Very low	Very low
Oil	Very low	Very low

Table 12: Authors' qualitative judgement of *"Estimated additional integration costs at increasing penetration levels based on uncertainty/variability and distance/location"* for different electricity generation technologies.

Sources: Milligan et al., 2011; Borenstein, 2012; IPCC, 2012; OECD, 2012; Ueckerdt et al., 2013; IRENA, 2015.

Table 12 summarizes the qualitative judgement and illustrates the values derived for the second indicator for each technology[13]. From an integration costs' perspective, the comparison shows that as of today dispatchable and baseload power plants offer more value to the electricity system than all RE. Of the RE technologies, utility-scale hydro-electric power plants score best due to their favourable variability and location specifics. CSP would receive similar results as utility-scale hydro-electric plants do, but its greater distance from demand centres means comparably higher transmission costs. The unfavourable values for utility PV and onshore wind place them last in the ranking and illustrate that integration costs could become an economic barrier to their large deployment.

Notwithstanding the fact that a comprehensive evaluation would require sound country-level data and considering the high uncertainties stemming from this

13 It should be noted that the assessment (very low–very high) only illustrates the relative variations between the different technologies and does not constitute an absolute evaluation.

simplifying assessment, these estimations are also reflected by several studies on integration costs. For example Ueckerdt et al. (2013) estimate the integration costs of utility PV and onshore wind at a penetration above 20 per cent in Germany (ranges that are well within projections for North African countries) to be in the same range as generation costs (LCOE), thereby doubling the electricity system costs that would have been estimated based on LCOE values only (Ueckerdt et al., 2013, p. 23–27). In another quantitative assessment of grid-level system costs, OECD (2012) calculates the balancing (variability) and grid connection (distance) costs for utility PV and onshore wind at penetration rates of 10 and 30 per cent for different OECD countries to increase by 5-50 and 16-180 per cent per MWh, whereas costs for dispatchable and baseload technologies would only suffer from slight cost increases (OECD, 2012, p. 6–8).

Morocco

For Morocco, national LCOE data was limited but available for all technologies, with the exception of nuclear as it is only considered to become an alternative after 2030 (see Table 13).

Based on the latest available LCOE data, new utility-scale onshore wind projects are estimated at 27.47 EUR/MWh and have experienced even sharper cost reductions than utility PV, which is currently estimated at 67.57 EUR/MWh. Utility hydro-electric power plants in Morocco rank second lowest with 45.2 EUR/MWh, closely followed by coal[14] with 48.65 EUR/MWh. Current power purchase agreement (PPA) prices for gas are estimated to be around 89.9 EUR/MWh. However, the gas LCOE value considered for Morocco in this study does not take into account that Morocco will rely more on imported and costly liquefied natural gas (LNG) in the near future and thus should be considered rather optimistic. CSP in the south of Morocco has also experienced advancements along its learning and cost curves in recent years. (LCOEs have fallen by around one third over the last five years.) The latest tender for a 200 MW parabolic trough project including seven hours storage capacities (Noor II) was won with the lowest bid coming in at around 130 EUR/MWh. Besides the cost reductions, solar and wind technologies in Morocco additionally benefit from concessionary financing from international financing institutions, which lowers their LCOEs significantly.

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[14] According to a recently published news report (Parkinson, 2016), the Moroccan vice minister of MEMEE said that the LCOE for coal is currently at 73.35 EUR/MWh. However, the authors could not verify this statement based on a coal project in development.

Utility PV[15]	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
67.57 EUR/MWh 75 MW Noor in Tafilalt	130 EUR/MWh 200 MW Noor II in Ouarzazate	27.47 EUR/MWh 850 MW (tender bid)	45.2 EUR/MWh Reference case	97.75 EUR/MWh no national reference case	48.65 EUR/MWh 1380 MW Jorf Lasfar in El Jadida	89.9 EUR/MWh Reference case	194 EUR/MWh Reference case
Source: World Bank, 2015)	*Source: RES4MED, 2015*	*Source: Parkinson, 2016*	*Source: UNFCCC, 2010*	Source: WEC, 2013	*Source: UNFCCC, 2010*	*Source: World Bank, 2014*	*Source: World Bank, 2015a*

Table 13: LCOE values for different electricity generation technologies in Morocco.

Sources: MDB reports and national data.

Note: Most of the values illustrated in the table were converted from national currencies into Euro (from Moroccan Dirham (MAD)) based on the exchange rates of the cited studies' publication dates and thus may differ slightly from the original LCOE values.

All these LCOE values are in line with the ranges provided by regional meta-studies (see Figure 9). Yet an exception is marked by heavy fuel oil for which the Moroccan LCOE value of 194 EUR/MWh not only makes it the most expensive technology but also places it outside the regional range. As no data for nuclear could be obtained, an international value of 97.75 EUR/MWh and 25% below the bottom end of the range stated by WEC (2013) was chosen.

[15] Although the 70 MW PV facility Noor$_0$ IV in Ouarzazate is assumed to have even lower LCOE, this could, however, not yet be validated by official sources.

3 LOCAL IMPACT SENSITIVITY

While investments in new utility-scale electricity infrastructures are a precondition for achieving national development goals, they furthermore have the potential to transform communities in the vicinity of project sites. This chapter outlines how the deployment of different electricity technologies could predominantly impact on social, economic and environmental issues at the local level in Morocco, Jordan and Tunisia. While these criteria have proven salient for community support or opposition to energy and other facilities, they are neither comprehensive nor decisive.

3.1 Criterion 6: On-Site Job Creation

Description: *The technology should have a high potential to create direct on-site jobs over the entire lifetime of the power plant*

Indicators (quantitative, maximize):

\ MCI: Average amount of labour in full time equivalent (FTE) person years per MW

\ OM: Average amount of labour in FTE permanent jobs per MW

Direct employment

Direct employment refers to employment that is generated directly by core activities without the intermediate inputs necessary to manufacture equipment or construct and operate facilities (IRENA, 2013a,

Given the enormous development challenges of unemployment and industrial deficits, creating jobs is one of the explicit policy objectives in Morocco, Jordan and Tunisia (see for example Schinke et al., 2016). Utility-scale electricity technologies create direct employment opportunities during their lifecycle phases. Accordingly, the indicator of the *"On-Site Job Creation"* criterion could be defined as the amount of direct labour on-site during construction and operation for each technology. Yet, a more specific definition is needed to account for the employment differences during each project phase. This translates into two indicators.

3.1.1 Indicators

For manufacturing, construction and installation (MCI) the first indicator is measured by the *"Average amount of labour in FTE person years per installed MW"*, whereas the indicator of operation and maintenance (OM) is defined as the "*Average amount of labour in FTE permanent jobs per installed MW"*. For the purpose of the MCDA, and consistent with the criterion objective, it is assumed that higher values of the indicator are preferred to lower values. However, fuel extraction and processing, the decommissioning phase at the end of a technology's lifetime as well as employment factor decline rates due to learning curves and efficiency gains, are not considered in this study.

3.1.2 Results

Due to a lack of data for establishing accurate, average labour statistics for the technologies across the countries' electricity sector, the assessment combined two data sets to calculate the job attribute values for each technology: international meta-studies and regional data derived from industry sources and environmental social impact assessments (ESIA) of existing or planned power facilities in Jordan, Egypt, Morocco, Sudan and the United Arab Emirates (Table 14 and Table 35 in the Annex).

This approach was required since the majority of available scientific publications do not consider employment effects of fossil-based energy sources in the MENA region and lack detailed regional data on RE technologies. Where regional data was available, it was compared and supplemented with international data in order to check data coherence and to fill existing regional data gaps. Thereby, scientifically sound and regionally-specific average values for each technology were obtained. One exception was utility PV where large uncertainties remain in international data sets and no clear distinction is made between centralized and decentralized PV applications. Where regional data was lacking, international averages were used for the MCDA (as was the case with utility scale hydro-electric plants). Also, differences in methodologies and calculations were taken into account by considering different lifetimes and construction periods of technologies, averaging start and peak labour demand and calculating the attribute values in comparable units.

	References
International meta-studies	Kammen, D.M., Kapadia, K., & M. Fripp (2004)
	Rutovitz, J., & A. Atherton (2009)
	Wei, M.; Patadia, S., & D.M. Kammen (2010)
	The climate institute (2011)
	Welters, R., Reedman, L., & W. Mitchell (2011)
	Rutovitz, J., & Harris, S. (2012)
	IRENA (2013)
	Van der Zwaan, B. Cameron, L., & T. Kober (2013)
	Greenpeace (2015)
	Van der Zwaan, B., & L. Cameron (2015)

	Technology	Country	Project	Capacity (MW)
Regional data	Utility PV	Jordan	PV Plant North Jordan	20
		Jordan	Shams Ma'an	50
		Jordan	Arabia One	10
		Morocco	Solar PV project - Erfud	25
		Morocco	Soar PV project - Missour	25
		Morocco	Solar PV project - Zagora	25
	CSP	Morocco	Noor1	160
		Morocco	Noor 2	200
		Morocco	Noor 3	150
		Israel	Ashalim	121
		UAE	Shams One	100
	Onshore Wind	Morocco	Tangiers 2	100
		Morocco	Midelt	180
		Morocco	Jbel Al Hadid	200
		Morocco	Khalladi	120
		Tunisia	Sidi Daoud	34.32
	Nuclear	Jordan	White Paper	2000
	Coal	Morocco	Jorf Lasfar 1-6	2056
		Morocco	Safi energy hub	1386
		Sudan	Red Sea Coal-fired Plant	600
		Morocco	Jerada Extension	350
	Gas	Morocco	Tahaddart cc power plant	384
		Egypt	Al-Minya	3100
		Jordan	Amman East IPP	370
		Jordan	Al Qatrana IPP	373
		Egypt	Helwan South	1950
	Oil	Jordan	IPP4 Al-Manakher Power Project	250
		Egypt	Combined Gas/Oil El-Ain Al-Sokhna	1300

Table 14: Literature used to derive direct jobs in MCI and OM phases based on international and regional data (for more details see Table 35 in the Annex).

Figure 10 and 11 illustrate all attribute values for the direct MCI and OM on-site job creation potential of the different technologies under study as derived from the literature review. While the analysis shows that the MENA averages of direct employment effects during the MCI and OM phases are lower for RE technologies, they are higher for most fossil-based alternatives compared to the international average. Nonetheless, they are still within international ranges and data uncertainties. Moreover, the figures depict that solar technologies (utility PV and CSP) and nuclear energy have the highest relative ratio of direct MCI and OM jobs and are thus characterized by relatively high direct employment effects. Onshore wind and utility hydro-electric power plants, on the other hand, show less potential to create direct jobs. Fossil-based alternatives rank at the lower part of the analysis.

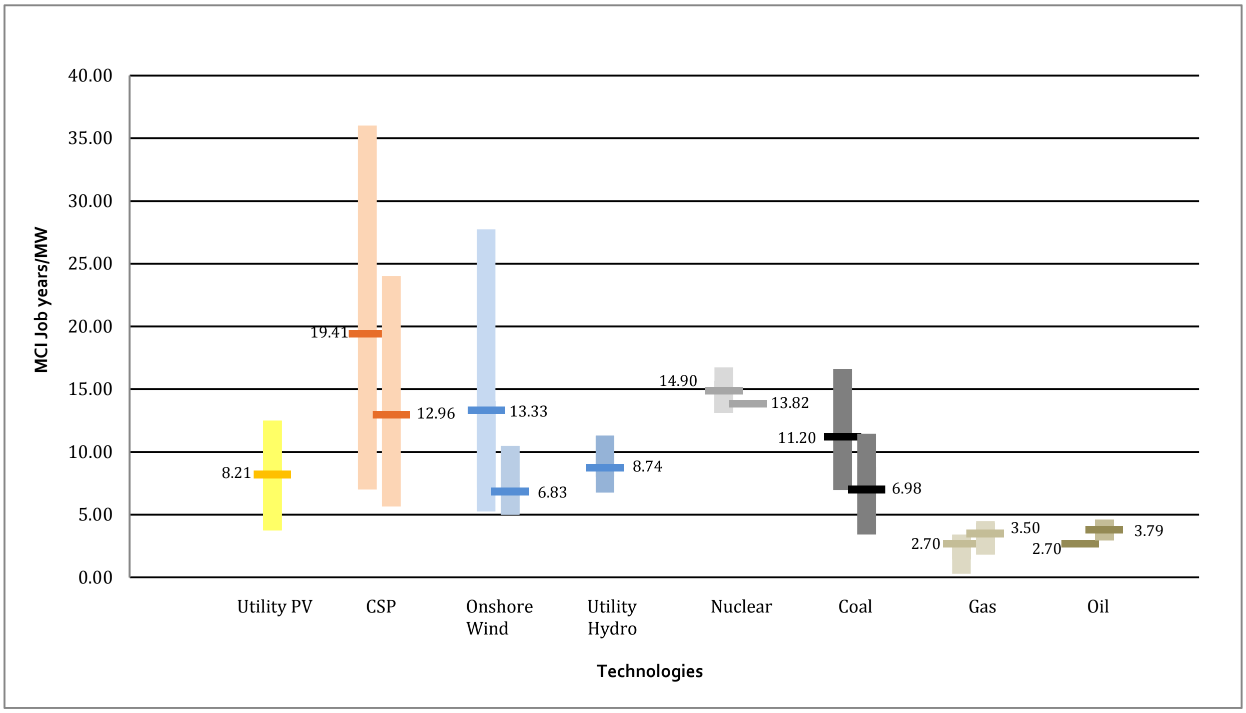

Figure 10: Estimated direct MCI job years per MW for different electricity technologies.

Note: Left: International data. Right: Regional data. Lines mark the average values.

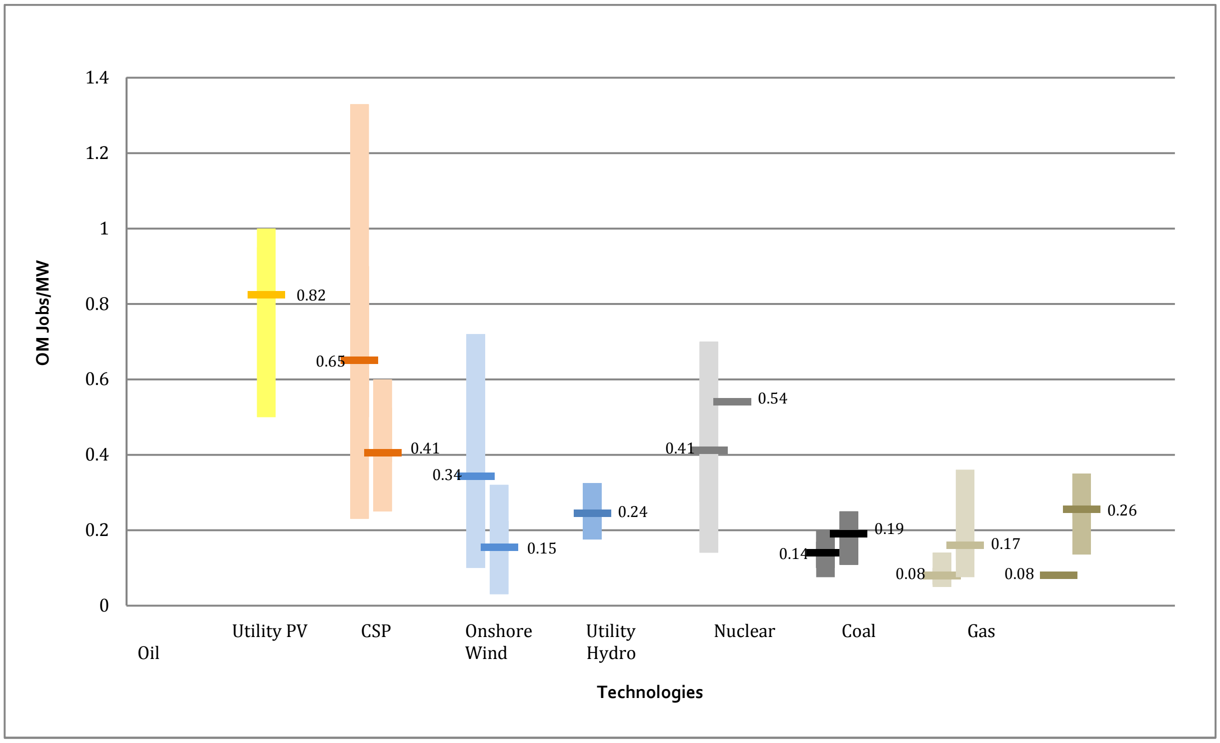

Figure 11: Estimated direct OM jobs per MW for different electricity technologies.

Note: Left: International data. Right: Regional data. Lines mark the average values.

Table 15 provides an overview of all minima, maxima and averages of the different technologies used for the criterion *"On-site Job Creation"* in the MCDA as derived from the quantitative data set.

		Utility PV	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
MCI Job years/MW	Min	3.75	5.67	5.00	6.50		3.43	1.82	3.69
	Average	8.21	12.96	6.83	8.74	13.82	6.98	3.50	3.79
	Max	12.50	24.00	10.49	11.30		10.71	4.33	3.89
OM Jobs/MW	Min	0.50	0.25	0.03	0.20		0.10	0.10	0.16
	Average	0.82	0.41	0.15	0.24	0.54	0.19	0.17	0.26
	Max	1.00	0.63	0.32	0.30		0.25	0.36	0.35

Table 15: Maxima, minima and averages for the direct on-site job creation potential of different electricity generation technologies during the MCI (in job years/MW) and the OM (in jobs/MW) phase.

Sources: Based on the reviewed literature in Table 14.

However, these labour calculations do not consider how much of the employment potential can actually be localized in the MENA region (versus employment of foreigners). Therefore, the beneficial employment effects for the region are rather hypothetical. In this regard, the criterion *"Domestic Value Chain Integration"* sheds additional light on the actual socio-economic benefits stemming from each technology.

3.2 Criterion 7: Pressure on Local Land Resources

Objective: *The technology should cause minimal additional pressure on valuable land resources in terms of amount and value of required land in order to avoid the deprivation of any locally relevant livelihood resources*

Indicators (quantitative/qualitative with a 5-step descriptive scale, minimize):

\ Land requirement: The area of land directly required by the technology at the site of its deployment in ha per MW (quantitative)

\ Land value: The value of the land surrounding typical project sites for providing livelihood resources and services to adjacent communities (qualitative)

Arable land across the MENA region is sparse (FAO, 2011, p. 22), placing the land requirements of power-generation technologies in the critical nexus of local livelihood security (e.g. food security), traditional and customary land rights as well as the protection of natural habitats. In the countries along the southern coastline of the Mediterranean Sea, land is of multidimensional importance for the livelihoods and identities of local communities. It provides a variety of environmental services and important income opportunities stemming from subsistence farming and other livelihood activities, such as grazing and collecting fodder, firewood, or medicinal herbs (MA, 2005, p. 56). The high value of land for livelihood security is reflected by the importance of the agricultural sector in the region, sustaining the livelihoods of one-third of the population in MENA countries (IFAD, 2009, p. 5). Apart from its economic value, local communities are often culturally and emotionally attached to "their" land. This place attachment, or sense of place, is mirrored in the complexity of existing land tenure systems that relates to “legal pluralism”, in which informal user rights defined by traditions and cultural norms exist alongside formal state or collective tenure systems defined by national legislation (*Land of Jmaa*) (Schinke et al., 2015, p. 211). Adding to this complexity is the fact that in MENA countries, land is regularly used collectively with the individual land users not being the formal landowners. This applies to urban or semi-urban communities, those in rural areas and just as much as to arid and sparsely inhabited lands like deserts, which to the outsider’s eyes appear to be “no man’s land” or “useless” but in fact have a socio-economic, cultural and psychological value that is often enshrined in customary tenure rights (Schinke et al., 2015, p. 195-196 and 210-211; Rignall, 2012, p. 31). Moreover, land can be of great environmental value for the biodiversity and resilience of local flora (e.g. seed banks) and fauna (breeding grounds) and their corresponding ecosystem services to local communities. Since any utility-scale electricity generation technology requires land at its location for the duration of its construction and operation, this land is no longer available and accessible to adjacent communities. The loss of land or restricted access to it thus bears the potential of evoking individual and collective concerns that can develop into conflicts among residents about the interference with present and future communal livelihood assets, the local sense of place and the functioning of their environment.

Against this background the criterion *"Pressure on Local Land Resources"* takes into account future land requirements for electricity generation and the associated ramifications at the local level. It is evaluated through two indicators.

3.2.1 Indicators

The first indicator explores the land requirements of each electricity generation technology. It is defined as the *"The area of land directly required by the technology at the site of its deployment in ha/MW"*. In order to more accurately illustrate the reality of land requirements of electricity generation technologies in the MENA region, regional data were obtained by remote sensing. Using geo-reference data and satellite images of the power plants listed in Table 36 in the Annex, polygons were drawn over the total fenced area of the utilities, and the power plant's land requirements in ha/MW were calculated based on the size of these polygons.

Yet, impacts of different electricity generation technologies on local land resources not only depend on the quantities of consumed land, but also on the site-specific value land has for local communities in regards to the provision of livelihood resources and services. Therefore, the second indicator takes into account the local land value at existing and planned utility sites in the case countries. It is defined as *"The value of the land surrounding typical project sites for providing livelihood resources and services to adjacent communities"*.

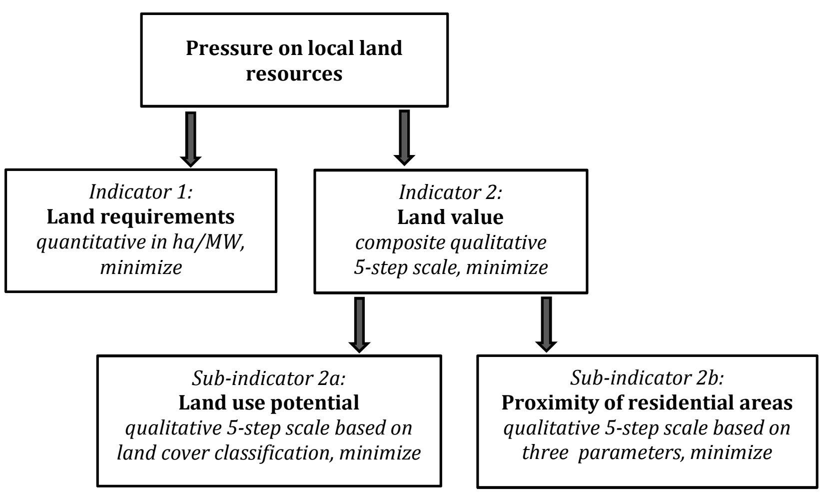

Figure 12: (Sub)-Indicators for the criterion *"Pressure on local land resources".*

With a particular focus on the socio-economic and ecological properties of the land required (IPCC, 2012, p. 744), the second indicator was further divided into two sub-indicators: a) The "*Land use potential*" at the site of deployment and b) "*Proximity of residential areas"* to the plant location (see Figure 12). This division was made by assuming that a) the higher the benefits for subsistence agriculture, the higher the land value to the community and b) the higher the population density surrounding the power plant, the higher the competition over access and use of local land resources. Both sub-indicators are country-specific and were derived through the evaluation of remote sensing data on existing power plant facilities in Morocco, Jordan and Tunisia. In a preparatory step for both sub-indicators, perimeters of one km (red circle), three km (green circle) and five km (blue circle) were drawn around the centre point of each examined power plant in satellite images, based on geo-reference data of the centre of the site (see Figure 13). Where utilities covered larger areas of land, like wind farms, CSP and PV plants, the perimeters were not drawn around the centre of the facility, but along the corner points of the entire premise. For the number of examined power plants in the three case countries see Table 16.

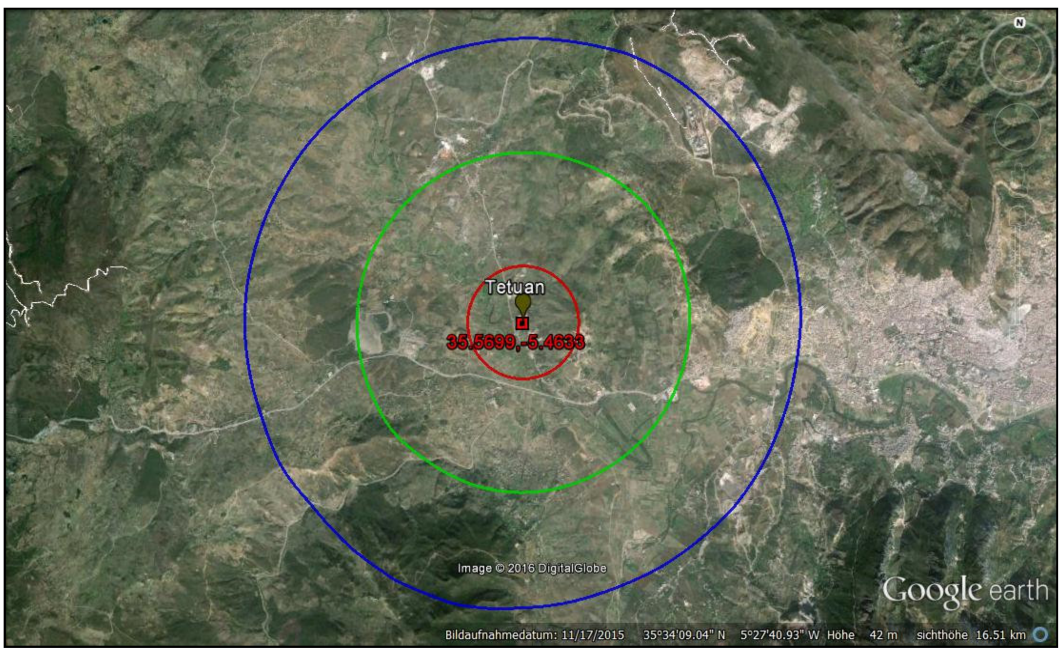

Figure 13: Illustrative example for the evaluation of "Land value" using the one km, three km and five km perimeters around the oil-fired power plant Tétouan, Morocco.(c) Google earth.

	Morocco	Jordan	Tunisia	Total
Utility PV	4	11		15
CSP	4	1		5
Onshore Wind	10	6		16
Utility Hydro	-	-		-
Nuclear	1	1		2
Coal	4	1		5
Gas	4	8		12
Oil	9	5		14
Total	**36**	**33**		**69**

Table 16: Number of examined power plants in all three case countries to evaluate *"Land value".*

For the sub-indicator *"Land use potential"*, a land classification with five different land cover types was established and then assessed in regards to the land use potential within a one km radius (red circle) around the project sites of different electricity generation technologies in the three case countries. This study distinguishes four types of land cover and its assumed land use benefits to local communities in terms of ecological and economic services:

- Cultivated agricultural land: The soil has been cultivated for agricultural production. No further distinction is made between irrigated or rain-fed agriculture, nor regarding seasonal cultivation.
- Uncultivated shrub land or forests: Trees, bushes and grass can offer multiple environmental and economic services to the local communities, like fodder for livestock or the collection of firewood and herbs.
- Built-up land: The soil is sealed by housing or urban infrastructure with only very limited environmental benefits to the local community.[16]
- Desert land: Without land reclamation effort through e.g. irrigation, arid land only offers limited environmental and economic services.

Multiple land cover types can be observed within a one km radius. The normative evaluation of the land value at a project site thus needs to take into account different potential land use options. On a scale from very low (1) to very high (5) land use potential, cultivated agricultural land was assumed to have "very high" livelihood value to local communities. Arid desert land and built-up areas offer the least environmental services and were thus evaluated as having "very low" land use

[16] Built-up areas do offer the potential for urban farming, which contribute substantially to people's subsistence in many of the MENA-countries. An evaluation of the extent and relevance of such urban agricultural activities at a project site of a power plant was beyond the means of this study. Furthermore, the value of urban areas as market place had to be neglected within the scope of this indicator.

potential. The assessment of “low” (2), “moderate” (3) and “high” (4) land use potential was determined by the assumption that the higher the share of potentially beneficial land cover types within the radius is, the higher the value of the land to local communities. Consequently, a mixture of cultivated agricultural land and uncultivated shrub or forest land was evaluated as offering “high” land use potential. A mixture of all observable land cover types indicates high competition over land use, which cannot all be attributed to the construction of the power plant. However, the power plant was constructed in a sensitive land use context, thus evaluated as “moderate”. A mixture of agricultural land and desert land is assumed to have a “low” land use potential. This assessment results from the assumption that agricultural production in arid areas is made possible through land reclamation efforts, while the soil itself is of limited fertility. Furthermore, desert areas offer sufficient space for such land reclamation effort, hence a competition with the project site over land use cannot be assumed automatically. Table 17 presents the line of arguments used to arrive at a normative judgement about the land cover observation.

Logic of the process	Evaluation scheme				
Observation of land cover mixture within a 1 km radius	\ Build-up land \ Desert land	\ Desert land \ Cultivated agricultural land	\ Uncultivated shrub or grazing land \ Forest \ Cultivated agricultural land \ Built-up land \ Desert land	\ Cultivated agricultural land \ Uncultivated shrub or grazing land \ Forest	\ Cultivated agricultural land
Inferences about the overall land use potential of a mixture of land cover	Limited natural assets remain for exploitation of both urban and arid land. The project site was constructed on land either type of land.	Soil with limited fertility for agricultural production. The agricultural production is limited reclaimed spaces. The project site was built on desert land Abundant space is available for expanding land reclamation.	Competition between urban expansion, agricultural activities and environmental protection. Potential for expanding agricultural activities into shrub land.	Only partial agricultural activities. Potential for expansion of land cultivation. The uncultivated shrub, grazing and forest offer valuable services.	The entire area is predominantly used for agricultural production, either the whole year or seasonally.
Concluding inference about the power plant location	The construction of the power plant did not cause significant loss of valuable land resources.	The power plant only competes to a minor degree with agricultural activities.		The construction of the power plant competed with environmental services for local communities.	Agricultural land was lost due to the construction of the power plant.
Evaluation of the land use potential	**Very low**	**Low**	**Moderate**	**High**	**Very high**

Table 17: Evaluation table for sub-indicator *"Land use potential"* based on a land use assessment of mixed land covers.

The evaluation of the second sub-indicator *"Proximity of residential areas"* assesses the population density in the vicinity of the examined power plants for each separate case country. The underlying assumption here is that the higher the population density around the power plant, the more people seek access to the land and compete over using its resources. Any loss of land valuable to the communities in the context of high population exacerbates this pressure on the remaining land resources.

The method for evaluating population density is based on the three perimeters (one km, three km, and five km) drawn around the power plants as exemplified before in Figure 13. Within these perimeters, the authors assessed the population density by examining the existence and category of residential settlements (industrial infrastructure was excluded here). For this purpose, the study distinguishes four categories, each one with an assigned value reflecting the scale of the settlement structure (see Table 18). Each category was assigned a value on a scale from 0 to 3 to indicate their size and population density.

Category[17]	No settlements	Scattered homes	Village	Town/City
Observation	No residential settlement structures	Scattered single houses and small hamlets	Groups of houses forming a village	Urban infrastructure with expanded residential areas
Value	0	1	2	3

Table 18: Categories of residential areas.

Radius	Scoring	
weight	***absolute***	***weighted***
5 km	city	
0.1	*3*	*0.3*
3 km	village	
0.3	*2*	*0.6*
1 km	scattered	
0.6	*1*	*0.6*
Weighted sum		**1.5**

Table 19: Illustrative example for arriving at the weighted sum for evaluating *"Proximity of residential areas"* for the oil power plant in Tétouan, Morocco.

In the next step of the assessment, it was observed, which kind of settlement structure occurred within the three perimeters, and the respective value was listed. Since people living in the 1 km radius are more immediately affected by the power plant than the habitants living farther away, the distance between a given settlement and the power plant needed to be taken into account.

Therefore, a weighted sum was used to give a more adequate description of the settlement distance to the power plant. Each radius was assigned a weight with which the value for the settlement category was multiplied. As people living in the 1 km-radius are most immediately affected by the power plant, this

17 There is no existing universal definition marking the quantitative and qualitative boundaries between hamlets, villages, towns and cities. Therefore the evaluation was based on the authors' assessment within the particular context of the case countries.

radius received a weight of 0.6. Accordingly, residential areas in the 3 km-radius were weighted with 0.3 and those within the 5 km-radius were accounted for with a weight of 0.1. Table 19 exemplifies the approach showing the evaluation for the oil-fired power plant in Tétouan, Morocco. In the 5 km-radius of this project are urban areas, receiving the value 3, multiplied by the weight of 0.1. The village within the 3 km radius receives a higher weighting of 0.3, resulting in a score of 0.6. The scattered houses observed within the 1 km radius also received a weighted score of 0.6 due to the higher weight of 0.6. Power plants can receive weighted scores on a scale from 0 to 3.0, which was then transferred into a five-step qualitative scale from very low (1) to very high (5) as presented in Table 20. For the purpose of the MCDA, it was assumed that both indicators had to be minimized.

Scale of the weighted sum	Min. 0.0				Max. 3.0
Ranges for 5-step scale	0-0.5	0.6-1.1	1.2-1.7	1.8-2.3	2.4-3
Value	Very low	Low	Moderate	High	Very high

Table 20: Boundaries for transforming the weighted sum scale to a 5-step qualitative scale.

While the evaluation of land requirements for fossil, nuclear, wind and solar technologies is rather straight forward, uncertainties remain about utility-scale hydro-electric facilities because of two reasons:

- Land requirements for hydro-electric power plants with a reservoir are significantly high, but vary greatly according to the site-specific geographical and hydrological conditions. Generic data on the average land requirements can be collected, but such a statistical aggregation does not give any robust indication about typical reservoir sizes in the real world.[18]
- Land requirements of reservoir-based facilities might not be problematic *per se* because they usually serve multiple purposes. In many cases, severe land requirements for reservoirs are set off by land reclamation, increasing agricultural activities as well as improved food security, and therefore cannot solely be attributed to electricity generation (see Gagnon et al., 2002, p. 1268 and Criterion 8).

Though these issues are beyond the scope of this study, an approximation to the possible performance attributes needs to be fed into the MCDA. Therefore, the authors decided to assume that the performance of hydro-electric power plants in the case countries ranges between the minimum and maximum attribute value of all other technologies.

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[18] World Bank (2003, p. 9) suggests a land requirement of 60 ha/MW and Jacobsen (2009, p. 262) presents the value of 50 ha/MW. To test the values, this study applied the remote sensing method to 16 utility-scale hydro-electric power plants with reservoirs across the MENA region as a test. The result of 52 ha/MW appears consistent with international estimations.

3.2.2 Results

Due to a lack of MENA-specific data as well as the given level of uncertainty in regard to how data in various publications was obtained, this study established a primary regional data set to derive attribute values for the first indicator.

Through remote sensing methods as described above in the method section for the indicators, data on regional land requirements was obtained by examining 1235 power plants across the MENA region (operational, under construction and in planning, including:

\ 13 PV utilities;

\ 8 CSP utilities;

\ 8 wind farms;

\ 5 coal-fired plants;

\ 67 gas-fired plants;

\ 34 oil-fired plants.

For details see Table 39 in the Annex. The results were verified by consulting 25 international studies offering land requirements per installed capacity for the selected technologies. Because of the focus of the criterion on immediate local impacts, only the land requirements at the project site of the technologies within the total fenced area were taken into account.[19] Up- and downstream land requirements (e.g. during mining of fuel, transportation, fuel processing and off-site storage as well as land requirements during construction, land fillings or land affected by pollution) that are usually accounted for in LCAs were neglected (Gagnon et al., 2002; Heath et al., 2011; Skone et al., 2014; Spath, 1999; Spath, 2000). Table 21 illustrates all minimum and maximum ranges, and the average land requirement in ha/MW for the first indicator as derived from the remote sensing research presented and the verification with international publication shown in Figure 14.

19 Noise pollution, shadows of the towers and flickering from the rotation of the baldes increase the on-site footprint of wind farms and can have adverse impact on neighboring communities. Despite their critical relevane for project siting, these factors were not taken into account in the land criterion as they are beyond the criterion's scope.

		Utility PV	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
Land requirement in ha/MW	Min	1.23	2.34	0.16	n.a.	0.001	0.05	0.01	0.01
	Average	2.77	3.61	0.31	n.a.	0.42	0.11	0.05	0.05
	Max	5.0	5.0	0.45	n.a.	0.75	0.22	0.29	0.13

Table 21: Maxima, minima and averages for the land requirement (in ha/MW) of different electricity generation technologies based on the regional remote sensing research (and international data in the case of nuclear).

Land requirements of electricity generation technologies vary greatly during the operation phase. Generally, it can be said that utility PV and CSP consume considerably more land than fossil-fired and nuclear power plants. Regional average land requirements for PV of 2.77 ha/MW are higher than the international with 2.53 ha/MW.[20] Total land requirement of PV-utilities show a broad range from 1.23 ha/MW up to 5 ha/MW. Utility sizes vary depending on the geographical conditions of the project site and the technical configuration of the panels. These conditions determine the positioning of the panels and the space between them to avoid mutual shading (Denholm & Margolis, 2008, p. 3534). Regional average values for CSP (3.61 ha/MW) are considerably higher than international studies suggest (2.77 ha/MW). In this regard, it must be noted that relevant studies on CSP only take into account theoretical values for the size of the collector field while neglecting either multiplier factors (IPCC, 2012, p. 371), storage capacities (ibid.; Dahle et al., 2008, p. 7) or the turbine (Mai et al., 2012, p. 224). Those studies incorporating all relevant components are consistent with the higher regional remote sensing value ranging from 3.12 (ibid.) to 4.25 ha/MW (Jacobsen, 2009, p. 161).[21]

Wind farms expand over large areas of land, depending on geographical conditions, turbine size and the row positioning of the towers. Denholm et al. (2009) conclude that a wind park expands on average over a total area of 34.4 ha/MW. However, only five to 10 per cent of the total area is actually being occupied by physical installations of the park (BLM, 2005, p. 3-4). Furthermore, as the area between the towers remains open for dual-use during operation, e.g. for agricultural activities, only the permanently occupied area during operation

20 For eight of the twelve examined PV utilities for the first indicator, the study relied on information provided by project documents like ESIAs, either by taking the information on area size in hectare or by using the geo-reference data to calculate the land requirement.

21 Looking at the high on-site land requirements of solar technologies, it is worth noting that taking the entire fuel-cycle into account, though not on-site, land requirements for fossil and nuclear energy are at least equal, if not higher than those of solar technologies (Fthenakis & Kim, 2009, p. 1466).

was considered by this study.[22] The average regional value of 0.31 ha/MW is slightly lower than the international average of 0.35 ha/MW (Denholm et al., 2009; Mai et al., 2012). With values between 0.05 ha/MW and 0.11 ha/MW, coal, gas and oil power plants have the lowest land requirement in MENA countries. Over the last decades, coal power plants have become more and more efficient, resulting in a decrease of land requirements. Older studies (e.g. Robeck et al., 1980, p. 69; Pasqualetti & Miller, 1984, p. 197; DOE, 2003, p. 7) suggest average land requirements of 0.41 ha/MW. The more recent study considered here, published by the Indian Central Electricity Authority (2007, p. 20) examines the size of different components of six coal power plants in India, concluding an average of 0.11 ha/MW. The study further shows that coal power plants located at the coast using sea water-based cooling systems require less land than plants without direct access to the sea. All coal power plants in the MENA region are coastal stations, except Jerrada in Morocco, which shows above regional average land requirements of 0.22 ha/MW. As no nuclear power plant has yet been deployed in the study's target countries, only the international average value of 0.42 ha/MW has been adopted for the case of nuclear power (MIT, 2006, p. 8-8; DOE, 1983, p. 17, 19; BLM, 2005, p. 6-22; Rovere et al., 2010, p. 427).

The second indicator with its two sub-indicators is country-specific and therefore described separately for Morocco. Ranges based on the averages of the other technologies were applied for utility-scale hydro-electric facilities due to existing uncertainties and the multiple-purposes of reservoirs.

22 Temporary impact as presented in the cited literature can amount up to 1 ha/MW, depending on the on-site landscape according to Denholm et al. (2009).

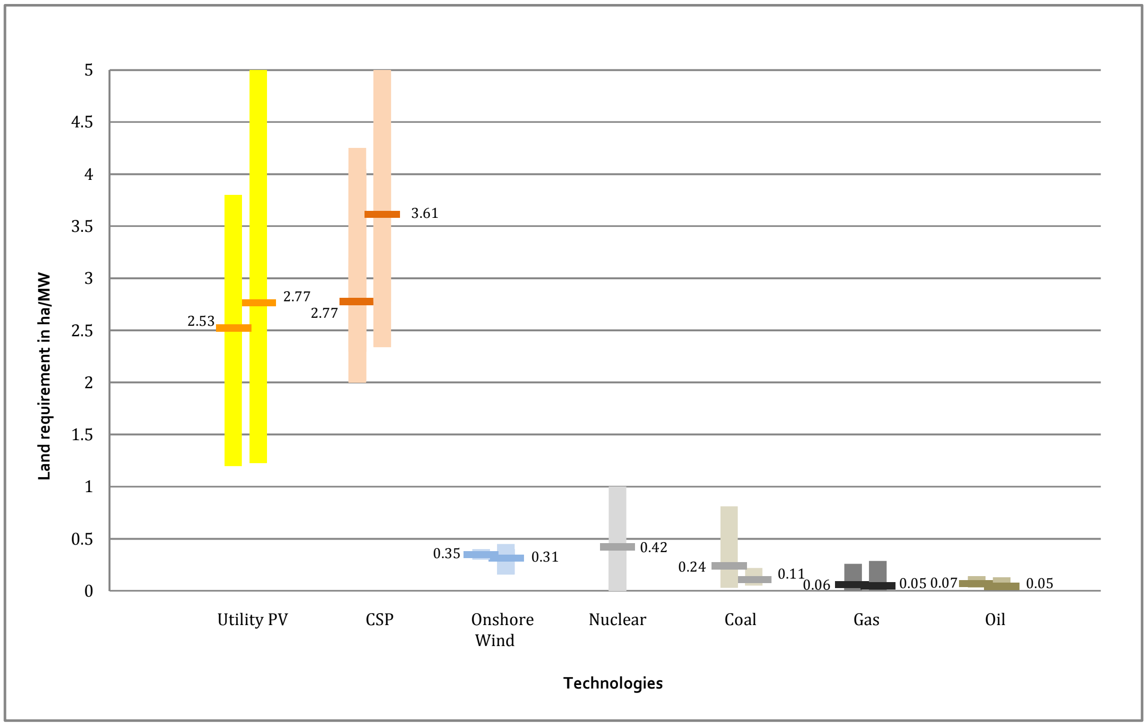

Figure 14: Minimum/Maximum ranges and averages of operational land requirement in ha/MW by fossil, nuclear and RE technologies.

Note: Left: International data. Right: Regional data obtained by remote sensing research. Lines mark the average values.[23]

Morocco

Table 22 shows the results for the first sub-indicator *"Land use potential"*. Both solar technologies are situated on land of "very low" to "low" use potential, since they are commonly deployed on unfertile, rocky land in arid desert areas. Wind farms in Morocco are mostly built on shrub land, thus on land with "high" land use potential. The planned nuclear power plant in Sidi Boulbra is to be located in an area, which is to the largest extent cultivated, thus on land with "very high" value for livelihood resources. Coal and oil power plants are located within different contexts of land use potential ranging from "very low" to "very high", resulting in a national average assessment of "moderate" land use potential for oil and coal, which is assumed for the purpose of the MCDA. With values ranging from "very low" to "moderate", gas fired technologies show a tendency to be located in areas less sensitive to communities' livelihood assets.

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23 Land data for the planned PV-utilities Shams Ma'an in Jordan, Noor Boujdour and Noor Laayoune as well as Noor Ouarzazate III in Morocco and Shams I in the UAE were taken from project documents instead of remote sensing research.

	Land use potential evaluation at project sites in Morocco										
	Very low (1)		Low (2)		Moderate (3)		High (4)		Very high (5)		Average
	Project and location	Installed capacity (MW)	Project and location	Installed capacity (MW)	Project and location	Installed capacity (MW)	Project and location	Installed capacity (MW)	Project and location	Installed capacity (MW)	
Utility PV	Noor$_O$ IV[a]	70	Noor$_T$ Missour[a]	25							Very low (1.3)
	Noor$_T$ Zagora[a]	25									
	Noor$_T$ Erfoud[a]	25									
CSP	Noor$_O$ I	160	Ain Beni Mathar	20							Very low (1.3)
	Noor$_O$ II	200									
	Noor$_O$ III	150									
Onshore Wind			Tarfaya	301	Lafarge	32.2	Tanger	140			Moderate (3.3)
			Akhefnir	200			Amogdul	60.35			
			Tiskrad[b]	300			Koudia Baida	300			
							Fouma Alouad	50			
							Khalladi[b]	120			
							Jbel Alhadid[b]	200			
Nuclear							Sidi Boulbra[c]	1300			High (4.0)
Coal	Mohammedia	300	Jerrada	318	Jorf Lasfar	2100			Safi - Safi	1386	Moderate (2.8)
Gas	Mohammadia	300	Ain Beni Mathar	450	Kenitra	450					Low (2.3)
					Tahaddart	384					
Oil	Dakhla	16			Tiznit	72			Tit Mellil	102	Moderate (2.6)
	Sidi Kacem	16			Tantan	100			Tétouan	105	
	Laayoune	150			Kenitra	300					
	Mohammadia	300									

Table 22: Assessment of the *"Land use potential"* at project sites of power plants that are under development (dark grey), in construction (grey) or in operation (light grey) in Morocco. [a]Planned PV locations verified by ONEE (2015a, 2015b, 2015c), MASEN (2015); [b]planned wind farm locations verified by ACWA Power(2015), ONEE (2010a; 2013); [c]planned nuclear site verified by ONEE (2010b).

	Residential proximity evaluation at project sites in Morocco															
	Very low (0-0.5)			Low (0.6-1.1)			Moderate (1.2-1.7)			High (1.8-2.3)			Very high (2.4-3)			Average
	Project and location	Installed capacity (MW)	Score	Project and location	Installed capacity (MW)	Score	Project and location	Installed capacity (MW)	Score	Project and location	Installed capacity (MW)	Score	Project and location	Installed capacity (MW)	Score	
Utility PV	Noor$_T$ Zagora[a]	25	0.5	Noor$_O$ IV[a]	70	0.8										Very low (0.3)
	Noor$_T$ Erfoud[a]	25	0													
	Noor$_T$ Missour[a]	25	0													
CSP	Ain Beni Mathar	20	0.5	Noor$_O$ I	160	0.8				Noor$_O$ III	150	2				Low (1.0)
				Noor$_O$ II	200	0.8										
Onshore Wind	Akhefnir	200	0				Jbel Alhadid[b]	200	1.4	Tanger I	140	2				Moderate (1.2)
	Fouma Alouad	50	0							Amogdul	60.35	2				
	Tarfaya	301	0							A. Torres	300	2				
	Tiskrad[b]	300	0							Lafarge	32.2	2.1				
										Khalladi[b]	120	2				
Nuclear				Sidi Boulbra[c]	1300	1.1										Low (1.1)
Coal				Mohamma-dia	300	0.9				Jorf Lasfar	2100	2	Jerrada	318	3	Moderate (1.7)
				Safi	1386	1.0										
Gas	Tahaddart	384	0.5	Mohamma-dia	300	0.9							Kenitra	450	2.7	Moderate (1.2)
	Ain Beni Mathar	470	0.5													
Oil	Tiznit	72	0.3	Mohamma-dia	300	0.9	Tétouan	105	1.5	Tit Mellil	102	1.8	Sidi Kacem	16	3	Moderate (1.5)
				Tantan	100	0.8	Laa-youne	150	1.2				Kenitra	300	2.7	
							Dakhla	16	1.2							

Table 23: Assessment of the *"Proximity of residential areas"* at project sites of power plants that are under development (dark grey), in construction (grey) or in operation (light grey) in Morocco (Noor$_O$ III reaches the value high, because it located the closest of all Noor$_O$ projects to a nearby village in the north). [a]Planned PV locations verified by ONEE (2015a, 2015b, 2015c), MASEN (2015); [b]planned wind farm locations verified by ACWA Power (2015), ONEE (2010a; 2013); [c]planned nuclear site verified by ONEE (2010b).

Table 23 shows the results for the second sub-indicator *"Proximity of residential areas"* for Morocco. The results illustrate that due to the typical location of solar technologies in arid desert areas, population density around the power plant location is "very low" to "low" with the exception for the CSP-plant Noor$_0$ III with the value "high".[24] As it is surrounded predominantly by farm and shrub land, population density around the planned nuclear facility in Sidi Boulbra is ranked "low". Fossil-fired power plants are usually deployed close to consumption centres with high population density. This pattern is also indicated by the results for coal, gas and oil power plants in Morocco, which are located in "moderate" proximity to residential areas. Population density at Moroccan wind farms is "moderate", with facilities in the southern parts of the country being located in sparsely populated desert areas, whereas those deployed in the northern region are in high proximity to communities.

3.3 Criterion 8: Pressure on Local Water Security

Objective: *The water consumption of the technology should be appropriate to the local water risk context and cause minimal pressure on local water security*

Indicators (quantitative/qualitative with a 5-step descriptive scale, minimize):

\ Average operational water consumption of each technology measured in L per MWh (quantitative)

\ Average water risk at typical project sites of each technology based on the Water Risk index of WRI (2014) (qualitative)

The MENA region is widely considered to be the most water-scarce region in the world, with actual renewable water resources per capita of about 565 m^3/year (World Bank, 2015b). This is significantly below the water scarcity threshold of 1,700 m^3/year and far lower than the worldwide average of 7000 m^3/year (Terink et al., 2013, p. 3055–3072). As a consequence, already half of the region's population lives under conditions of water stress and faces exceptional water-related challenges in the foreseeable future.

Moreover, most of the MENA region is expected to become hotter and drier throughout the century. Higher temperatures and reduced precipitation will

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[24] While Noor$_0$ I and Noor$_0$ II of the Ouarzazate solar complex are only bordering communities in the five km radius—thus ranked "low" —Noor$_0$ III as the most northern part of the solar complex, is closer to communities within the one km-radius, resulting in a "high" rank.

intensify the occurrence of droughts and thereby increase the risk of widespread water scarcity (Schilling et al., 2012). This effect is already materializing in the Maghreb countries. In combination with the expected population growth from around 300 million today to around 500 million in 2025 the per capita values are anticipated to further decline dramatically in the coming decades (World Bank, 2010; Gregoire, 2012). Due to its importance for food security, economic growth and sustainable livelihoods, water consequently is a major consideration in MENA countries' sustainable development strategies. And as water is indispensable for power generation—the so-called water–energy nexus—(Siddiqi & Anadon, 2011, p. 4529–4540), it is important to understand how the choice of different electricity generation technologies (with long operational lifetimes) could impact water security as well as compete with other water uses in the target countries of this study. A consideration that becomes even more critical at times of increasing electricity demands, exploited freshwater supplies and climate change.

In this light, the criterion *"Pressure on Local Water Security"*, defined as the impact of each technology's water consumption on "the availability of an acceptable *quantity* and *quality*[25] of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies" (Grey & Sadoff, 2007, p. 545), is evaluated through two indicators.

3.3.1 Indicators

The first indicator explores the operational water requirements of each technology for power generation. It is defined as the *"Average operational water consumption of each technology measured in L/MWh"*. Yet, impacts of different electricity generation technologies on local water resources not only depend on the quantities of consumed and discharged water, but also on site-specific local water resource supply and demand characteristics. Therefore, the second indicator takes into account the local water conditions at existing and planned power project sites in the target countries. It is defined as the *"Average water risk at typical project sites of each technology based on the Water Risk index of WRI (2014)"*. For the purpose of the MCDA, it was assumed that both indicators had to be minimized.

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25 The differentiation between water *quantity*/availability and *quality* in this definition of water security is of great importance, as fossil and nuclear power plants in the MENA region are mostly relying on brackish or seawater, whereas RE technologies depend on freshwater resources. Consequently, the impacts of the operational water requirements of nuclear and fossil power plants are mainly related to water quality, while RE technologies directly impact on the quantity of freshwater resources.

3.3.2 Results

The attribute values for the first indicator were obtained by a literature review of international meta-studies (see Table 26) that evaluated the operational water consumption for different technologies, herewith understood as "the volume of water withdrawn that is not returned to the source, i.e. it is evaporated or transported to another location" (IEA, 2012, p. 5).

As, for the majority of power generation technologies, the bulk of water use in the life-cycle of the plants occurs during the operational phase (Macknick et al., 2011, p. 2; IPCC, 2012, p. 741) and with the local focus of the criterion, only the operational water consumption was evaluated, whereas upstream and downstream activities were not considered. During operation, water consumption of electricity generation technologies varies greatly, depending on the technologies' configuration and applied cooling systems. Generally, it can be said that utility PV and CSP consume water for occasional panel and mirror cleaning, whereas onshore wind requires hardly any water if at all for eliminating dust and insect build-up, which otherwise would deform the shape of the airfoil and degrade its performance.

References	Utility PV	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
Macknick et al., 2011	X	X	X	n.a.	X	X	X	
Mielke et al., 2010	X	X	X	n.a.	X		X	
Meldrum et al., 2013		X		n.a.	X		X	
Spang et al., 2014				n.a.		X	X	X
Halstead et al., 2014		X		n.a.	X	X	X	

Table 24: Literature reviewed to derive the values for the operational water consumption of electricity generation technologies.

Note: Some of the water consumption values were originally calculated in gallons/MWh, but have been converted into L/MWh for the purpose of this study.

Thermal power plants, such as coal, nuclear, gas, oil and CSP (in addition to the mirror cleaning), basically consume water as the working and cooling fluid in their Rankine/Brayton cycle. Based on the assessment conducted by Siddiqqi & Diaz Anadon (2011) stating that once-through cooling systems are most commonly deployed in electricity generation in the MENA region (Siddiqqi & Diaz Anadon, 2011, p. 4534), the water consumption volumes for these technologies are based on once-through cooling system data. In the case of CSP, dry cooling is starting to catch attention in the region for new power plants installed. In Morocco for the 200 MW

Noor II and the 150 MW Noor III CSP projects, as well as in Saudi Arabia for the 100 MW Shams 1 CSP facility water scarcity challenges were taken into account by deploying dry-cooling instead of wet-cooling. Therefore, and because dry-cooling can already be cost-competitive to wet-cooling alternatives in hot areas in MENA countries, only dry-cooling for CSP has been considered in this study (Ligreina & Qoaider, 2014, pp. 417–424).

While the quantitative evaluation of water consumption for these technologies is rather clear-cut, uncertainties remain about utility-scale hydro-electric facilities because of three reasons:

\ Water flowing through the turbines of hydro-electric plants cannot be considered consumptive as it is still immediately available for other uses (Torcelline et al., 2003, p. 2; IPCC, 2012, p. 740).

\ Water consumption of reservoir-based facilities—as the typical deployed hydro-electric facilities in MENA countries—might not be problematic *per se* because they usually fulfil multiple purposes besides electricity generation. In contrast to run-of-river and pumped-storage systems, reservoirs and dams can serve for flood/drought control, as well as agricultural, domestic and industrial purposes (IPCC, 2012, p. 740) and thereby enhance the water security in a region. These beneficial services make the attribution of evaporation losses resulting from stored water behind hydropower dams and reservoirs to electricity generation difficult and a comparison with other technologies complex.

\ Although scientific evidence has proven that substantial evaporation losses stemming from utility-scale hydro-electric power plants can make them significant water consumers (e.g., Torcelline et al., 2003; Pasqualetti and Kelly, 2008; Mekonnen and Hoekstra, 2011; Zhao and Liu, 2015), these studies are not considered representative as there is no universal agreement on the methods for calculating the water losses stemming from hydro-electric facilities (IPCC, 2012, p. 741; Bakken et al., 2013, p. 3983).

However, for the comparison of different technologies within the MCDA of this research, it is necessary to determine attribute values also for hydro-electric facilities. Given the arguments above and existing uncertainties, the research team decided to take the minimum and the maximum average values of all technologies as ranges for hydro-electric power plants. This decision is based on the assumption that the performance of hydro-electric power plants ranges between the minimum and maximum average attribute values of all other technologies.

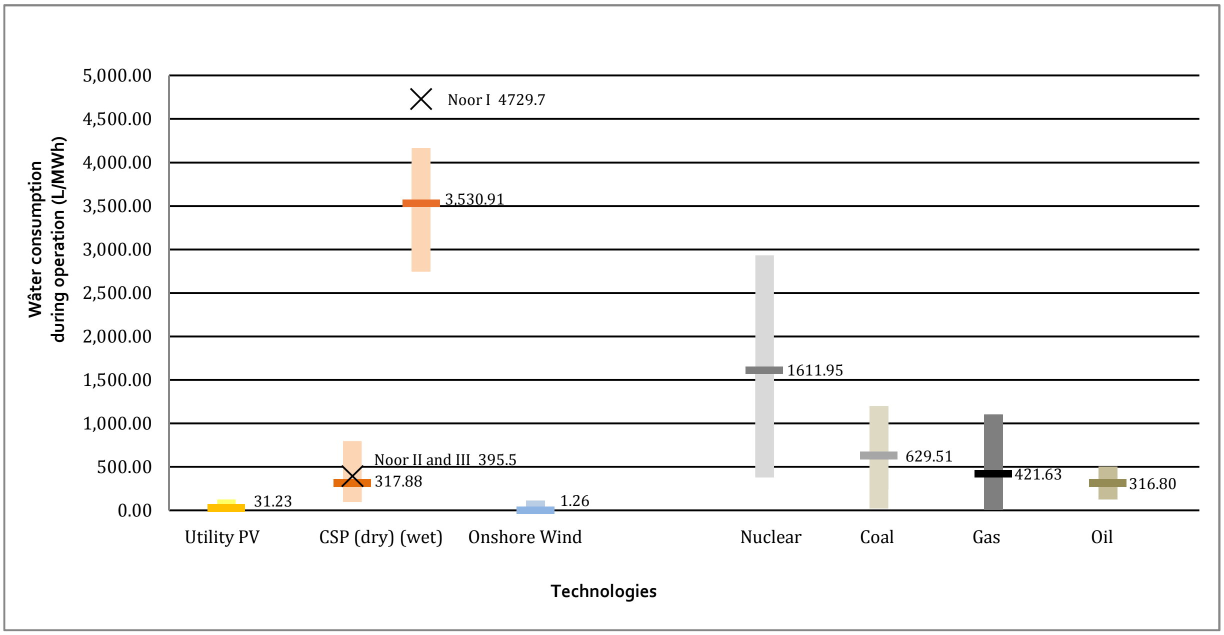

Figure 15: Minimum/Maximum ranges and averages of operational water consumption in L/MWh by fossil, nuclear and RE technologies.

Sources: Based on reviewed literature (see Table 24).

		Utility PV	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
Water consumption in L/MWh	Min	0.00	98.42	0.00	n.a.	378.54	21.6	3.6	129.6
	Average	31.23	317.88	1.26	n.a.	1611.95	629.51	421.63	316.8
	Max	124.92	794.94	3.7	n.a.	2933.69	1200.00	1102.00	504.00

Table 25: Maxima, minima and averages for the water consumption (in L/MWh) of different electricity generation technologies.

Sources: Based on the reviewed literature (see Table 24).

Figure 15 and Table 25[26] illustrate all the minimum and maximum ranges as well as the average water consumption in L/MWh for the first indicator as derived from the literature review. The averages used are the simple mean of the low and high estimates provided by all studies considered.

[26] Note: The analysis is based on international data and should thus be treated with some caution in its application to the target countries of this study. Different technological configurations of thermal power plants with once-through cooling, e.g., for generic, subcritical and supercritical coal, steam and combined cycle natural gas as well as for dry-cooling of CSP trough and power tower have been combined, and the overall average for these configurations was taken. The values for Noor I, II and III have been derived from the official ESIA studies (Schinke et al., 2015; 5 Capitals, 2015a; 5 Capitals 2015b).

Overall, the reviewed data shows that the biggest water consumer is CSP with wet-cooling. However, for the reasons outlined in the previous paragraph, this cooling system has been disregarded in this study. Of all relevant technologies, nuclear has the highest range and average water consumption, followed by coal, gas and oil. Yet, according to Siddiqi & Anadon, these thermo-electric power plants are "largely decoupled from fresh water supplies" in the MENA region (2011, p. 4536) and generally sited in coastal areas where the cooling systems uses brackish or seawater instead of freshwater supplies from rivers or lakes. One exception is Egypt, where 25 per cent of installed thermo-electric capacity is based on fresh water cooling (Siddiqi & Anadon, 2011, p. 4534). As a result, their impacts on local water security are more on the quality of water than on its available quantity and thus accounted for by the second indicator (see next page). Thermal pollution from the discharges of cooling water at higher temperatures into local water bodies (the sea, lakes or rivers) as well as the water-intake systems below the water surface can be detrimental to local aquatic life and marine ecosystems in coastal estuaries, wetlands and coasts (IEA, 2012, p. 8). The consequences of these processes, such as a reduction of dissolved oxygen and increases in toxicity, affect the full spectrum of aquatic livestock at all life stages—eggs, larvae, juveniles and adults—from small photosynthetic organisms to fish, shrimp, crabs, birds and marine mammals (Sierra Club, 2011, p. 5). And as functioning aquatic ecosystems are closely tied to human welfare and food security, with rural populations depending heavily on fishing and other marine services, the operational water consumption of thermo-electric power plants in MENA countries sited in close proximity to human settlements is critical. Dry cooled CSP power plants, on the other hand, use relatively little water and considerably less than once-through cooled nuclear, coal and gas facilities. Nonetheless, as they are generally sited in desert areas far from large population centres, the water requirements are typically met by locally available freshwater supplies. As a consequence, the operational water consumption of CSP projects impacts more on the quantity side of local water security, in contrast to fossil and nuclear facilities that mainly rely on brackish or seawater for cooling in MENA countries. And as CSP deployment in North Africa takes place in areas that are also some of the most water-scarce regions in the countries, a possible competition over local water resources between the operational water requirements of CSP power generation and local demands can significantly constrain the well-being of local communities and ecosystems (Schinke et al., 2015, p. 211–212; Bracken et al., 2015, p. 44–50). An issue that becomes even more critical in light of long-term droughts, depleting groundwater supplies and increasing water demands for agricultural and domestic purposes in many North African countries. Utility PV and onshore wind mark the bottom of the assessment with only marginal water requirements during the operation phase.

As explained in the previous paragraphs, the impacts on local water security cannot be evaluated by the technologies' water consumption values alone. Instead, the water risk—as a sum of water quality and availability—at project sites must be regarded critical as well. Accordingly, the second indicator was assessed by drawing on the Water Risk Index of the World Resource Institute (WRI) published in 2014 (Gassert et al., 2014). The WRI dataset was chosen for this study as it provides a robust, peer-reviewed methodology and the best-available, high resolution GIS maps on water risk for all target countries of this study. By covering more than 15,000 catchments worldwide, and incorporating 12 water availability/*quantity* and *quality* indicators (Reig et al., 2013), the WRI index calculates the overall water risk in a given location on a scale of one to five, where one is low, two is low-medium, three is medium-high, four is high and five is extremely high. In order to assess the average water risk at the locations of the different electricity generation technologies, these maps were combined with a second GIS layer based on the power plant inventory for each country (see Annex). By combining the two GIS layers it was possible to identify the average water risk for the different technologies per installed capacity (MW) in Morocco. This was done by categorizing the locations of all planned, constructed and operating power plant facilities for each country under the five categories provided by the Water Risk Index. For deriving the average water risk value at typical project sites for each technology, the weighted mean of the overall installed capacity (MW) of each technology in each water risk category was selected.

However, as all countries under study are characterized by a very large annual and inter-annual precipitation variability, which is marked by alternating wet and dry periods, interspersed with exceptionally wet and dry years, the value of reservoir-based hydro-electric power plants goes beyond the generation of electricity. Especially with the climate projected to become hotter and drier, as well as with rainfalls to become more unpredictable and erratic, the management of water resources through water storage reservoirs is widely regarded an important adaptation strategy to respond to the impacts of future climate change and to ensure water security. An objective that is also reflected in the national water strategies of Morocco, Jordan and Tunisia aiming to harness water resources and excessive runoff for agricultural, industrial and domestic uses as well as to increase security of risk against droughts through the construction of large quantities of new water storage capacities (UNDP, 2013; ACWUA, 2014)[27].

Because of this special climate–water-energy nexus and its high value for enhancing water and food security as well as socio-economic development in the countries under study, the authors decided to disregard the attribute values of utility-scale hydro-electric power plants in the cumulative assessment. In line with Zyadin (2013) and Bakken et al. (2013) the authors argue that improving large-scale water harvesting techniques are not always a problem, but might rather be one of the solutions to problems of increasing water scarcity in MENA countries—especially as climatic variability and unpredictability are projected to intensify. Therefore, and in the context of the MCDA, utility-scale hydro-electric power plants are assumed to perform within the range of the minimum and maximum average performance of all other technologies.

The results of the assessment for the second indicator are herewith described separately for Morocco.

Morocco

The annual water availability per capita in Morocco is around 700 - 867 m^3 which puts the country into the "water scarce" category (MEMEE, 2016, p. 129; Worldbank, 2015b). In the latest global water risk ranking conducted by the WRI, Morocco currently ranks as the 25th most water stressed country in the world and is projected to rank 19th by 2040 (Luo et al., 2015, p. 6-10). The critical water situation of the kingdom is reflected in the GIS map of the Water Risk Index (see Figure 16 and the GIS-maps in the Annex). Figure 16 illustrates that Morocco is characterized by an uneven spatial distribution of water resources, with the south being significantly less endowed with water resources than the northern parts and some coastal areas having less available freshwater resources than the central provinces (UNESCO, 2012, p. 799). Based on this map, the average water risk value at typical project sites for each technology in Morocco was calculated (see Table 26).

27 It must be noted that despite the fact that dams and reservoirs have indeed sustained water security in many regions throughout the countries under study, further investments in these storage capacities will not yield as much benefits as in the past due to the projected decreases in rainfall and anticipated increases of evapotranspiration resulting from higher temperatures. Furthermore, finding suitable site locations for new reservoirs and dams is widely considered a challenge in Morocco, Jordan and Tunisia (Thomas & Luo, 2013, p. 169–170). Therefore, water management must go beyond large dams and reservoirs and also encompass small-scale watershed approaches, such as unlocking the storage capacity of soils and aquifers.

With regard to the quality component of water security, most of the thermo-electric power plants in Morocco are sited close to the population centres along the Atlantic coast. In these areas, the relatively higher endowment with water resources is thwarted by high population density and water demands as well as urban pollution. This is reflected by the average Water Risk Index category of "high" for coal and gas, as well as "very high" for oil-fired power plants. One exception is nuclear due to the fact that the planned nuclear site in Morocco is located in an area that is marked by the Water Risk Index as of "medium-high" water risk.

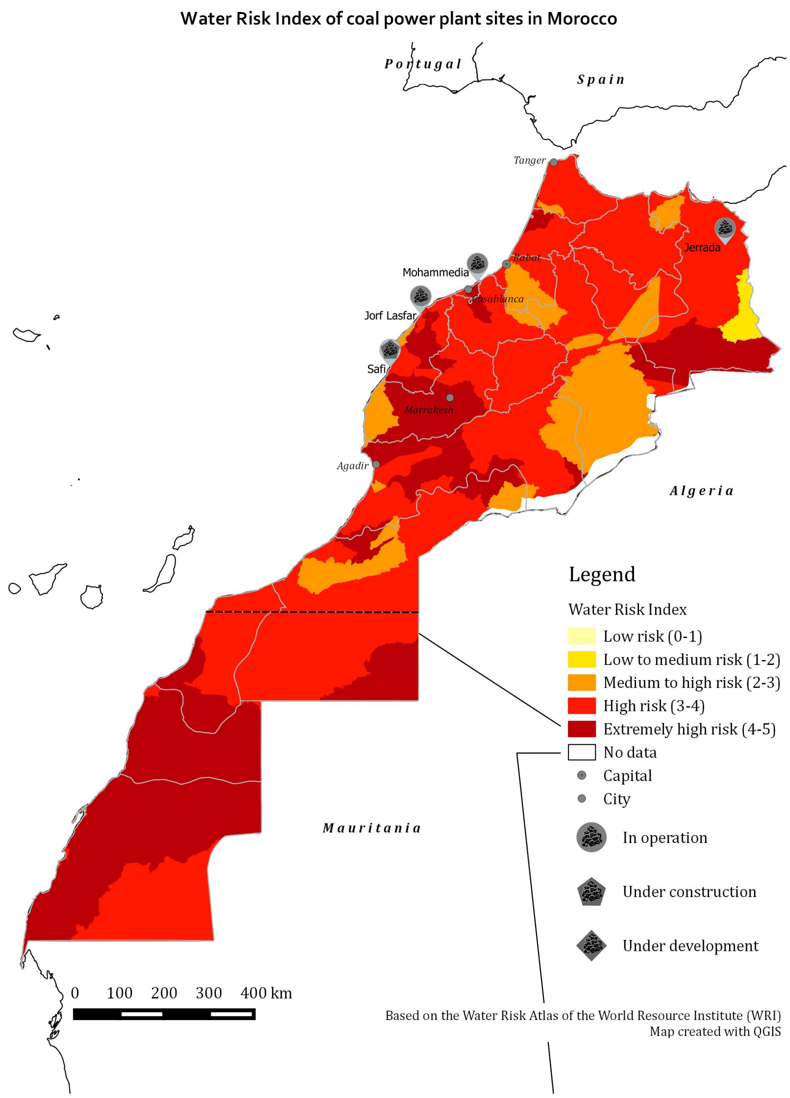

Figure 16: Illustrative example of the WRI Water Risk Index (Gassert et al., 2014) in combination with the locations of coal-fired power plants in Morocco.

	Water risk level at project sites in Morocco										
	Low (0-1)		Low-medium (1-2)		Medium-high (2-3)		High (3-4)		Extremely high (4-5)		Weighted mean (1-5)
	Project and location	Installed capacity (MW)	Project and location	Installed capacity (MW)	Project and location	Installed capacity (MW)	Project and location	Installed capacity (MW)	Project and location	Installed capacity (MW)	
Utility PV					Noor Tafilalt - Erfut	25	NoorL - Laayoune	50	Noor Atlas Bouizakarne	n.a.	High (3.8)
					Noor Tafilalt - Missour	25	NoorO - Ouarzazate	70	Noor Atlas Boudnib	n.a.	
					Noor Atlas Tantan	n.a.	NoorB - Boujdour	50	Noor Atlas Bouanane	n.a.	
					Noor Atlas Tantan	n.a.	Noor Tafilalt - Zagora	25	Noor Argana Tensift	n.a.	
					Noor Atlas Outat El Haj	n.a.	Noor Atlas Tata	n.a.	Noor Argana Errahmana	n.a.	
							Noor Atlas Ain Beni Mathar	n.a.			
							Noor Atlas Enjil	n.a.			
							Noor Aragana Boumalen	n.a.			
CSP					NoorM - Midelt	500	NoorT – Tata	500			High (3.67)
							Ain Beni Mathar - Ain Beni Mathar	20			
							NoorO I - Ouarzazate	160			
							NoorO II - Ouarzazate	200			
							NoorO III - Ouarzazate	150			
Onshore Wind					Midelt - Midelt	150	Tanger I - Tanger	140	Fouma Alouad - Laayoune	50	High (4.0)
					Amogdul - Essaouira	60	Tarfaya - Tarfaya	301	Jbel Alhadid - Essaouira	200	
					Eolien Essaouira II - Essaouira	50	Lafarge - Tetouan	32			
							A.Torres - Tetouan	50			
							Akhefnir 1 - Tantan	100			
							Akhefnir 2 - Tantan	100			
							Khalladi - Tanger	120			
							Tanger II - Tanger	100			
							Boujdour - Boujdour	100			
							Tiskrad - Laayoune	300			

							Koudia Baida - Tetouan	300			
							Taza - Taza	150			
Utility Hydro					Oued El Makhazine - Kenitra	36	Afourer - Azilal	94	Lalla Takerkoust - Marrakesh	12	**High (4.12)**
							Ahmed El Hansali - Kasbat Tadla	92	Step Abdelmoumen - Taroudant	350	
							Al Massira - Settat	128			
							Step Afourer - Afourer	464			
							Bine el Ouidane - Beni Mellal	135			
							Moulay Youssef - Fes	24			
							Tanafnit-El Borj - Khenifra	40			
							Mohammed V - Zaio	23			
							Hassan I - Demnate	67			
							Imfout - El Jadida	32			
							Mansour Dahbi - Ouarzazate	20			
							Al Wahda - Ouezzane	240			
							Asfalou - Taounate	20			
							Allal El Fassi - Sefrou	240			
							El Kansara - Sidi Slimane	14			
							Ouljet Essoultane - Khemissat	19			
							Hassan II - Midelt	12			
							Idriss I - Taounate	40			
							Sidi Said Maachou - El Jadida	21			
							Daourat - Settat	17			
							Tarmast - Azilal	14			
							Mechra Sfa - Nador	30			
							Tillouguite Amont - Azilal	8			
							Tillouguite Aval - Azilal	30			
							Imezedilfane - Khenifra	63			

							Taskdert - Khenifra	38			
							El Menzel - Sefrou	125			
							Mdez El Menzel - Khemssiat	170			
							Boutferda - Beni Mellal	18			
							Tajemout - Fes	28			
Nuclear					Sidi Boulbra - Dar el Mguemda	1300					**Medium (3.00)**
Coal							Jerrada - Jerrada	318	Moahammedia - Mohammedia	300	**High (4.07)**
							Jorf Lasfar 1-6 - El Jadida	2100			
							Safi - Safi	1386			
Gas					Oued El Makhazine CCGT - Kenitra	1200	Ain Beni Mathar - Ain Beni Mathar	470	Mohammadia II - Mohammedia	300	**High (4.01)**
							Dhar Doum - Tanger	1200	Tahaddart CCGT - Tanger	600	
							Jorf Lasfar CCGT - El Jadida	1200	Tahaddart - Tanger	384	
							Kenitra GT - Kenitra	450			
							Al Wahda CCGT - Ouezzane	1200			
Oil							Tanger - Tanger	40	Dakhla - Dakhla	16	**Very high (4.47)**
							Tetouan - Tetouan	105	Tit Mellil - Tit Mellil	102	
							Kenitra - Kenitra	300	Mohammadia - Mohammedia	300	
							Tantan - Tantan	100	Laayoune - Laayoune	150	
							Sidi Kacem - Sidi Kacem	16			
							Tiznit - Tiznit	72			

Table 26: Assessment of the water risk level at the project sites of power plants that are under development (dark grey), in construction (grey) or in operation (light grey) in Morocco based on the Water Risk Index of the WRI (Gassert et al., 2014). Detailed GIS maps of the assessment for each technology can be found in the Annex.

Although the country's water scarcity challenge has been taken into account through the use of brackish or seawater for the cooling of the bulk of thermo-electric power plants, their thermal discharges nonetheless pose substantial water security risks for adjacent coastal communities and marine ecosystems. Morocco's Atlantic coast—part of the highly productive and nutrient-rich Canary Current Large Marine Ecosystem (UNEP, 2005, p. 172)—has already suffered from industrial and urban wastewater discharges. As a consequence, the water quality (especially its oxygen saturation) along the densely populated areas of the Atlantic coast has deteriorated substantially due to increased industrial activities and urban population growth in recent years. The fact that the already highly polluted and water scarce coastal areas around Mohammedia, Casablanca, El Jadida, Safi and Kenitra (Chafik et al., 2001, p. 248; MoE, 2015, p. 59), are coinciding with already existing or planned thermo-electric power plants and suffer from the thermal discharge of these technologies results in additional high pressure on local water security, with potentially cascading effects on food security[28] and ecological stability.

In terms of the quantity component of local water security, the siting of onshore wind farms in areas that are mostly categorized as "high" by the WRI Water Risk Index can be explained by the geographical concentration of onshore wind facilities along the densely populated coastal areas. In these areas, even small operational water requirements could already have significant effects on locally available freshwater resources. In the desert areas of Morocco, where most of the solar technologies are or will be sited, the operational water consumption coincides with an average "high" water risk for PV and CSP, as well as increasing water scarcity levels towards the south. This is where the quantity component of local water security becomes conflictual in the siting and operation of utility PV and CSP facilities. Although difficult to judge, utility hydro-electric projects in Morocco are generally sited in regions marked as of "high" water risk. Therefore, and in the context of the MCDA, utility hydro-electric power plants are assumed to perform within the range of the minimum and maximum average performance of all other technologies.

28 According to World Bank (2003), the fishery sector in Morocco supplies about 25 per cent of animal protein intake in the country (ftp://ftp.fao.org/docrep/fao/006/y4961e/Y4961E00.pdf).

3.4 Criterion 9: Occurrence and Manageability of Non-Emission Hazardous Waste

Objective: *The disposal of non-emission hazardous waste produced during the operation of the technology as well as the risk stemming from national waste management capabilities should be low in order to minimize adverse consequences on human health and the environment*

Indicators (qualitative with a 5-step descriptive scale, minimize/maximize):

\ Disposal of non-emission hazardous waste

\ Potential national capabilities to manage the disposal of the respective types of non-emission hazardous waste

Although gaseous and particulate emissions (see Criterion 2 and 10) are the most prominent adverse externalities of electricity generation, the operation of some technologies also results in non-emission hazardous waste. Disposed and stored in landfills or surface impoundments, leachable elements of these ground-level by-products can have significant negative consequences on ecosystems and human health. As a result, non-emission hazardous waste has become an important consideration in electricity technology choices and of sustainable energy planning. Accordingly, the criterion *"Occurrence and Manageability of Non-Emission Hazardous Waste"* refers to the impacts of solid and liquid hazardous wastes stemming from different electricity generation technologies. The criterion was assessed through two indicators.

3.4.1 Indicators

The severity of ecological and health effects stemming from hazardous waste released in the course of electricity generation generally correlates with the impurity level of the used energy carrier and the quantities of waste (Rashad, 2000, p. 216). The first indicator *"Disposal of non-emission hazardous waste",* therefore, takes into account the quantity of hazardous waste produced during the operation phase of each electricity generation technology. Due to the different characteristics of waste (non-radioactive and radioactive waste), missing comparable data for each technology and no widely accepted method for comparing technologies (Hirschberg & Dones, n.d., p. 10), a quantitative evaluation of the first indicator was not possible. Instead the indicator was judged by the authors based on existing literature on a scale ranging from one to five (one representing very low and five very high disposal of hazardous waste). In this context, effects of thermal releases into water bodies on aquatic ecosystems, despite being a major ecological problem in many countries throughout the world, have no direct human health impact and thus are not considered here (see Criterion 8).

Yet, impacts of non-emission hazardous waste are difficult to predict since they not only depend on the quantities of waste, but also on a country's waste management capabilities. Accordingly, the second indicator is the *"Potential national capabilities to manage the disposal of the respective types of non-emission hazardous waste"* and refers to a country's capacity to manage the respective type of waste. These capacities include applied abatement technologies, present and future waste management regulations and their enforcement, mitigation measures, and recycling practices. For the purpose of the MCDA, it was assumed that the first indicator had to be minimized whereas the second had to be maximized.

The attribute values for the second indicator were obtained qualitatively by consulting national experts in each country due to the lack of data. The question included in the expert consultation was:

"How high would you assess the country's potential capabilities (i.e., environmental waste management regulations and their enforcement, waste management facilities, waste management monitoring, and recycling practices) to handle the disposal of hazardous waste stemming from each technology?"

As with all expert consultations within this study, the provided scale ranged from one to five (1 = very low capabilities, 2 = low capabilities, 3 = moderate capabilities, 4 = high capabilities, 5 = very high capabilities).

3.4.2 Results

The authors' judgment of the first indicator *"Disposal of non-emission hazardous waste"* was based on scientific literature and risk assessments for each technology. For instance, onshore wind and utility hydro-electric power plants do not produce significant amounts of solid waste during operation and are, thus, ranked "very low (1)". Utility PV plants, on the other hand, can result in small but toxic amounts of waste if panels are improperly disposed instead of recycled (Silicon Valley Toxics Coalition, 2014) but are still marked as "very low (1)". In CSP operation, chemicals are released during water treatment and oil and other lubricants may be used as cooling or Heat Transfer Fluids (HTFs). Despite their quantities being relatively small, they require waste management treatment (Schinke et al., 2015, p. 151) and consequently lead to a "low (2)" evaluation for CSP.

Non-emission hazardous wastes generated from fossil-fuel technologies are critical in terms of quantity and toxicity as they can lead to severe and long-term consequences for the functioning of ecosystems (flora and fauna) and human well-being. While the combustion of natural gas results in rather marginal amounts of residual ashes (fly and bottom ash) and sludge for off-site disposal (IFC, 2008, p. 12; Golhosseini, 2015), oil combustion waste includes significant quantities of both, with considerably high concentrations of heavy metals, such as vanadium, aluminium and zinc (Bady et al., 2011, p. 1). The health burdens associated with oil-fired power plants are therefore higher ("high (4)") than those stemming from natural gas ("moderate (3)").

Yet, the largest quantities of hazardous waste are generated during the operation phase of coal-fired power plants. Data from a number of sources suggest, that the amount of disposable ash produced during the combustion processes of a 1000 MW coal power plant typically ranges from 200,000 to 600,000 tons annually, containing an average of 400 tons of heavy metals and toxic chemicals, such as arsenic, selenium, cadmium, lead, aluminium and uranium (Seitz, 1997; Epstein et al., 2011). If modern abatement technologies are applied or low quality lignite is burned, the amount of solid waste produced can increase significantly due to the required disposal of filter systems (Rashad, 2000, p. 216). When leached out and released from their disposal sites into soils as well as surface water and groundwater aquifers these pollutants are known to cause cancer, birth defects, kidney disease and neurological damage (Schaeffer & Widawsky, 2009; EPA, 2009). As a consequence, coal is ranked "very high (5)".

Waste being produced as by-product of nuclear power generation differs a lot from the others because of its radioactivity. Typically, the various sub-processes of a 1000 MW nuclear power plant require the underground storage of around 30 tons of high-level radioactive waste, along with 800 tons of low-level radioactive waste annually. This may threaten people and the environment beyond the proximity of waste sites for generations to come, albeit indirectly (Rashad, 2000, p. 216–17) and thus ranks nuclear equal to coal as "very high (5)".

	Utility PV	**CSP**	**Onshore Wind**	**Utility Hydro**	**Nuclear**	**Coal**	**Gas**	**Oil**
Authors' judgement	Very low (1)	Low (2)	Very low (1)	Very low (1)	Very high (5)	Very high (5)	Moderate (3)	High (4)

Table 27: Authors' judgement of the *"Disposal of non-emission hazardous waste"* for different electricity generation technologies.

Sources: Silicon Valley Toxics Coalition, 2014; Schinke, 2015; IFC, 2008; Golhosseini, 2015; Bady et al., 2011; Seitz, 1997; Epstein et al., 2011; Rashad, 2000; Environmental Integrity Project, 2009; EPA, 2009; Rashad, 2000.

The second indicator was obtained through a qualitative expert consultation in each country. The results of the expert consultations on the second indicator *"National capabilities to manage the disposal of the respective types of non-emission hazardous waste"* are herewith described separately for each country (for more details on the consulted experts see Figure 20 in the Annex).

Morocco

For Morocco, the expert judgement illustrates the country's critical capabilities to manage non-emission hazardous waste stemming from the high waste-producing fossil and nuclear technologies, with slightly better results for coal, gas and oil. In contrast, RE technologies were judged favourably with particular high waste management capabilities awarded to onshore wind, utility PV and utility hydro-electric power plants (see Figure 17 and Table 28). The results are mirrored in the authors' judgement on the first indicator.

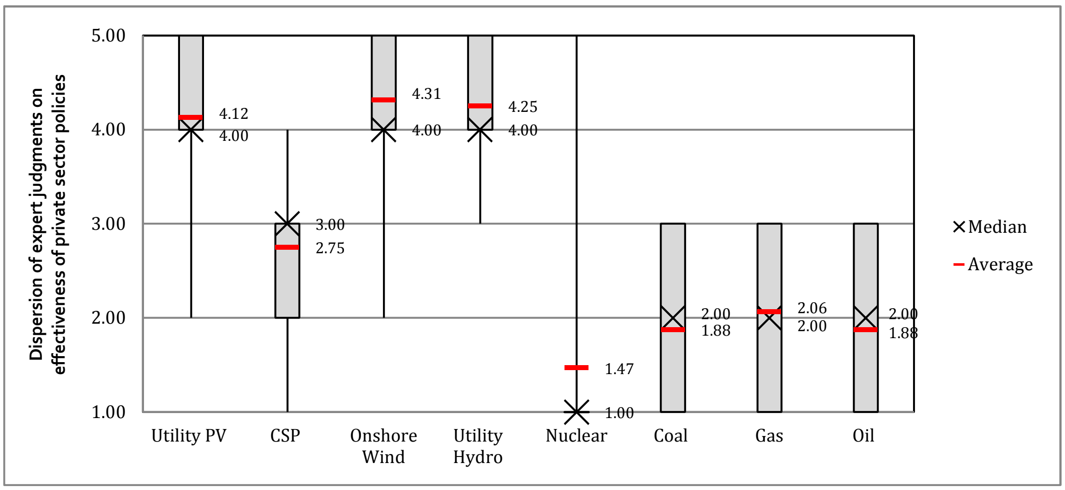

Figure 17: Dispersion of the expert judgement on the *"Potential national capabilities to manage the disposal of the respective types of non-emission hazardous waste"* in Morocco.

Note: Whisker ends represent maxima and minima. Upper and lower ends of boxes represent 75th and 25th percentile, respectively.

	Utility PV	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
Quantile 1 (25%)	4.00	2.00	4.00	4.00	1.00	1.00	1.00	1.00
Min	2.00	1.00	2.00	3.00	1.00	1.00	1.00	1.00
Median	4.00	3.00	4.00	4.00	1.00	2.00	2.00	2.00
Average	4.13	2.75	4.31	4.25	1.47	1.88	2.06	1.88
Max	5.00	4.00	5.00	5.00	5.00	3.00	3.00	3.00
Quantile 3 (75%)	5.00	3.00	5.00	5.00	1.00	3.00	3.00	3.00

Table 28: Statistics of the expert judgement on the *"Potential national capabilities to manage the disposal of the respective types of non-emission hazardous waste"* in Morocco.

3.5 Criterion 10: Local Air Pollution and Health

Objective: *The amount of air pollutants emitted by the technology should be low in order to minimize pressure on local air quality and health risks for people in adjacent communities*

Indicators (quantitative, minimize):

\ Air pollutants (SO_2, NO_x, and $PM_{2.5}$) emitted by OM activities of power plants in kilotons (kt) per generated MWh

\ Premature deaths from emissions of $PM_{2.5}$/MWh and radionuclides resulting from nuclear accidents per generated MWh of electricity produced

According to the IPCC (2012, p. 736), air pollutants, such as nitrous oxides (NO_x), sulphur dioxide (SO_2) and particulate matter (PM), can have adverse impacts on the environment and human health. For example, $PM_{2.5}$ could cause respiratory and cardiovascular illnesses whereas concentrations slightly above the background concentration can already pose a threat to people's health (WHO, 2006, p. 9). Furthermore, symptoms of bronchitis as well as reduced lung function growth for children can be linked to elevated NO_x concentrations. Air pollutants also have adverse effects on environment. Besides hydrogen nitride (NH_3), which is primarily emitted from animal waste, SO_2 and NO_x are the main cause for acidification and eutrophication (Turconi et al., 2013). NO_x and SO_2 are both groups of compounds that are considered ozone depleting. They further react with the atmosphere and transform into acid forms or salts, nitrite salts in the case of NO_x. Acid rain and salts can have adverse effects on ecosystems as well as human health (EPA, 2016a). Increased concentrations of NO_x, especially in combination with SO_x, can reduce plant growth and have adverse effects on vegetation, lakes and ecosystems (EPA, 2016a). However, a more detailed in-depth analysis of the effects pollutants have on the environment was beyond the scope of this report, the main focus of this criterion being impacts on human health. Accordingly, the criterion *"Local Air Pollution and Health"* refers to the air polluting emissions stemming from the operation and maintenance (OM) phases of different electricity generation technologies and the fatal health impacts of $PM_{2.5}$. The criterion was assessed through two indicators.

3.5.1 Indicator

The first indicator of the *"Local Air Pollution and Health"* criterion is defined as the *"Air pollutants (NO_x, SO_2 and $PM_{2.5}$) emitted by OM activities of power plants in kt/MWh"*. Data on air pollution from OM activities of power plants is provided by the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model, an air pollution emission and impact model that identifies air pollution impacts on health and the environment. The GAINS model integrates comprehensive data on emissions by energy sector only for Europe, East and South Asia. Unfortunately, due to the limited monitoring procedures of air pollution during OM of power plants in the MENA region, no sufficient data for the indicators of this criterion were available for Jordan, Morocco, and Tunisia. To accommodate for this lack of data in the MENA region, there is a valid argument to use data from the East and South Asian region, as the standards in the regulatory framework of air pollution monitoring and the prevalent air pollution abatement technologies installed in power plants may be comparable with those in Jordan, Morocco, and Tunisia. However, the GAINS model does not provide calculations of premature deaths (indicator two) for East and South Asia. Therefore, this criterion is based on data developed for the EU countries as they have strict monitoring standards, aiming to provide realistic data of air pollutants on a national level. Among the EU-countries, the data for Germany are the most reliable data due to the country's large variety of installed electricity technologies and the high regulatory standards for monitoring of air pollution. Therefore, Germany is considered to be an example of the best international standards in terms of regulation and monitoring of power plant emissions. Acknowledging the existing difference in regulations and abatement technologies application between Germany and MENA countries, the existing data for Germany were complimented by additional calculations based on the opinions of experts from Jordan about the difference in abatement technologies between these two countries. Further on, the data from Germany were adapted to reflect the Jordanian condition through a weighting process, which is described below.

To assess the first indicator, the data provided by the GAINS model was further normalised by calculating the kt per MWh of electricity produced. The GAINS model provides data on air pollution such as SO_2 and NO_x as well as $PM_{2.5}$ from operation of all considered electricity generation technologies, except nuclear. Furthermore, it provides calculations of premature deaths caused by $PM_{2.5}$ as well as premature deaths resulting from radionuclide air pollution. The data includes air pollution from routine operation as well as accidents and is based on the World Energy Outlook report of 2015. The German Federal Statistical Office (Statistisches Bundesamt Deutschland, 2016) provides data on the total annual electricity production per energy technology for the year 2015. Such data are needed to attribute and normalize the particular share of each technology in the total amount of air pollution produced by the entire annual German electricity generation. The technology-specific data on pollutants per MWh is provided by the GAINS model.

The data for Germany were adapted to the Jordanian conditions based on the results of the experts' survey, which was conducted in the period from September to December 2016.[29] Experts in Jordan have been asked to rank each technology on the scale 0 to 100 according to "*the abatement capabilities of the Jordanian authorities and private sector for decreasing air pollution from power plants and improving air quality"* in comparison with international practice, such as Germany. If experts rank a technology as 100, this means that in their assessment, Jordanian abatement capacities match the international practice (exemplified by data from Germany for the above mentioned reasons) by 100 per cent. In this case, data for air pollution will remain the same. If Jordanian capacities are rated lower than 100 per cent, the data from Germany will be adjusted accordingly. A technology's rating of 50, for example, leads to a 50 per cent increase of the amount of air pollution, assuming that abatement capabilities are only half as good as international practice. Thus the difference in percentage to international practice was used to calculate additional approximate pollution, which was then added to the baseline data to arrive at a final approximation on air pollutants emitted during Jordanian electricity generation.

The second indicator measures *"Premature deaths by $PM_{2.5}$ and by emissions of radionuclides from nuclear accidents per MWh of electricity produced"* and is based on the data of the first indicator. Pollutants for the OM phases of electricity generation technologies were calculated by the GAINS model for $PM_{2.5}$.

Particulate matter can be distinguished by the particulates' size: PM_{10} are "inhalable coarse particles" that are larger than 2.5 micrometers and smaller than 10 micrometers. $PM_{2.5}$ are "fine particles", found in smoke and haze, and are smaller than 2.5 micrometers (EPA, 2016b). $PM_{2.5}$ is a composition of nitrates, sulphates, carbon and other fine particles. $PM_{2.5}$ is considered to have the most adverse effects on human health (EPA, 2016b; WHO, 2016a), which is why it was selected as indicator in this study. However, SO_2 and NO_x, which are emitted during OM additionally to $PM_{2.5}$, do have significant detrimental impacts on human health as well (see e.g. Copper, 2012).

[29] The weighting process from the expert survey was not applied in the case of Morocco, only in Jordan and Tunisia. Assuming that the abatement capacities in Morocco are more similar to the situation in Jordan than in Germany, Jordanian estimations on air pollutants are used for Morocco as well.

The methodological approach to producing estimates on premature deaths developed for the GAINS model is based on several epidemiological studies conducted by, among others, the American Cancer Society and the Health Effects Institute that studied the associations between ambient $PM_{2.5}$ concentration and cause of mortality. Building on previous studies, the GAINS model uses calculations of relative risk for all-cause mortality and, using specific mortality rates, calculates shortening of life expectancy and associated lost life years (Amann & Schöpp, 2011). Amann & Schöpp (2011) observed that in those non-EU countries included in the study the difference in premature deaths amounts to 54 per cent compared to EU countries. This, as well as different regulatory standards in the MENA region must be taken into account when transferring the calculations from the example case of Germany to the situation in the MENA region.

The second indicator further includes data on emissions of radionuclides from accidents in nuclear power plants and resulting premature deaths. Public perceptions of nuclear power are primarily concerned with the effects of radioactive contamination stemming from nuclear accidents, which forms another reason to include premature deaths from accidents. These had to be limited to the Chernobyl nuclear accident in 1986. More recent accidents, such as the accidents in Three Mile Island and Fukushima, were not accounted for in this data as the long latency time for late radiation health effects has not allowed for latent health effects to be studied (IAEA, 2014). These calculations do not include uranium mining or nuclear waste disposal which does cause some radiation. Also excluded here is the natural radiation occurring in other energy chains, for example radiation from coal, which occurs in the mining phase of the coal life-cycle (Vanmarcke, 2000).

For calculating the second indicator, the data for the first indicator had to be complimented by data on nuclear electricity production and nuclear accidents. This data was provided by WHO et al. (2005) and Sovacool et al. (2016). It presents data on nuclear electricity production and accidents as well as on premature deaths which resulted from the Chernobyl nuclear accident.

The normalized values for fossil fuels and RE technologies were calculated as follows:

\ The share of air pollution emitted from the energy sector compared to the national total of air pollution emitted, was calculated for the pollutants NO_x, SO_2 and $PM_{2.5;}$.

\ Using the percentages calculated in the first step, the premature deaths due to $PM_{2.5}$ were adjusted to indicate premature deaths from the energy sector[30] only;

\ Using the data on total electricity production in Germany for the year 2015 (except nuclear) the values were normalized to indicate premature deaths per MWh of electricity produced. In other words, the shares of each energy carrier in the electricity mix were calculated and then the values for premature deaths were derived from this.

The normalized values for nuclear energy were calculated as follows: Normalized values for premature deaths and immediate deaths caused by the Chernobyl accident were calculated using the data on total nuclear energy production provided by Sovacool et al. (2016).

3.5.2 Results

Morocco and Jordan

Figure 18 and Table 29 show the expert evaluation of the abatement capabilities of Jordanian authorities and private sector to reduce air pollution. Jordan's capabilities are ranked highest for PV with a median value of 76 per cent, followed by onshore wind (60 per cent), utility hydro (59 per cent) and CSP (54 per cent). Abatement capacities for coal were assessed with 44.5 per cent, which is higher than gas with 32 per cent. Nuclear (21 per cent) as second lowest technology only outranks oil with the lowest value of 15 per cent.

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30 This study focuses on electricity production. However, in regard to air pollution, production of *energy* must be considered as air pollution stems from the production of heat, parts of which are then transformed into electricity. In order to account for the share of energy actually being transformed into electricity, this report further considers the amount of electricity produced (MWh). In short, indicator two accounts for air pollution from energy production and electricity derived from the energy produced.

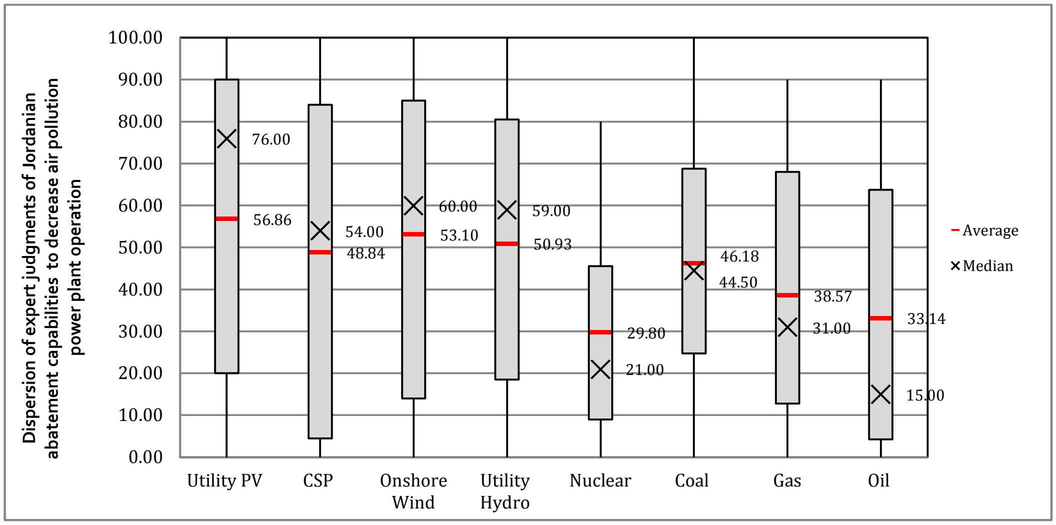

Figure 18: Dispersion of the expert judgement on the *"Abatement capabilities of the Jordanian authorities and private sector for decreasing air pollution from power plants and improving air quality"* in Jordan.

Note: Whisker ends represent maxima and minima. Upper and lower ends of boxes represent 75th and 25th percentile, respectively.

	Utility PV	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
Quantile 1 (25%)	20.00	4.50	14.00	18.50	9.00	24.75	12.75	4.25
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Median	76.00	54.00	60.00	59.00	21.00	44.50	31.00	15.00
Average	56.86	48.84	53.10	50.93	29.80	46.18	38.57	33.14
Max	100.00	100.00	100.00	100.00	80.00	100.00	90.00	90.00
Quantile 3 (75%)	90.00	84.00	85.00	80.50	45.50	68.75	68.00	63.75

Table 29: Statistics of the expert judgement on the *"Abatement capabilities of the Jordanian authorities and private sector for decreasing air pollution from power plants and improving air quality"* in Jordan.

Table 30 presents the result of the proximate air pollution values for NO_x SO_2 and $PM_{2.5}$ for Morocco and Jordan, based on the pollution data on Germany collated from the GAINS-model and adjusted through the expert evaluation of Jordan's abatement capabilities compared to international practice.

		Utility PV	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
Jordan's abatement capacities in % (median)		57.19	49.84	53.71	52.20	29.27	46.18	40.79	33.57
Difference in %		*42.81*	*50.16*	*46.29*	*47.80*	*70.73*	*53.82*	*59.21*	*66.43*
NO_x	baseline data	0.00	0.00	0.00	0.00	0.00	128.82	35.42	2.67
	additional pollution	0.00	0.00	0.00	0.00	0.00	69.33	20.97	1.77
	adjusted data	0.00	0.00	0.00	0.00	0.00	198.15	56.39	4.44
SO_2	baseline data	0.00	0.00	0.00	0.00	0.00	120.94	0.00	4.03
	additional pollution	0.00	0.00	0.00	0.00	0.00	65.09	0.00	2.68
	adjusted data	0.00	0.00	0.00	0.00	0.00	186.03	0.00	6.71
$PM_{2.5}$	baseline data	0.00	0.00	0.00	0.00	0.00	5.82	0.12	0.18
	additional pollution	0.00	0.00	0.00	0.00	0.00	3.13	0.07	0.12
	adjusted data	0.00	0.00	0.00	0.00	0.00	8.95	0.19	0.30

Table 30: Adjusted air pollution levels from O&M activities of power and heating plants presented in kt/MWh for Jordan and Morocco.

Sources: GAINS[31]; Statistisches Bundesamt, 2016; Expert survey Jordan.

RE technologies and nuclear energy have no emissions during power plant operation and maintenance. In comparison to natural gas and oil, coal power plants are the biggest emitter of NO_x, SO_2 and $PM_{2.5}$. Coal emits 3.5 times more NO_x than natural gas and more than 44 times more than oil. Furthermore, the data shows that while natural gas emits no SO_2, coal emits 27 times more SO_2 than oil. Similarly, $PM_{2.5}$ emissions from coal power plants are almost 50 times higher than those from natural gas and 30 times higher than from oil fired power plants.

Table 31 presents values for premature deaths due to $PM_{2.5}$ and radionuclides per MWh in Germany for the second indicator on premature deaths. Based on historical data of regular operation and accident-caused air pollution, it can be concluded that oil and coal have the most adverse effects on human health, causing more premature deaths per MWh than the other technologies taken into account in this study combined. While RE technologies have no emissions during operational activities, oil, coal and natural gas powered power plants are the cause for premature deaths

31 Available information at http://gains.iiasa.ac.at/models/index.html

due to $PM_{2.5}$ emissions, whereas premature deaths caused by nuclear power plants are due to radionuclide air pollution in cases of an accident similar to Chernobyl. Premature deaths per MWh of electricity produced related to oil power plants are 14 times higher than those caused by gas power plants and 1.2 times higher than those caused by emissions from coal power plants. It is to be acknowledged however that these normalised values depend greatly on the energy mix employed in the country.

Premature deaths/MWh		Utility PV	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
Jordan's abatement capacities in % (median)		57.19	49.84	53.71	52.20	29.27	46.18	40.79	33.57
Difference in %		*42.81*	*50.16*	*46.29*	*47.80*	*70.73*	*53.82*	*59.21*	*66.43*
$PM_{2.5}$	baseline data *(in E-09)*	0.00	0.00	0.00	0.00	7.96	9633.74	848.09	11926.31
	additional premature deaths *(in E-09)*	0.00	0.00	0.00	0.00	5.63	4448.86	502.16	7922.65
	adjusted data *(in E-09)*	0.00	0.00	0.00	0.00	13.59	14082.61	1350.25	19848.96

Table 31: Normalised values for premature deaths by technology per MWh of electricity produced. The data represents pollution from routine operation of power plants as well as radionuclide pollution that occurred during the nuclear accident in Chernobyl.

Sources: GAINS (see Footnote 31; Sovacool et al., 2016; Statistisches Bundesamt Deutschland, 2016; WHO et al., 2005).

Interestingly, radionuclide air pollution caused by nuclear accidents cause significantly less fatalities than that of fossil-fired power plants. Literature research further showed that radionuclide emissions caused by mineral processing is insignificant compared to those released after a nuclear accident such as the 1986 Chernobyl nuclear reactor meltdown.

3.6 Criterion 11: Safety

Objective: *Severe accidents from the construction, operation and maintenance of electricity generation technologies, as well as during the transport and storage of resources and equipment, should be minimized in order to reduce accidents resulting in fatalities within and outside power plants*

Indicators (quantitative/qualitative with a 5-step descriptive scale, minimize/maximize)

\ Historical immediate fatalities from severe accidents during transport and storage of resources and equipment, and operation and maintenance activities of power plants, per generated MWh (hereafter referred to as "normalized fatalities") (quantitative)

\ Potential of regulatory and operational emergency preparedness and response capabilities of the private and public sector to mitigate and manage the risk of catastrophic accidents with maximum and severe consequences during the construction and operation phase of each technology (hereafter referred to as "normalized fatalities" (qualitative)

Accidents during the OM phase of electricity generation technologies are those occurring during the power plant's running and upkeep and, as such, happen within its premises. Accidents during the transport and storage phase of the energy life-cycle are those that occur during the transport and storage (TS) of natural resources and equipment needed for the operation of a power plant. OM and TS accidents can pose a risk to neighbouring communities, and especially the risk of sudden and catastrophic accidents can be viewed as unacceptable by the public. It is the high-consequence and low-probability accidents (extremes) that raise intense public anxiety even though the expected losses in fatalities might compare with lower-consequence but more frequent accidents.

Examples of OM and TS accidents include the following:

\ *Wind*: In 2013, during bad weather a helicopter collided with a wind turbine in a wind farm in Pennsylvania, resulting in five fatalities (Sovacool et al., 2016);

\ *Oil*: A catastrophic OM accident occurred in 1982 in Venezuela, where an explosion in an oil-fired plant killed 160 people in the community (Hirschberg et al., 1998);

\ *Coal*: In 1990, a coal-fired power plant explosion in Shandong, China, caused 45 fatalities (Hirschberg et al., 1998);

\ *Natural gas*: The 2012 Pemex natural gas distribution plant fire in Mexico caused 26 fatalities (Reuters, 2012). According to Burgherr & Hirschberg (2008) processing accidents are the most common accidents in natural gas power and heating plants.

\ *Hydro-electric*: Catastrophic dam breaks in India (1979 and 1980) and China (1993) resulted in 2.500, 1.000 and 1.250 deaths, respectively (Hirschberg et al., 1998);

\ *Nuclear*: The 1986 Chernobyl nuclear power plant accident resulted in latent 4,056 fatalities, although the reported number of immediate fatalities was much lower (Gordelier, 2010).

This search revealed no recorded severe accidents for utility PV and CSP technologies.

3.6.1 Indicators

Keeping in mind that the safety criterion does not measure public risk perception, the criterion includes two indicators: expected or normalized fatalities (NF) and risk management (RM). NF is expressed in terms of historical fatalities from severe accidents per produced unit of electricity. RM is expressed in terms of public and private capabilities for risk management (regulating and incentivizing risk reduction, and preparing for and responding to severe accidents).

The indicator for NF is limited to severe accidents in TS and OM electricity generation activities. Following the definition of Burgherr & Hirschberg (2008) severe accidents are those with "at least five immediate fatalities", which includes accidents ranging from five deaths to very large, even catastrophic, consequences (in the case of energy technologies, up to 10,000 deaths). For this indicator the unit of produced electricity, MWh, is used in this context as opposed to installed capacities, MW, as it is common scientific practice to evaluate safety and risk based on produced electricity previously illustrated in Burgherr & Hirschberg (2014) and Sovacool et al. (2016).

Variations of this measurement are frequently used in scientific practice (Burgherr & Hirschberg, 2008), but there are limitations. Statistics on severe accidents have improved significantly during the last three decades; however, they are still difficult to compare due to the absence of standard definitions and methodologies (OECD, 2010). Moreover, NF do not capture society's aversion to very infrequent, high consequence (catastrophic) accidents.

Since there are no published data that provide information on NF directly, estimates were derived for fossil fuel, nuclear and RE technologies based on the following sources and are presented in Table 32:

\ Burgherr & Hirschberg (2014) provide historical data on fatalities in fossil fuel fired power plants;

\ Gordelier (2010) provides historical data for fatalities in fossil fuel and nuclear power plants;

\ Sovacool et al. (2016) provide historical data on fatalities for low-carbon energy generation (1950-2014), including utility hydro, nuclear, solar and wind technologies. As mentioned earlier, there is no or little historical data on severe accidents during operation and maintenance of solar PV and CSP, respectively.

NF was estimated from these data sources as follows:

\ Data on fatalities from severe accidents and their distribution among the energy life-cycle stages were collected from OECD (2016), Burgherr & Hirschberg (2014) and Sovacool et al. (2016);

\ Fatalities during OM and TS activities were estimated by applying the percentages of total fatalities (including plant operation) presented by Burgherr & Hirschberg (2014). For low carbon energy technologies, with the exception of nuclear power, OM accidents and fatalities were identified based on data presented by Sovacool et al. (2016);

\ Total production of electricity per technology (converted into MWh) was estimated based on data presented by Gordelier (2010) and Sovacool (2016);

\ Data on fatalities from OM and TS operations were averaged over the total production of electricity per technology (Chinese accidents in the coal energy life-cycle were excluded due to the high prevalence of coal related accidents in China).

This indicator includes only immediate, and not latent, fatalities from nuclear and other accidents. Latent fatalities from emissions of radionuclides are included in Criterion 10.

Since the human risk imposed by electric power plants depends not only on the international historical record of fatal accidents but also on the country-specific capabilities of the public authorities and private actors to manage risk, these capabilities are also taken into account through the second indicator. The indicator "*Potential regulatory and operational emergency preparedness and response capabilities of the private and public sector to mitigate and manage the risk of catastrophic accidents with maximum and severe consequences during the* *construction and operation phase of each technology"* reflects national expert views on the country's capabilities (in comparison with international experience) for regulating and incentivizing operations and preparing for and responding to emergencies.

Values for RM were elicited with a questionnaire administered to national experts in Morocco, Jordan and Tunisia. The question for Morocco was worded as follows:

What is the potential of regulatory and operational emergency preparedness and response capabilities of the private and public sector to mitigate and manage the risk of catastrophic accidents during the construction and operation phase of each technology?

For Jordan and Tunisia, the question was framed as follows:

In comparison with international practice, how would you rate the future risk management capabilities of the Jordanian authorities and private sector for preventing, responding to and recovering from accidents?

As with all expert consultations within this study, the provided scale ranged from 1 to 5 (1 = very low potential, 2 = low potential, 3 = moderate potential, 4 = high potential, 5 = very high potential).

Conducting three consecutive case studies offered the unique opportunity to learn from experiences and amend applied methods. The question for Jordan and Tunisia was re-framed in the spirit of this learning process. As the data presented within this criterion includes international historical events, and it is assumed that the technologies applied will be similar to the technologies applied internationally, this question gives insights on Jordan's current risk status.

3.6.2 Results

Table 32 presents an overview of the data and analysis for estimating the NF indicator and the results. The original data sources provided estimates of fatalities from severe accidents across the life cycle of the selected electricity generation technologies. This was converted to (1) fatalities per gigawatt-year of electric power (GWey) and to (2) OM and TS fatalities per MWh. (based on: Gordelier, 2010; Burgherr & Hirschberg, 2014; Sovacool et al., 2016; own calculations). Based on available statistics, immediate fatalities from severe accidents in the TS and OM phases of electric power plants per MWh are the highest for oil, followed by gas power followed by wind and hydro-electric power technologies. Although a significant number of fatalities per MWh is caused during the life cycle of technology, the majority of these fatalities occur during mining. Therefore, coal ranks very low compared to other technologies. On this scale, the least fatalities per MWh are caused during nuclear TS and OM activities. Because of short operating history, solar PV and CSP have had no reported severe accidents (according to the reviewed sources) (Sovacool et al., 2016). The normalized fatalities from severe accidents for the solar CSP and PV technologies are thus set at zero.

		Utility PV	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
Life cycle	Severe accidents	n.a.	n.a.	3	26	1	177	135	397
	Fatalities	n.a.	n.a.	27	177665	32	7090	2043	20218
	Fatalities per GWey	n.a.	n.a.	n.a.	n.a.	n.a.	0.754	0.196	1.029
T&S O&M	Fatalities	n.a.	n.a.	22	23564	31	202	1695	17913
	Fatailies per TWh	n.a.	n.a.	0.01	0.0235	0.000063	n.a.	n.a.	n.a.
	Fatalities/MWh (E-09)	0.00	0.00	6.11	3.12	0.06	0.94	9.09	43.90

Table 32: Data and results for estimating normalized fatalities.

Sources: Gordelier (2010); Burgherr & Hirschberg (2014); Sovacool et al. (2016).

Morocco

Figure 19 and Table 33 present the dispersion and statistics of expert judgement in Morocco for the RM indicator. Overall it can be observed that RE technologies are rated with a much higher potential for emergency preparedness and response capabilities than their conventional counterparts On average, experts rated emergency preparedness and response capabilities for utility PV installations and wind farms the highest, followed by CSP, utility hydro-electric, coal and gas installations. Oil and nuclear mark the bottom of the expert judgement in Morocco.

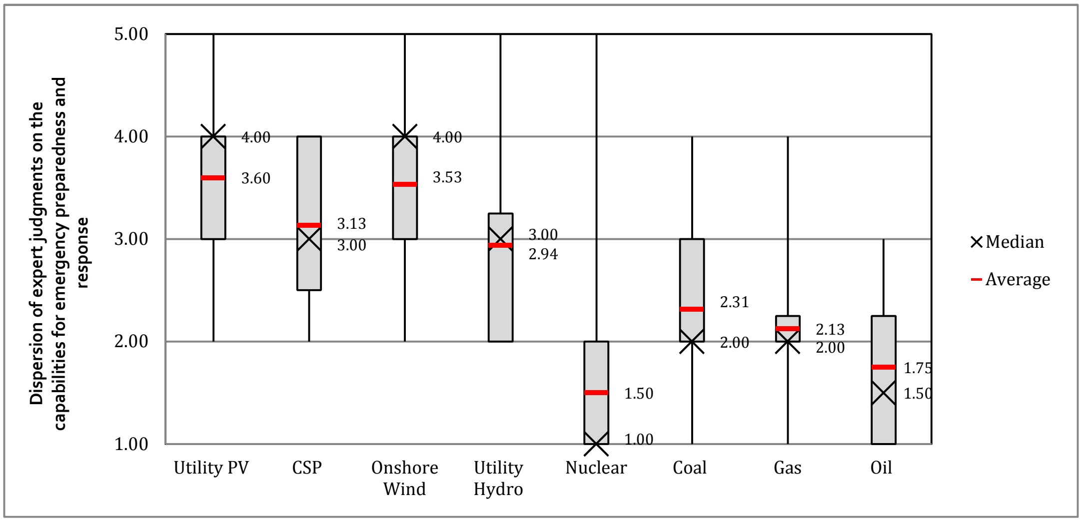

Figure 19: Dispersion of the expert judgement on the "*Potential regulatory and operational emergency preparedness and response capabilities of the private and public sector to mitigate and manage the risk of catastrophic accidents with maximum and severe consequences during the construction and operation phase of each technology"* in Morocco.

Note: Whisker ends represent maxima and minima. Upper and lower ends of boxes represent 75th and 25th percentile, respectively.

	Utility PV	CSP	Onshore Wind	Utility Hydro	Nuclear	Coal	Gas	Oil
Quantile 1 (25%)	3.00	2.50	3.00	2.00	1.00	2.00	2.00	1.00
Min	2.00	2.00	2.00	2.00	1.00	1.00	1.00	1.00
Median	4.00	3.00	4.00	3.00	1.00	2.00	2.00	1.50
Average	3.60	3.13	3.53	2.94	1.50	2.31	2.13	1.75
Max	5.00	4.00	5.00	5.00	5.00	4.00	4.00	3.00
Quantile 3 (75%)	4.00	4.00	4.00	3.25	2.00	3.00	2.25	2.25

Table 33: Statistics of the expert judgement on the *"Potential regulatory and operational emergency preparedness and response capabilities of the private and public sector to mitigate and manage the risk of catastrophic accidents with maximum and severe consequences during the construction and operation phase of each technology"* in Morocco.

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