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Scenario development and multi-criteria analysis for Morocco's future electricity system in 2050. Summary of workshop results

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Middle East North Africa Sustainable Electricity Trajectories

Energy Pathways for Sustainable Development in the MENA Region

Summary of workshop results:

Scenario development and multi-criteria analysis for Morocco's future electricity system in 2050

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The energy and environmental management (EEM) department at Europa-Universität Flensburg has two core fields of research activity aiming at a sustainable development of energy systems: the development of local and regional climate protection schemes and the analysis and development of energy systems going 100% renewable. EEM is part of the interdisciplinary cross-university Centre for Sustainable Energy Systems (ZNES).

International Institute for Applied Systems Analysis (IIASA) conducts policy-oriented research, based on integrated systems analysis of natural, technology and infrastructure and human and social systems to develop solutions for sustainability transformations. The Governance in Transition research theme within the Risk and Resilience program analyzes how governance structures shape decisions and subsequent outcomes by building on and contributing to research on decision-making processes, public acceptance, risk perception, cognitive biases, and cultural perspectives, as well as participatory governance design.

The Wuppertal Institute undertakes research and develops models, strategies and instruments for transitions to a sustainable development at local, national and international level. Sustainability research at the Wuppertal Institute focuses on the resources, climate and energy related challenges and their relation to economy and society. The research group “Future Energy and Mobility Structures” involved in this project is working on these questions from a technical and systems analytical point of view.

Project partners

SUMMARY

In the scope of the MENA SELECT research project, a workshop was conducted in Rabat, Morocco, from 23 to 24 May 2016. During the workshop, stakeholders from different national societal groups discussed and developed future settings of Morocco's power supply with the help of an advanced spreadsheet model, accompanied by an evaluation of the developed scenarios. In this paper, the results of the workshop are summarized.

In the first part of the workshop, the participants were introduced to the modeling approach. Central input parameters, procedures and assumptions were presented. This formed the basis for the subsequent development of scenarios on Morocco's power supply until 2050. With the help of the spreadsheet model, four consistent scenarios were developed, reaching renewable energy shares ranging from approximately 60 to 100 per cent.

In the second part of the workshop, the workshop participants weighted the developed scenarios. For this purpose a multi-criteria analysis was conducted, which included quantitative and qualitative criteria for fossil fuels and renewable energy technologies. The participants weighted the selected criteria against each other according to the preferences of the respective institutions they represented. In combination with the criteria performance for each technology a ranking of the developed electricity scenarios took place resulting in the fact that the workshop participants would accept the scenario with the highest share of renewable energies in 2050 most.

The workshop successfully illustrated that it was possible to develop options of Morocco's future power supply by combining technical and economic parameters that were acceptable to the workshop participants.

CONTENTS

ABREVIATIONS

AHP	Analytical hierarchy process
CAPEX	Capital expenditures
CO_2	Carbon dioxide
CSP	Concentrated solar power
cts	Moroccan Dirham cents
EUF	Europa-Universität Flensburg
IIASA	International Institute of Applied Systems Analysis
LCOE	Levelized cost of electricity
MCA	Multi-criteria analysis
MENA	Middle East and North Africa
MENARES	MENA Renewables and Sustainability
NGO	Non-governmental organization
O&M	Operation and maintenance
OPEX	Operational expenditures
PV	Photovoltaics
RENPASS	Renewable Energy Pathway Simulation System
RES	Renewable energy sources
STEP	Pumped-storage hydroelectricity (*Station de Transfer d'Énergie par Pompage, pompage-turbinage*)
WACC	Weighted average cost of capital
WI	Wuppertal Institut
WP	Working packages

1 Introduction

1.1 The MENA SELECT research project

The Middle East and North African region (MENA) currently faces a number of challenges, such as growing electricity demand, depleting fossil fuel resources and geopolitical risks as well as a volatility of energy prices. Several options exist to satisfy the growing electricity demand, including scaling up renewable energy sources (RES), fossil fuels (coal, gas and oil) and nuclear power. Large-scale deployment of any of these options can lead to a transition of the energy system and, consequently, to a societal transformation. Involving principles of democratic governance in this process would allow to address risks of conflicting opinions and views among stakeholders of the process.

Despite existing scientific evidence about technical and economic capacities and capabilities for such transitions of the energy system and of society, the knowledge about human factors influencing these processes is comparably small at large and almost non-existent for the MENA region. The MENA SELECT research project addresses the perceptions and views of different stakeholder groups about the benefits and costs of different electricity pathways, which will allow the sustainable development of common solutions for the future.

The combination of quantitative and qualitative methods of analysis, including the development and implementation of modelling tools such as scenario modelling, a multi-criteria analysis as well as the stakeholders' views goes far beyond traditional methods of stakeholder involvement. This work actively involves the stakeholders in frames of so-called participatory modelling, allowing extensive inclusion of the stakeholders' feedback.

The MENA SELECT project is financed by the German Federal Ministry of Economic Cooperation and Development. The project consortium consists of the Bonn International Center for Conversion (BICC), Europa-University Flensburg (EUF), Germanwatch, International Institute for Applied Systems Analysis (IIASA) and Wuppertal Institute (WI). The project has been subdivided into four work packages (WP) that are led by the different project partners:

- WP 1 (IIASA and EUF) deals with the techno–economic modelling of different electricity pathways up to 2050 based on participatory workshops with national stakeholders.
- WP 2 (Germanwatch, IIASA and BICC) analyses the social, political, economic and ecological effects of different technologies together with local stakeholders.
- WP 3 (WI) combines the results of both WP 1 and 2 to evaluate the developed scenarios based on predefined criteria with help of a multi-criteria analysis.
- WP 4 includes the dissemination of results by all project partners.

1.2 Workshop objectives

To involve local stakeholders in the work of the MENA SELECT research project, the research team conducted a workshop with representatives from different societal groups. The workshop "Elaboration et évaluation des différents scénarios du mix électrique futur du Maroc" took place at the La Tour Hassan hotel in Rabat, Morocco, on 23 and 24 May 2016. It was organized jointly by EUF, IIASA and WI as well as by the local partner MENARES.

The research project consists of several work packages (WPs). The workshop covered questions addressing two of them. Its aims were the common development of consistent scenarios of Morocco's power future (WP1 of the project) and an assessment of these scenarios (WP3). During the first day of the workshop, the workshop participants developed consistent scenarios of Morocco's future power system up to 2050. On the second day, the stakeholders weighted criteria describing different impacts of the power system and ranked scenarios according to their preferences.

The workshop was also intended to act as a platform for knowledge transfer, an exchange of ideas and discussions between the different stakeholder groups. The workshop benefited from intense and profound discussions on technical, economic and social aspects of different scenario settings.

EUF, IIASA and WI are deeply grateful to Professor Driss Zejli, Professor Touria Barradi and Dr Mostafa Jamea from MENARES for all their contributions to the organization of the workshop as well as for their enthusiasm in conducting the workshop and all their efforts leading to a successful performance of the research tasks. MENARES is a research institution located in Casablanca, which has strong expertise in the area of green economy, climate change and sustainability

1.3 Workshop participants

The workshop was attended by approximately 20 participants (see photograph) representing different sectors.

Workshop participants and organizers
Photo: Safaa El Alami

Besides representatives from academia and the private sector, the following participants from the public sector, NGOs, civil society and young leaders took part in the workshop.

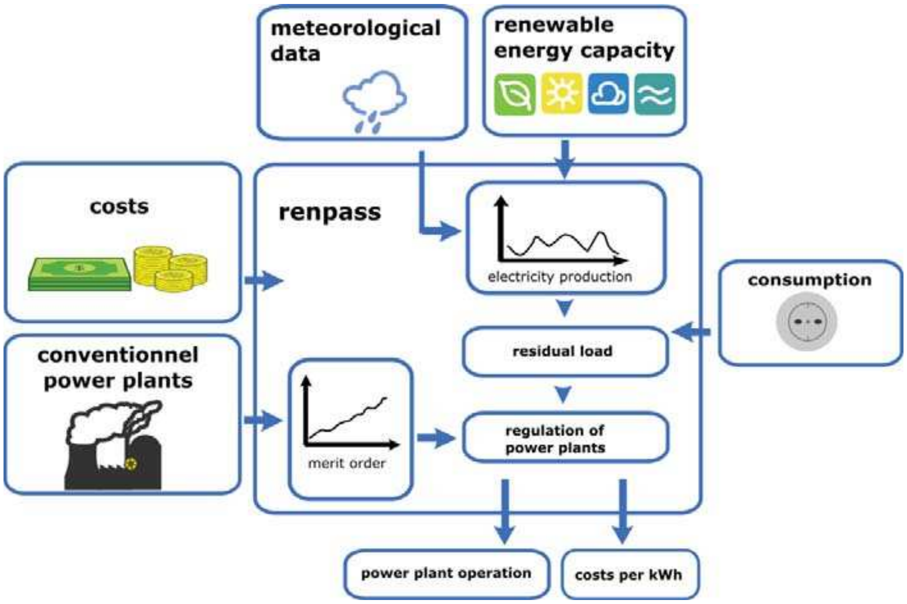
- Public sector:
  - MEMEE (Ministère de l’Energie, des Mines, de l’Eau et de l’Environnnement)
  - ONEE (Office National de l'Electricité et de l'Eau Potable)
  - Adminstration of the Sous Massa region
- Academia:
  - Université Chouaib Doukkali, Faculté des Sciences El Jadida
  - Université Ibn Zohr, Faculté des Sciences Agadir
  - ENSA Kénitra (Ecole Nationale des Science Appliquées Kénitra)
  - ENS Rabat (Ecole Normale Supérieure Rabat)
- Private sector:
  - Société EuroSol Maroc
  - SMAEE (Société Marocaine d’Audit Efficacité Energétique)
  - Cluster Solaire
  - INJAZ Al-Maghrib
  - Sahara Wind
  - Oussama
  - Uplinegroup
  - Super Cerame
- Civil society:
  - AMADES-Morocco (Moroccan Association of Solid Waste)
  - Association Femmed Bladi
  - Club Environnement-Association Ribat Al Fath
  - Association Action Citoyenne et Ecologique

2 Modelling electricity systems

2.1 Fundamentals of modelling

Scenarios within the MENA SELECT project can be calculated with the help of the RENPASS model developed by the Europa-Universität Flensburg. RENPASS is an open source model that is freely available and uses open data. During the workshop, a simplified spreadsheet model was applied that incorporated the main features of the RENPASS model. With this, most relevant input parameters could easily be adjusted and results were obtained instantly. The basic structure of the RENPASS model and the spreadsheet model is illustrated in Figure 1.

Figure 1
Basic structure of the RENPASS model



Central input data to the model include meteorological data such as solar radiation, precipitation and wind speeds in a high temporal and spatial resolution, technical parameters of different types of power plants and the transmission grid, financial parameters such as capital and operational expenditures. The main driver of the model is the electricity demand, represented by the load curve.

It was assumed that Morocco's 2050 power demand should be covered with domestic generation, and power transmission options with neighbouring countries were disregarded. This approach ensured the development of a consistent system. Any other system setting including cross-border transmission capacity would also work.

The fluctuating electricity production of wind and photovoltaics (PV) is based on the meteorological input data. Subtracting this energy production from the hourly load results in the so-called residual load, A positive residual load requires additional power generation from other sources, a negative residual load reflects surplus energy in the system that needs to be handled, for example stored. In the model approach, a positive residual load causes dispatchable technologies in the system to operate. Their order of utilization is based on the merit order, which means the technology with the lowest marginal costs produces first. In the spreadsheet model, the order of utilization of dispatchable technologies was pre-defined.

Based on the utilization of power plants, the model calculates the system costs per kWh, i.e. LCOE of the individual technologies, of a potential grid expansion and of storage.

2.2 Input and output parameters

The first part of the workshop mainly focussed on adjusting the capacity needed for 2050 to achieve a consistent scenario with a working system. It was also possible to adjust several other input parameters in the model. The modelling inputs introduced during the workshop could be grouped into load data, meteorological data, technology data and economic data, accompanied by further inputs, e.g. on the regional split into defined regions. All input parameters were based on literature research and insights gained during the workshop.

During the workshop, the model allowed participants to calculate scenarios of Morocco's future power supply. In all calculations, an hourly resolution of the target year 2050 and the development until this year including intermediate installation targets of 2030 were taken into account (cf. Schinke et al. 2016).

The load curve applied was derived from ONEE (2016) and prepared for a full year. In the model, it was scaled with the expected power demand in 2050 and split into regional demand according to the region size and population density. During the workshop the participants discussed possible future developments of the load until 2050 and their respective drivers. For the calculations, it was agreed to assume an annual power demand of 173 TWh in 2050 (cf. Trieb et al. 2015). This corresponds to a five-fold increase of Morocco's power demand of 2014, based on an assumed steady growth without a saturation effect before 2050.

In the model, relevant energy technologies, i.e. renewable and conventional generation, storage options and the transmission grid, with their technical and economic characteristics and their operational behaviour were taken into account. The dispatchable technologies were defined with their installed capacity, their ramping duration and minimum downtimes. Additionally, efficiencies and fuel inputs were taken into account in the model.

For the calculations, Morocco was split into four regions based on differences in wind speed conditions and solar radiation. During the calculations, all capacity installed was split up or allocated to the regions defined to model region-specific production. For each of the regions, one representative measuring point and its respective wind speed and solar radiation data (cf. NASA 2016) was applied.

The underlying wind speeds were utilized for the calculation of the electricity production from wind power. For the modelling of PV and concentrated solar power (CSP), solar radiation data were pre-processed, and region-specific normalized production curves as modelled with the SAM software (cf. NREL 2016) were utilized in the spreadsheet model. Economic data included capital expenditures (CAPEX) and operational expenditures (OPEX) that were also dependent on the technologies' service life and interest rates (weighted average cost of capital, WACC) and were assumed to decrease over time.

The transmission grid between the regions was based on figures presented in ONEE 2016. In the model, the residual load was calculated for the model regions. For the scenarios modelled, potentially necessary transmission grid enhancements were derived from excess power and power shortages in the regions, related to the existing transmission capacity. This needs to be regarded as an approximation to reality as the future transmission requirement will heavily depend on the very location of the installed capacity.

Pumped hydro power plants (STEP) were assumed to be the only storage option in the system. In the model, existing storage capacity was taken into account and was adjustable in the scenarios.

The spreadsheet model delivered several outputs that were fed into the successive multi-criteria analysis (MCA, cf. Chapter 3). First of all, the energy amounts produced in the target year 2050 and their shares in the installed production capacity and generated electricity were calculated for all technologies. Moreover, the fuel input for conventional power generation was calculated and the resulting direct CO_2 emissions were derived from this.

Additionally, the specific cost in 2050 was calculated. For this calculation, all CAPEX of the installed capacity in 2050 was annuitized. Supplemented by the OPEX and, if necessary, fuel cost in 2050, the total annual cost was divided by the electricity produced and levelized cost of electricity (LCOE) of the system resulted. This approach was also applied to storage and potentially necessary grid enhancements.

2.3 Scenarios of Morocco's electricity future in 2050

With the spreadsheet model introduced, the workshop participants developed four consistent scenarios of Morocco's 2050 power supply. The scenarios corresponded to the stakeholders' preferences voiced at the beginning of the workshop. The workshop participants stated that low electricity cost, high shares of renewable energies, low imports and low CO_2 emissions were the most important issues for them.

It became evident that installation targets of 2030 would not cover Morocco's power demand in 2050. That is why the installed capacity needed to be adjusted to find options to cover the demand in 2050 for every hour of the year. The workshop participants therefore discussed and altered the installed capacity in the model according to their preferences. When a working scenario was completed, the model was reset and the workshop participants adjusted the installed capacity again. A full list of the main scenario results can be found in Table 1.

The load and production in the scenarios developed is exemplarily illustrated for the first week of 2050 in Figure 1 of the Annex.

In the first scenario developed (scenario A), wind power was increased to 35 GW and PV to 15 GW in 2050. All the other energy sources did not differ substantially from the 2030 targets. The scenario was characterized by a share of 2/3 of the total installed capacity provided by technologies using intermittent energy sources. For the scenario, the pumping capacity of pumped storage (*Stations de transfert d'énergie par pompage*, STEP) was increased to 9 GW, and its turbine capacity was increased to 9.6 GW. The calculations resulted in CO_2 emissions of 18.5 Mt in 2050. In sum, the LCOE of the system was 93.7 cts/kWh. This scenario was called "Mix 1" as it implied a variety of energy sources installed in 2050.

In the second scenario developed (scenario B), wind power was further increased to 45 GW and PV to 30 GW in 2050. All conventional power generation was assumed to be taken out of operation by 2050. With this system setting, it was only possible to cover the load in every hour of the year with an increase in STEP capacity (pumps: 10 GW, turbines: 17.9 GW) and an increase in the amount of storable energy (2000 GWh). With this scenario setting, it was possible to cover approximately 100 per cent of Morocco's power demand in 2050 by renewable energy production. Intermittent capacity was 78% of the capacity installed. With no conventional power generation in the system, CO_2 emissions were reduced to zero. Total LCOE was 106.4 cts/kWh, thus higher than in scenario A. The scenario was called "100% RES" as its installed generation technology in 2050 consisted entirely of renewable energy technologies.

In the third scenario developed (scenario C) the focus was set on solar PV with an installed capacity of 50 GW in 2050. Wind power (10 GW) and conventional power generation remained at a comparably low level. Due to energy surpluses during sunshine hours, a substantially high STEP pump capacity of 23.9 GW was necessary to have the load covered in every hour of the year. In sum, the share of renewable energies in the energy produced was approximately 60 per cent. LCOE was found to be 103.3 cts/kWh, thus between scenario A and scenario B. The resulting CO_2 emissions (29 Mt), however, were substantially greater than in scenario A.

In the fourth scenario (scenario D), wind power capacity was increased to 40 GW and PV to 10 GW. Similar to scenario A, conventional power generation was not substantially altered compared to the 2030 targets. The capacity of STEP was increased to 10 GW (pumps) and 7.5 GW (turbines), respectively. With this combination of capacity, a share of RES of 78.4 per cent was reached in 2050. Due to the power production from conventional technologies, CO_2 emissions of 19 Mt resulted. LCOE was slightly higher than in scenario A (94.2 cts/kWh).

Table 1

Central results of the scenarios developed

A: Capacities and energy amounts

Scenario	**A**		**B**		**C**		**D**	
Name	**Mix 1**		**100% RES**		**PV**		**Mix 2**	
	Capacity (MW)	Energy (TWh/a)	Capacity (MW)	Energy (TWh/a)	Capacity (MW)	Energy (TWh/a)	Capacity (MW)	Energy (TWh/a)
Wind power	35,000	98.4	45,000	126.6	10,000	28.1	40,000	112.5
PV	15,000	21.8	30,000	43.6	50,000	72.7	10,000	14.5
Hydro power	3,100	2.6	3,100	1.0	3,100	5.2	3,100	2.5
Biomass	3,000	20.4	5,000	20.0	0	0.0	3,000	19.0
CSP	2000	4.2	2,000	2.4	1,300	2.6	1,500	3.1
Coal	5000	26.6	0	0.0	4,937	35.0	6,000	28.9
Oil	741	4.2	0	0.0	741	5.5	741	4.0
Gas	500	11.5	0	0.0	6,172	37.2	6,172	9.2
TOTAL	***69,341***	***189.7***	***85,100***	***193.7***	***76,250***	***186.7***	***70,513***	***193.9***

B: Storage, emissions, cost

Scenario		**A**	**B**	**C**	**D**
Name		**Mix 1**	**100% RES**	**PV**	**Mix 2**
STEP (energy)	GWh	702	2,000	702	702
STEP (pump)	MW	9,000	10,000	23,906	10,000
STEP (turbine)	MW	9,635	17,926	14,283	7,511
CO_2 emissions	Mt	18.5	0.0	29.3	19.1
LCOE	cts/kWh	93.7	106.4	103.3	94.2

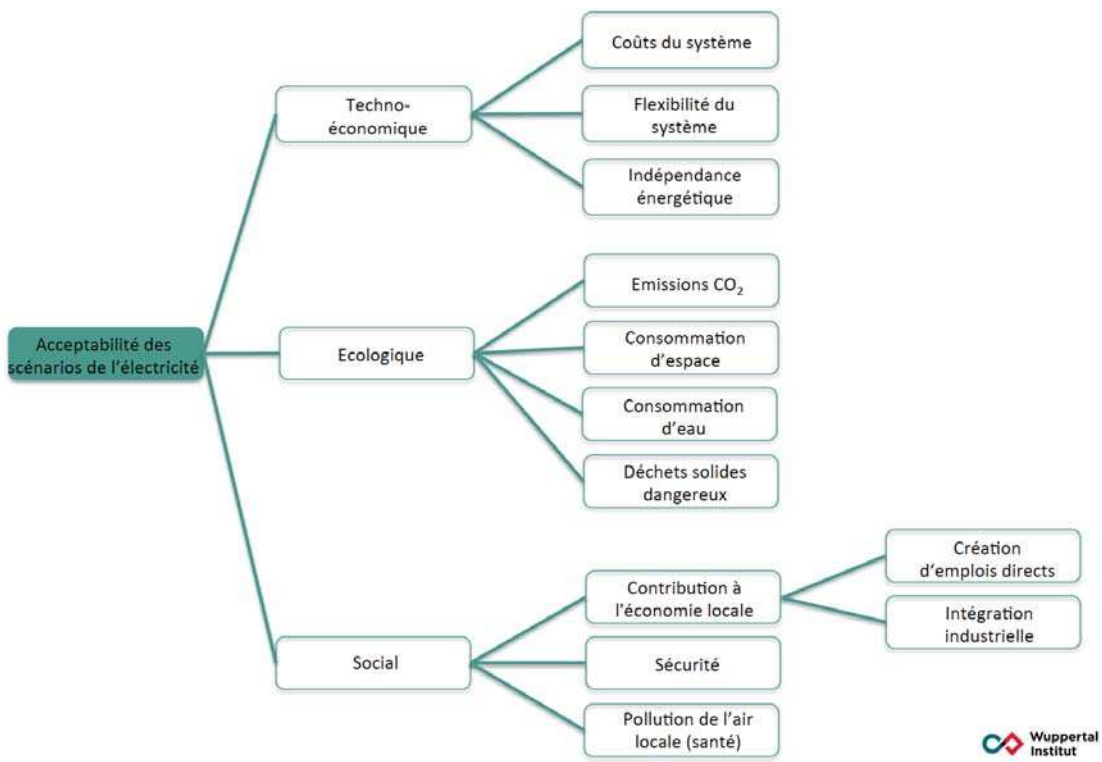
3 Multi-criteria analysis

3.1 Background

As part of the process, all stakeholders were introduced to the MCA carried out on the second day of the workshop. The analysis aimed at obtaining a weighting of a set of criteria (Figure 2) that had been compiled from data provided by work packages 1 and 2. The mathematical methodology AHP (analytical hierarchy process) was applied to calculate the weighting based on a pairwise comparison of the criteria. The definitions of all criteria taken into account can be found in Table 2 of the Annex.

Figure 2

The criteria set in hierarchical order



3.2 Stakeholder group identification and weighting process

The criteria categories at the highest level of the hierarchy (techno–economic, environmental, societal) including a short description of sub-criteria were presented. All stakeholders were asked to join one of the four following groups according to the preferences and values of their institutions:

/ Techno–economic group: Higher preference for techno–economic criteria;
/ Ecological group: Higher preference for environmental criteria;
/ Societal group: Higher preference for societal criteria;
/ Equal preference group: Equal preferences among the three categories of criteria.

As soon as the four groups were formed, the actual weighting process started. For this process, an individual questionnaire was handed out to each stakeholder, and each group received an additional group questionnaire. To understand the criteria correctly, a sheet with criteria descriptions was distributed among the stakeholders. The participants were asked to first fill out their individual questionnaire, then announce their choices to the other group members and finally discuss and decide on a group weighting that all group members can identify with.

3.3 Discussion and results of the weighting processes

Each stakeholder group was asked to briefly describe how they experienced the weighting process in their group, whether differences between the individual and the group weightings existed, and which criteria were finally discussed most.

Here, the majority of the stakeholder groups stated that there were only small differences between their individual weightings. Whenever diverging opinions were identified within a group, the participants discussed these differences and finally agreed on a consensus. The ecological group reported difficulties finding an appropriate weighting for the comparison between *safety* and *air pollution (health)* as they could not agree which one was more important from their point of view.

The results of the weightings of each group as well as the mathematical average weighting of all groups are displayed in Table 2.

Table 2
Group weightings and the mathematical average weighting across all groups in percentage points

	Techno-economic group	Ecological group	Social group	Equal preference group	Mathematical average
System cost	15.6	0.7	13.5	20.1	9.4
System flexibility	4.8	2.3	5.8	9.6	6.3
Energy independence	51.1	7.5	52.2	41.7	38.5
CO_2 emissions	1.0	6.1	0.7	1.3	1.9
Land requirements	0.9	2.6	1.2	0.7	1.5
Water requirements	5.9	39.3	6.2	9.2	13.6
Hazardous waste	6.4	15.8	6.2	3.1	8.5
On-site job creation	2.6	1.1	0.6	1.6	1.8
Domestic value chain integration	7.7	5.6	3.1	7.8	7.9
Safety	2.0	2.7	3.0	2.2	3.5
Air pollution (health)	2.0	16.5	7.5	2.6	7.1
Total	100	100	100	100	100

Most of the groups weighted *energy independence* as the most important criterion by far. The other criteria obtained a relatively low weighting compared to *energy independence*. Only the ecological group developed a structurally different weighting, resulting in *water requirements* as the most important criterion—followed by *hazardous waste* and *air pollution (health)*.

3.4 Finding a consensus

After discussing the mathematical average weighting, the stakeholders were given the chance to change the weighting in case it did not reflect their judgment. The Consensus 1 weighting in Table 3 shows these adjustments made. The *energy independence* lost on importance, but remained the most important criterion. It was argued that job creation and the establishment of domestic industry would be crucial for achieving energy independence. The criteria *domestic value chain integration* and *on-site job creation* therefore received a higher weighting. The weighting for the criterion *system cost* increased as well. It was said to be an important criterion, especially for a developing country like Morocco, as energy prices need to be low to be affordable for the people. The weighting of the criterion *system flexibility* was also increased. However, it was discussed that this criterion would probably be more important from the producer's point of view than from the consumer's point of view. The workshop participants further discussed that the weighting of the criterion *water requirements* should stay in the same range as Morocco is facing severe water scarcity. In turn, they decided to lower the weighting of the criterion *hazardous waste*. According to a number of stakeholders it is unlikely that there will be a nuclear power plant built in Morocco. They therefore concluded that this criterion is not as important as others.

Table 3

The mathematical average weighting compared to the first and second consensus weighting in percentage points.

	Mathematical average	Consensus 1	Consensus 2
System cost	9	12	16
System flexibility	6	12	12
Energy independence	38	29	25
CO_2 emissions	2	4	4
Land requirements	1	1	1
Water requirements	14	12	12
Hazardous waste	8	4	4
On-site job creation	2	6	6
Domestic value chain integration	8	11	11
Safety	3	3	3
Air pollution (health)	7	6	6

The results for Consensus 2 reflect the weighting after the clarification of a misunderstanding on the definition of system costs that has been faced by very few participants and was expressed only after the agreement on Consensus 1. The participants were given the chance to revise the consensus in light of the clarifications. This resulted in minor changes in favour of the criterion system cost, but did not include substantial changes to the consensus. Consensus 2 can finally be regarded as a common agreement of all workshop participants concerning the importance of the eleven criteria under study for the development of the Moroccan electricity system.

3.5 Ranking of the scenarios

The different weightings of criteria were combined with the four scenarios developed on the previous day (see part 1 of the workshop summary). This allowed to rank the scenarios according to the stakeholder's preferences elaborated through the weighting process. As presented in Table 4, the different weightings all lead to the same ranking except a small alternation in the consensus 2 weighting: The scenario featuring 100% Renewables ranked first, followed by scenario "Mix 2" and "Mix 1" (inverted order of Mix 2 and 1 in consensus 1) and scenario "PV" was least preferred across all scenarios.

Table 4

The ranking of the four scenarios according to the different weightings

	Techno–economic group	Ecological group	Social group	Equal preference group	Group average	Consensus 1	Consensus 2
100% renewable	1	1	1	1	1	1	1
Mix 2	2	2	2	2	2	2	3
Mix 1	3	3	3	3	3	3	2
PV	4	4	4	4	4	4	4

The identical ranking can be explained by the similar weighting patterns. As discussed earlier, in most weightings, the energy independence was by far considered the most important criterion. As the energy independence is highest in the 100 per cent renewable energy scenario (cf. Table 4), it is ranked first place. The ecological group was the only one weighting water requirements as the most important criterion and air pollution and hazardous waste as second most important criteria. As the 100 per cent renewable energy scenario achieves the best scores for these criteria as well, it also ranks first place when the ecological group weighting is applied. The exact indicator values for each scenario can be found in Table 1 of the Annex.

3.6 Conclusion

As a result, the scenario ranking obtained by means of a MCA turns out to be robust with regard to the preferences of all stakeholder groups involved in the workshop. The 100 per cent renewable energy scenario performs best in those subject areas that have been identified as most relevant for all participants (especially energy independence and water consumption). This scenario therefore ranks first place in the final ranking that results from the MCA of workshop day two. Achieving the outlines of this scenario in 2050 would result in an energy system solely based on renewable energies whereby the majority of the energy would be produced by wind and solar power plants.

4 Results of workshop discussions

The results of all discussions and results during the workshop are grouped into different topics.

/ **Use of technologies**
The workshop participants agreed on the goal to expand renewable energy technologies in Morocco in the future and to reduce or minimize investments in conventional power plants. For the year 2030, national targets have been set by the national government that correspond to a share of installed renewable capacity of about 52 per cent. An increase in installed capacity of conventional power plants after 2030 was not desired by the workshop participants.

The stakeholders furthermore agreed that the use of geothermal power plants, nuclear power plants and offshore wind farms would not be required to satisfy the electricity demand in 2050. These technologies have not been included in the national targets for 2030. The use of nuclear energy has been subject of an intense discussion in Morocco for a long time, and a potential site for a plant has already been identified. However, the workshop participants agreed that nuclear energy would not be an option for Morocco's future power supply due to safety reasons and due to the unanswered question of the disposal of nuclear waste.

It was also agreed to include a substantial share of gaseous biomass as another energy source in the scenarios calculated. Biomass has not been included in Morocco's 2030 targets. Although until now only few, and mostly small, biogas power plants have been in operation in Morocco, this technology seemed to be one option to reduce Morocco's increasing quantities of domestic and agricultural waste.

/ **Electricity cost**
During the workshop, several participants strongly emphasized that low electricity cost per kilowatt hour would be the key aspect in Morocco's energy future. This view was *inter alia* based on the envisaged affordability of electricity in the country.

Recently, the electricity price in Morocco has been relatively low due to stipulation by public authorities, and prices were found to be below actual cost of generation and transmission. Expectations for the future are aiming at an intensified use of domestic resources, such as renewable energies, which can reduce or limit generation cost as well as increase the nation's energetic independence.

- **Security and independence of supply**
  The participants agreed that an increasing energetic independence of Morocco should be envisaged. This however cannot only be achieved by the import of renewable technology but it also requires a profound knowledge transfer to Morocco. By doing so, more national production could be established, i.e. more parts of the value chain of production processes would be available in Morocco, which again would increase the national added value and job creation. The workshop participants assessed that in the case of wind power such a transformation has proven to be doable and has already been successfully ongoing in the country. It was mentioned that nearly 70 per cent of the added value from wind power would remain in the country and that Morocco has decreased its dependence on the import of technology components. Moreover, the workshop participants believed that Morocco should not base its power system on one single technology and they identified a need to explore the domestic potential of different renewable energy sources. This could increase and guarantee the security as well as the independence of supply.

- **Land and water use**
  The workshop participants considered the fundamental fact that sufficient space is available in Morocco for the installation of substantial amounts of renewable capacity. However, they showed great concern regarding the future use of important agricultural areas as sites of new power plants.
  Other than space, Morocco is faced with the problem of water scarcity. The fresh water demand has continuously increased within the last years, and resources have run short. This challenge could be tackled by producing cheap electricity from renewable energy resources for large scale seawater desalination. Seawater is comparably easy to access due to Morocco's long coast line.
  Given the challenge of water scarcity, most of the workshop participants agreed on not expanding the utilization of concentrated solar power (CSP) plants on a large scale assuming that CSP can require substantial amounts of cooling water.

In addition to the aforementioned aspects, the workshop participants agreed on the goal that Morocco should become an electricity exporting instead of an electricity importing nation. Due to high potentials of different renewable energy resources, Morocco could produce enough electricity for its national use as well as for export purposes.

5 Conclusion & Recommendations

From the workshop results described above, the following summary of expectations and preferences of the workshop stakeholders, i.e. a heterogenic group representing large shares of the Moroccan population, can be gleaned.

- Nuclear power has been regarded as an unpopular technology option in Morocco's future power supply.
- Workshop participants have not been in favour of the expansion of conventional power generation capacity.
- The expansion of capacity of renewable energy technologies has been desired the most, particularly diverse types of energy sources.
- The use of biogas plants on a large scale was regarded to be not just an option of a sustainable electricity production but also as an option to reduce waste in Morocco.
- The need to generate and provide electricity at low costs has been emphasized. If this cannot be achieved, the Moroccan population cannot pay for and use the electricity.

Based on these insights gained during the workshop, we present the following recommendations for the long-term development of the Moroccan power sector:

- To achieve a high level of energy independence, Morocco should focus in particular on renewable energy sources for its future power supply. Sustainable biomass technologies based on residual material flows should be considered in the national long-term goals. Conventional generation should play a minor role.
- Representatives of the population need to be included in the discussion on Morocco's future electricity supply to increase the public support of the national targets. There should be a strategy to assure that all societal groups are enabled to participate in this process.
- Opportunities should be investigated to establish an electricity system based on 100 per cent renewable energy while simultaneously limiting the required capacities for electricity generation and storage. These opportunities may include the combination of renewable technologies with different feed-in profiles or balancing of supply and demand with the help of different flexibility options.
- Application potentials of additional storage technologies apart from STEP should be identified to reduce the dependency of electricity storage on the availability of water resources.

6 Next steps

The scenarios developed with the spreadsheet model during the workshop will be utilized as inputs to the RENPASS model developed by EUF. The RENPASS model, again, will be provided to interested parties. Another workshop is expected to take place by the end of 2016 in Morocco in which interested parties will be trained in the utilization of the model.

Moreover, other publications are planned to provide further details concerning the modelling approach, the input and output parameters as well as the MCA methodology applied.

Within the framework of the MENA SELECT research project and apart from the workshop activities in Morocco, further research work and workshops with local stakeholders will be conducted in the state of Jordan.

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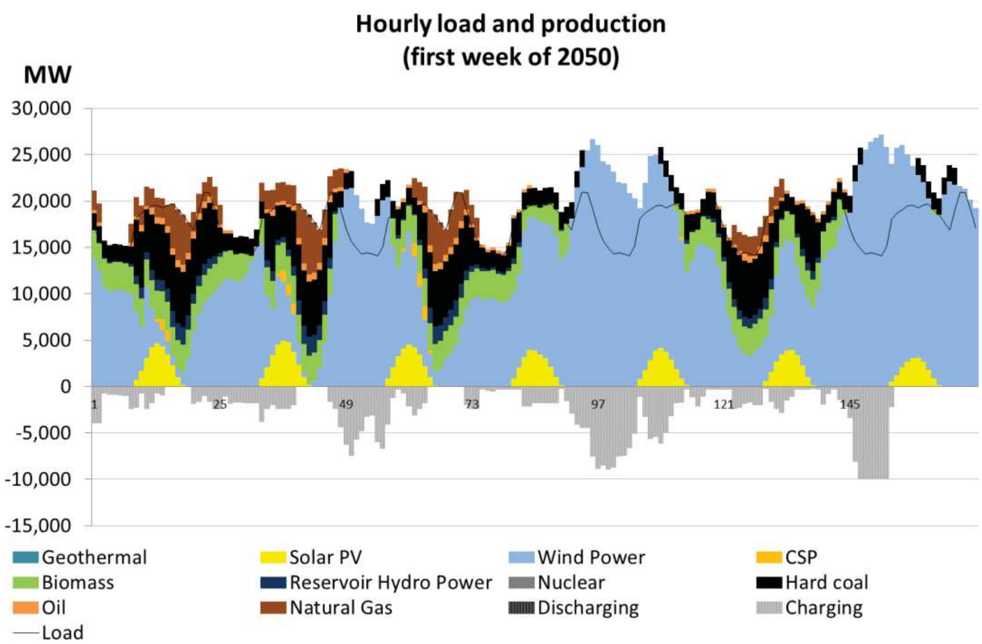
8 Annex

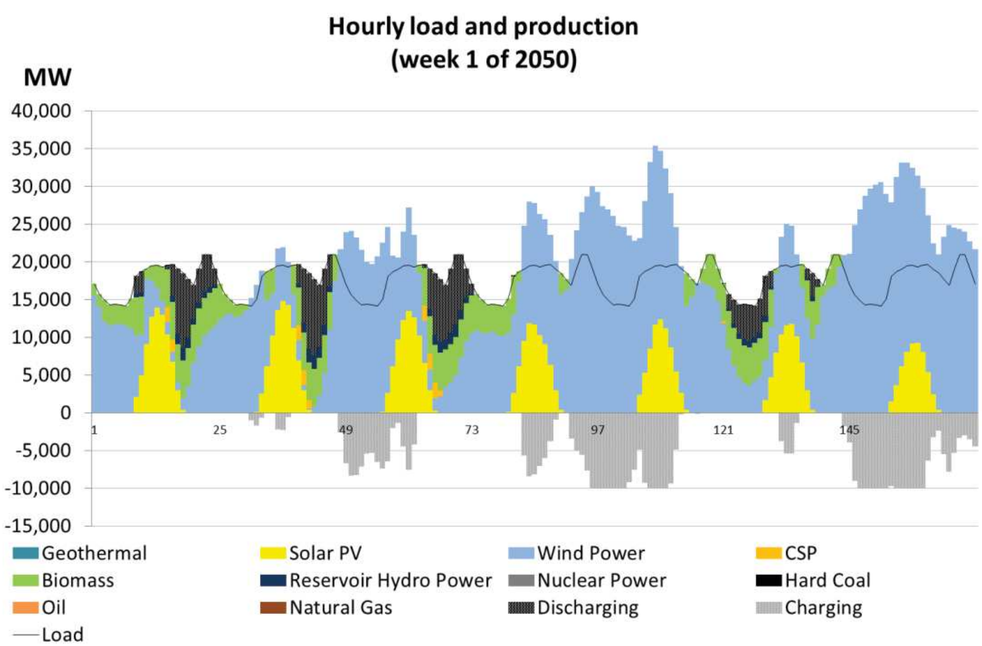
Figure 1

Exemplary load and production in the scenarios developed (week 1 in 2050)

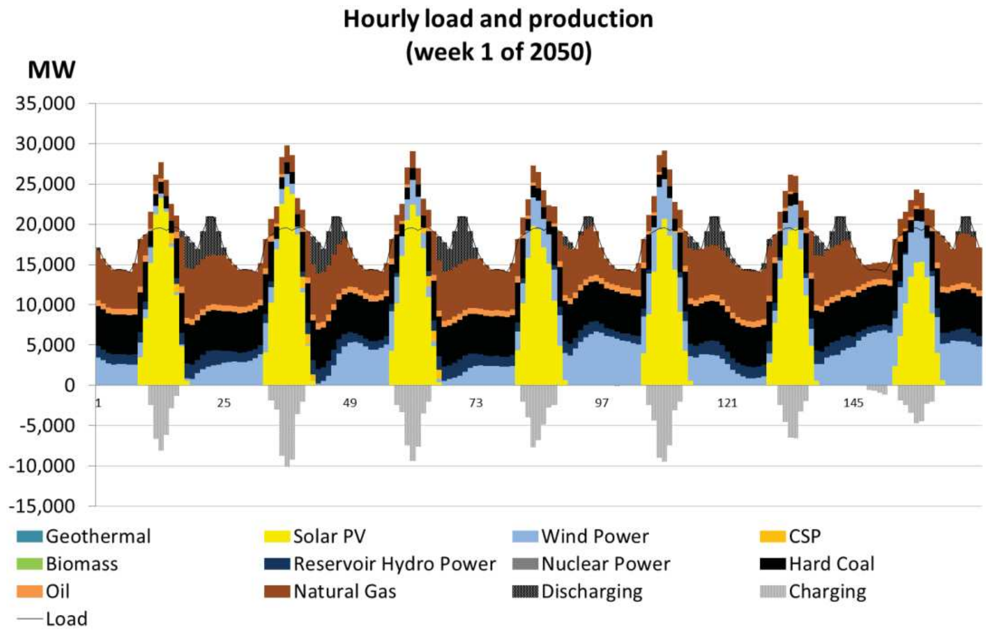
Scenario 1:



Scenario 2:



Scenario 3:



Scenario 4:

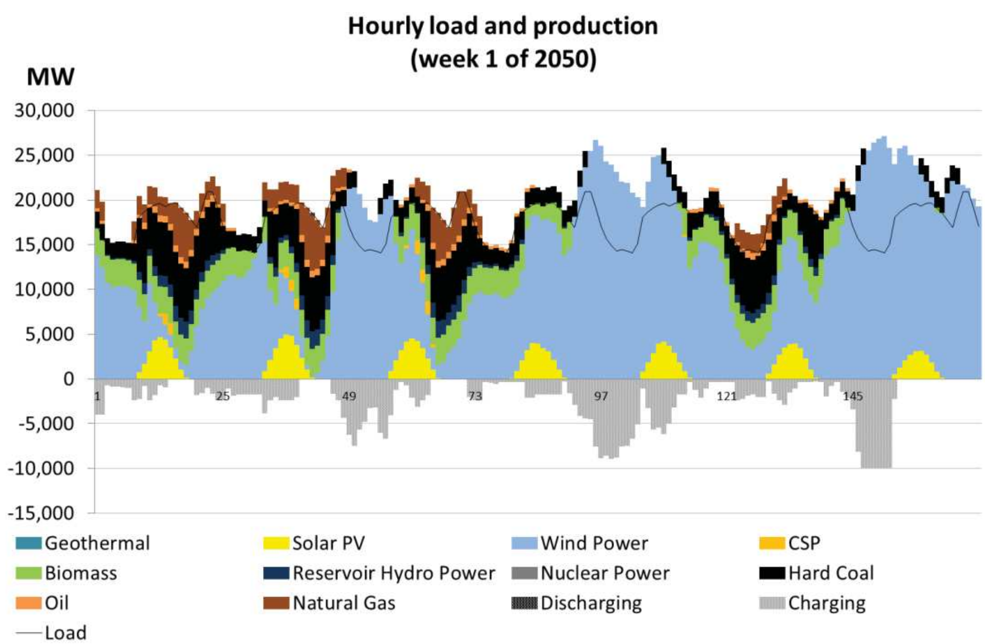


Table 1

Exact values of each criterion for each scenario

	Techno–économic				Social			Ecologique			
Critères	Coûts du système	Flexibilité du système	Indépendance énergétique	Sécurité	Pollution de l'air locale (santé)	Contribution à l'économie locale		Emissions CO2	Déchets solides dangereux	Consommation d'espace	Consommation d'eau
						Création d'emplois directs	Intégration industrielle				
	DhCt /kWh	Échelle 1-5	Échelle 1-5	Nombre de décès (E-10)	Mt	Échelle 1-5	Échelle 1-5	Mt	Échelle 1-5	ha	m³
Mix 1	93.3	2.41	3.66	10	0.25	2.27	3.08	18.47	1.91	61,312	24,277,572
100%	106.0	2.09	4.40	10	0.03	2.49	3.33	0.00	1.01	106,150	2,296,987
PV	102.9	2.25	3.20	5	0.52	2.66	3.14	29.26	2.42	150,539	39,264,302
Mix 2	93.9	2.40	3.68	11	0.24	2.16	3.04	19.05	1.88	47,056	24,421,041

Table 2

Criteria definition

Criteria	
Catégorie Techno-économique / Techno-economic category	Ce critère analyse les caractéristiques techniques et économiques du système électrique. Il considère les coûts de la production de l'électricité, la dépendance des importations de l'énergie et la volatilité de la production.
Catégorie Ecologique / Environmental category	Ce critère analyse les caractéristiques environnementales du système électrique. Il considère la consommation d'eau et d'espace du système électrique, émissions CO_2 et la gestion des déchets dangereux.
Catégorie Social / Societal category	Ce critère analyse les caractéristiques techniques et économiques du système électrique. Il considère les coûts de la production de l'électricité, la dépendance des importations de l'énergie et la volatilité de la production.
Coûts du système / System cost	Ce critère analyse les caractéristiques environnementales du système électrique. Il considère la consommation d'eau et d'espace du système électrique, émissions CO_2 et la gestion des déchets dangereux.
Flexibilité du système / System flexibility	Ce critère analyse les caractéristiques sociales du système électrique. Il considère les effets du système sur la santé publique, le risque des incidents graves et la promotion de l'économie locale.
Indépendance énergétique / Energy independence	Les coûts du système d'électricité sont les coûts de production, de l'expansion du réseau électrique et du stockage.
Emissions CO_2 / CO_2 Emissions	L'aptitude du système électrique à réagir de manière rapide et flexible aux changements de la demande électrique.
Consommation d'espace / *Land requirements*	Capacité future des scénarios à faire appel aux ressources locales pour réduire la dépendance énergétique
Consommation d'eau / Water *requirements*	La totalité des émissions directes de CO_2 émises par toutes les centrales électriques pendant la période d'observation.
Déchets solides dangereux / Hazardous waste	Occupation du sol attribuée à l'opération de toutes les centrales électriques (sur les sites des centrales).
Contribution à l'économie locale / Contribution *to local economy*	La consommation (directe) d'eau douce durant le fonctionnement de toutes les centrales (refroidissement, cycle de vapeur, nettoyage).
Sécurité / Safety	La quantité et qualité de déchets solides dangereux pour l'environnement naturel et humain produite par l'opération de toutes les centrales électriques
*Pollution de l'air locale (santé) / Air pollution (*health*)*	Capacité des scenarios à intégrer l'économie locale dans le système électrique.
Création d'emplois *directs / On-site job creation*	Le nombre de fatalités par conséquence des accidents graves pendant l'opération et l'entretien des centrales électriques.
Intégration industrielle / Domestic value *chain integration*	Niveau de dégradation de la qualité de l'air en fait de polluants atmosphériques qui peuvent entraîner des risques pour la santé.

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