MENA SELECT

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 Jordan'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 the Holiday Inn Hotel at the Dead Sea, Jordan, from 5 to 6 March 2017. Stakeholders from different national societal groups related to energy issues were invited to discuss and develop future settings of Jordan's power supply with the help of an advanced spreadsheet model, followed by an evaluation of the developed scenarios. In this paper, the results of the workshop are summarized.

The workshop served two purposes: In the first part of the workshop, the participants were introduced to the modelling approach. Central input parameters, procedures and assumptions were presented. This formed the basis for the subsequent development of scenarios for Jordan's electricity system in 2050. With the help of the spreadsheet model, five consistent scenarios were developed, featuring a wide range of renewable energy shares from approximately four to nearly 100 per cent of the future national electricity production.

In the second part of the workshop, a ranking of the developed scenarios according to the participants' preferences was established. 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, the aforementioned developed electricity scenarios were ranked, resulting in the fact that the workshop participants would prefer the scenario with the highest share of renewable energies (approaching 100% of electricity generation) in 2050.

The workshop successfully developed widely accepted options for Jordan's future power supply by taking into account technical, economic, environmental and social parameters.

CONTENTS

ABREVIATIONS

%	per cent
AHP	Analytical Hierarchy Process
BICC	Bonn International Center for Conversion
CAPEX	Capital expenditures
cf.	confer
CO_2	Carbon dioxide
CSP	Concentrated solar power
DLR	Deutsches Zentrum für Luft- und Raumfahrt
e.g.	exempli gratia
et al.	et altera
EUF	Europa-Universität Flensburg
GIZ	Gesellschaft für Internationale Zusammenarbeit
GW	Gigawatt
GWh	Gigawatt hour
GW_p	Gigawatt peak
H.E.	His Excellency
ha	hectare
i.e.	id est
IIASA	International Institute of Applied Systems Analysis
JOD	Jordanian Dinar
JUST	Jordan University of Science and Technology
JREEEF	Jordanian Renewable Energy and Energy Efficiency Fund
kWh	kilowatt hour
LCOE	Levelized cost of electricity
m^3	Cubic meter
MCA	Multi-criteria analysis
MENA	Middle East and North Africa
MENARES	MENA Renewables and Sustainability
MENA-SELECT	Middle East North Africa Sustainable Electricity Trajectories
Mt	Megatons
MW	Megawatt

MW_p	Megawatt peak
NASA	National Aeronautics and Space Administration
NEPCO	National Electric Power Company
NGO	Non-governmental organization
NREL	National Renewable Energy Laboratory
OPEX	Operational expenditures
PV	Photovoltaics
Prof.	Professor
RE	Renewable energies
RENPASS	Renewable Energy Pathway Simulation System
TWh	Terawatt hour
WACC	Weighted average cost of capital
WI	Wuppertal Institute
WP	Work packages
ZUJ	Al-Zaytoonah University of Jordan

1 Introduction

1.1 The MENA SELECT research project

The Middle East and North African (MENA) region currently faces a number of challenges such as dependency on fluctuating energy imports, growing energy demand due to population growth, an increase in living standards, as well as impacts of climate change resulting in energy-intensive tasks such as cooling and desalination. Currently, several options exist to satisfy the growing energy demand, namely through the use of renewable energy sources, further development of fossil fuels including oil, coal and gas but also unconventional sources such as shale oil and the deployment of nuclear power capacity. Large-scale deployment of any of these options will lead to a transition of the current energy systems and, based on this transition, to societal transformation in the MENA region. Like every transition process, it will lead to different opinions and views among different stakeholder groups. Therefore, there is a need for participatory governance of this energy transition to identify compromise solutions among different stakeholder groups by addressing differences in views, opinions and perceptions.

In science as well as in practice, several works exist on technical and economic factors of energy transitions in general, and in the MENA region, including Jordan, in particular. However, the knowledge about human factors, such as public perception, conflicting opinions or perceptions about costs, benefits and risks of an energy transition is comparatively small and almost non-existent for the MENA region.

The combination of qualitative and quantitative research methods, including scenario modelling and multi-criteria decision-making, but also the involvement of stakeholders in modelling exercises goes beyond traditional "research dissemination". The research methods of this work include participatory modelling, allowing for an in-depth and comprehensive stakeholder feedback.

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

\ WP1 (IIASA and EUF) deals with the techno-economic modelling of different electricity pathways up to 2050 based on participatory workshops with national stakeholders,
\ WP2 (Germanwatch, IIASA and BICC) analyzes the social, political, economic and ecological effects of different technologies, as they are perceived by local stakeholders,
\ WP3 (WI) combines results of WP1 and WP2 to evaluate the developed scenarios based on predefined criteria with the help of a multi-criteria analysis,
\ WP4 includes dissemination efforts conducted by all project partners.

The project further involves several partners in the MENA region such as MENARES from Morocco, the University of Jordan and ECO-Ser from Tunisia.

Team of workshop organizers
Photo: Bassam Maaytah, Arab Potash Company

1.2 Workshop objectives

The workshop "Shaping Jordan's future electricity system" took place on 5 and 6 March 2017 in the Holiday Inn Hotel at the Dead Sea, close to Amman, Jordan. It was organized by the Europa-Universität Flensburg (EUF), the International Institute for Applied Systems Analysis (IIASA) and Wuppertal Institute (WI), Germany, as well as by the Jordanian partner, the University of Jordan.

The goal of this workshop was to develop scenarios for Jordan's electricity future, taking into reference the planning horizon up to 2050. The workshop covered research questions of two work packages of the MENA SELECT project, namely the joint development of consistent scenarios of Jordan's future power system (WP1) and a participatory assessment of these scenarios (WP3). In the frame of WP1, the workshop's participants developed consistent scenarios of Jordan's future energy system on the first day. On the second day of the workshop, participants weighted different criteria describing social, techno-economic and environmental impacts of the power system. These weightings were eventually used to rank the scenarios above according to the stakeholders' preferences.

The workshop facilitated dialogue and exchange of views and information among different stakeholder groups and thereby provided an opportunity to learn from each other. Throughout the whole workshop, participants intensely discussed technical, economic, social and environmental aspects of energy scenario settings for Jordan.

EUF, IIASA and WI are deeply grateful to Professor Ahmed Al Salaymeh, Ms Leena Marashdeh and Ms Jumana Tanboor from the University of Jordan 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.

Workshop participants and organizers on Day 1
Photo: Nadejda Komendantova, IIASA

1.3 Workshop participants

The goal of the workshop was to bring together a variety of stakeholders from different sectors, such as policymakers, academia, the private sector, NGOs and civil society, as well as various development assistance organizations from Germany. Altogether a group of 25 high-level participants joined this event.

Small group of workshop participants during round-table discussion
Photo: Nadejda Komendantova, IIASA

The workshop participants represented the following sectors and companies.

- Policymakers
    - Ministry of Energy and Mineral Resources (at the level of Director of Renewable Energy Department and Minister Advisor)
    - Ministry for Agriculture as well as the Jordanian Renewable Energy and Energy Efficiency Fund (JREEEF)
    - National Electric Power Company (NEPCO)
- Academia
    - Jordan University of Science and Technology (JUST)
    - University of Jordan
    - The American University in Madaba
    - The Applied University of Science
    - The Al-Zaytoonah University of Jordan (ZUJ)
    - The Mutah University
    - The German Jordanian University
- Private sector
    - Wathba Investment Company
    - Super Solar for Energy and Engineering
    - Arab Potash Company

- Orange Company
- Solar Power Services Company

/ NGOs and civil society

- EDAMA Association
- GIZ Jordan
- Friedrich Ebert Foundation
- Council on Women in Energy and Environmental Leadership

The workshop benefited from the presence of H.E. Malek Kabariti, the former Minister of Energy and Mineral Resources and H.E. Prof. Reda Al-Khawaldeh, the Jordanian Senate and Former Minister of Agriculture.

Workshop participants and organizers on Day 2
Photo: Nadejda Komendantova, IIASA

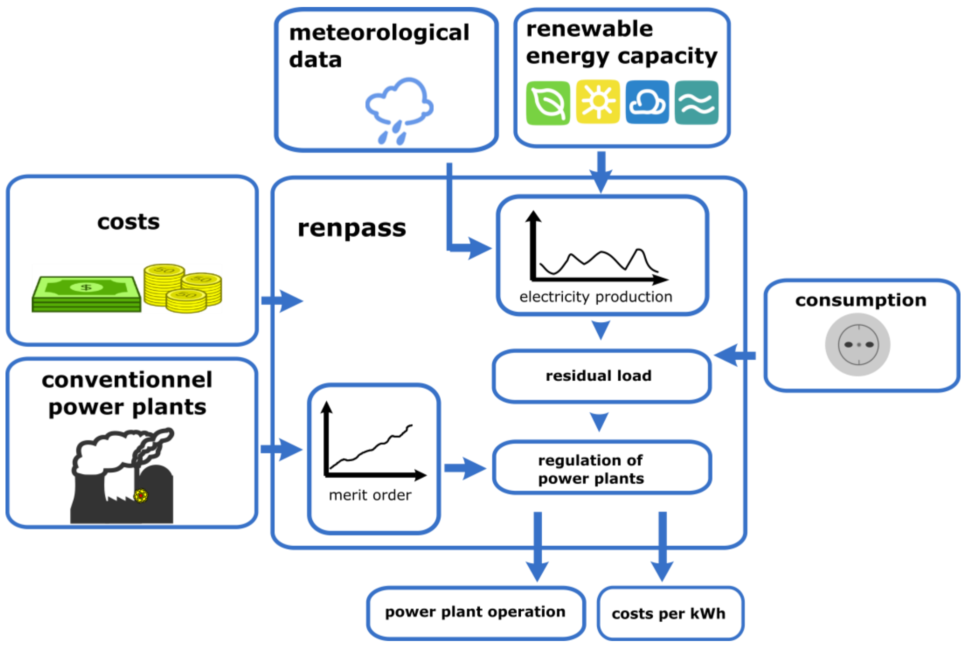
2 Modelling electricity systems

2.1 Fundamentals of modelling

Scenarios within the MENA SELECT project can be calculated with the help of the *RENPASSG!S* model developed by the Europa-Universität Flensburg. *RENPASSG!S* 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 and structure of the *RENPASSG!S* model which are illustrated in Figure 1. By using a simplified spreadsheet model during the workshop, all input parameters could easily be adjusted and results were obtained instantly.

Figure 1

Basic structure of the RENPASSG!S model



Source: Berg et al., 2016

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 hourly load curve.

It was assumed that Jordan's 2050 electricity 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

Analogous to the approach of the MENA SELECT research project in the country case of Morocco (cf. Berg et al. 2016), consistent scenarios of Jordan's power supply in the year 2050 were developed in the first part of the workshop. In the model applied, the installed capacities in Jordan's future power system were therefore modified to have the load covered in every hour of the year 2050. Workshop participants were also able to adjust several other input parameters. During the workshop, inputs to the model covering the categories load data, meteorological data, technical data and economic data were introduced, accompanied by further inputs, e.g. on the spatial split of the country into defined regions. All input parameters were based on literature research, expert judgment and insights gained during the workshop.

The model allowed to calculate scenarios for Jordan's power supply in an hourly resolution of the target year 2050. The development until that year including intermediate installation until 2020 (cf. Ministry of Energy and Mineral Resources Jordan 2013) was also taken into account.

For the calculations, Jordan was split into four regions based on differences in the technical potential of renewable energy resources and the existing transmission grid. Based on inputs from NEPCO (2006, 2012, 2015, 2017a), a normalized hourly resolved load curve was prepared, scaled with the expected national future power demand and split into regional load curves according to the size and the population density of the regions. The future development of the national power demand will depend on various factors, and it was agreed during the workshop to utilize an annual power demand of 106 TWh in 2050, based on data from NEPCO (2016) and own calculations. That corresponds to an increase on the upper end of the range compared with other research figures (e.g. Deutsches Zentrum für Luft- und Raumfahrt 2005, Khatib 2014) and means a substantial increase compared to the demand of 2016 (16.8 TWh, NEPCO 2017c, p. 18). The calculation with such a comparably high load level can be regarded as a conservative and challenging approach. If it can be shown that and how the load can be covered in every hour of the year, any other load level (e.g. based on additional efficiency gains) would be covered, too, and would result in a cheaper system.

In the model, all relevant technologies of the power system were taken into account, including renewable and conventional power generation, storage options and the transmission grid between the defined regions. Besides the installed capacity of all technologies, the ramping duration and minimum downtimes of dispatchable technologies as well as efficiencies and fuel inputs were included in the model.

To model the region-specific production, all installed capacity was allocated in the calculations to the defined regions. Differences in wind speeds and solar radiation conditions in the regions were taken into account by the utilization of meteorological data from representative measuring points in the regions (cf. National Aeronautics and Space Administration 2016). Those meteorological data were transformed in a pre-process into region-specific normalized production curves of wind power, PV and concentrated solar power (CSP). In the case of wind power, wind speed data were related to a normalized power curve of wind turbines, in the case of solar power the SAM software (cf. NREL 2017) was used for this pre-processing.

The model took economic parameters of all technologies such as capital expenditures (CAPEX), operational expenditures (OPEX) and also fuel costs into account and they were assumed to develop over time. Modelling also included assumptions on the service life and interest rates (weighted average cost of capital, WACC) of the technologies.

Due to modelling restrictions, all technologies were considered independently from each other in the applied model. However, in practice, combinations such as CSP and gas-fired power plants might be implemented, resulting in different installation figures, thus costs, than in the scenarios developed during the workshop. This issue should be subject to further research.

In the calculations, the residual load in the regions was determined and compared to the existing transfer capacity between the regions, based on figures from NEPCO (2017b). In case of excess or shortage power in the regions, potentially necessary transmission grid enhancements were thereby identified. In practice, the future transmission requirement will however heavily depend on the exact location of the installed capacity and the development of the load.

The workshop participants agreed that the only option to domestically store electrical energy would be batteries, which was taken into account in the model and in the scenarios. Participants regarded pumped hydro storage, another storage option altogether, to be unrealistic due to the existing water scarcity. During the workshop, the participants, however, briefly discussed the option of utilizing a connection between the Red Sea and the Dead Sea for pumped hydro storage only to find that this idea was either infeasible or at least very limited. Thus, they did not include it in the scenario modelling.

During the workshop, several output parameters were calculated with the spreadsheet model and fed into the successive multi-criteria analysis (MCA, cf. Chapter 3). Besides the energy amounts produced by the different technologies in the year of analysis, their respective shares in the installed production capacity and generated electricity were calculated. Moreover, the fuel input for the power generation of conventional power plants was calculated and converted into direct CO_2 emissions.

For the calculation of the specific costs of the system in 2050, the CAPEX of the installed capacity including storage and potentially necessary grid enhancements until and in

2050 were annuitized, supplemented by the OPEX and fuel cost in 2050. The total annual cost was divided by the electricity produced, resulting in levelized cost of electricity (LCOE) of the system.

2.3 Scenarios of Jordan's electricity future in 2050

With the spreadsheet model introduced, the workshop participants developed five consistent scenarios of Jordan's power supply in the year 2050, reflecting the stakeholders' preferences voiced at the beginning of the workshop during that procedure. The workshop participants stated that energy independence and high shares of renewable energies were the most important issues for them.

The development of the scenarios started with a comparison of the intermediate national installation targets and the potential power demand in 2050, showing that the installation targets of 2020 would not suffice to cover Jordan's power demand in 2050. This is why the installed capacity needed to be adjusted to find solutions that would cover the demand in every hour of the year in 2050. The workshop participants discussed and adjusted capacities in the model according to their stated preferences. When a setting of system components was found in which the load could be covered in every hour of the year, a working scenario was completed, and the model was reset to start the process again. An overview of the main resulting scenarios can be found in Table 1.

As an example, the load and the power production in the scenarios developed is illustrated for the first week in 2050 in Figure 1 of the Annex.

The first scenario (scenario A) is characterized by a wide mix of technologies, including nuclear power (2 GW). Wind power was increased to 8 GW and PV to 9 GW_p in 2050. Moreover, a capacity of 5 GW of CSP was included in the scenario, and an installation of 0.75 GW of geothermal power was assumed. Coal, oil and gas-fired power plants contributed up to a capacity of 14.5 GW. With this combination of technologies, technologies using intermittent energy sources provided for approximately 46 per cent of the total installed capacity. In scenario A, a substantial battery storage capacity of 9 GWh was assumed. The calculations of that scenario resulted in CO_2 emissions of 15.2 Mt in 2050. The total LCOE of the system amounted to 106.4 Jordanian Fils. Due to the variety of technologies involved, scenario A was named "Mix incl. Nuclear".

The second scenario (scenario B) is characterized by a comparably low installation of renewable technologies with a substantial increase of the capacity of gas-fired power plants in particular. For this scenario, the renewable installation targets of 2020 were assumed to be reached but not increased afterwards. Gas-fired power plants would cover all additionally required production. In the scenario, it was assumed that there would be no battery storage in the system. In this setting, approximately 11 per cent of the installed capacity and not more than five per cent of the produced electricity would come from renewable energy sources. The direct CO_2 emissions in that system were calculated to be 26.7 Mt in 2050. With 74.0 Fils the total LCOE were found to be lower than in scenario A. Based on the scenario inputs, the scenario was called "Current plans + Gas".

The third scenario (scenario C) focused on a higher renewable installation than in scenario B, and the installed capacity of CSP plants was substantially increased (to 2 GW). Here, a capacity of wind power and of PV of 4 GW each was included. The scenario included a battery storage with a capacity of 2 GWh. It also incorporated a substantial capacity of gas-fired power plants (17.5 GW) to be able to cover the load in every hour of the year. With this scenario setting, a share of 36 per cent (capacity) and 23.3 per cent (energy) respectively of renewable energy sources was reached. The LCOE were found to be 78.4 Fils, thus slightly higher than in scenario B. The scenario was named "RE + Gas".

While in the fourth scenario (scenario D), the installed capacity of wind power and PV was slightly reduced, it included a substantial capacity of biogas plants (1.5 GW). The capacity of wind power now amounted to 3 GW, the capacity of PV was 3.5 GW_p. With a battery storage capacity of 2 GWh as in scenario C, an installed capacity of 16 GW of gas-fired power plants was additionally required to cover the load in every hour of the year. As a result, this scenario setting would have a share of renewables of 37 per cent (capacity) and 32 per cent (energy), respectively. CO_2 emissions would be 18.4 Mt, and total LCOE would be 77.7 Fils. The scenario was called "medium RE + Gas" due to the variety of technologies included in the system.

The fifth scenario (scenario E) is characterized by a substantial increase in installed renewable capacity. While the installed capacity of wind power was assumed to reach 15 GW in 2050, the installed capacity of PV was increased to 25 GW_p and the installed capacity of CSP to 20 GW. Additionally, an installation of 3.5 GW of geothermal power and five GW of biogas plants contribute to the system in that scenario. Moreover, five GW of shale oil-fired power plants and four GW of gas-fired power plants and a substantial battery storage with a capacity of 40 GWh complemented the system. In sum, 88.5 per cent of the installed capacity would be renewable while this translates to a full load coverage (annual balance) by renewable sources. In such a system, surplus power would be stored in the batteries while, in case of a shortage, power would be drawn from the batteries or backed up by conventional power plants. The direct CO_2 emissions in such a system were modelled to be 0.3 Mt in 2050. Total system LCOE were calculated to be 219.3 Fils. This is substantially higher than the cost calculated for the other scenarios. The scenario was called "no imports" as the workshop participants agreed that the system would be based on renewable energy sources on the one hand and fuels from national sources on the other.

An illustration of the installed capacities of all scenarios can be found in Figure 2 of the Annex.

Table 1

Central results of the scenarios developed

A: Capacities and energy amounts

Scenario	**A**		**B**		**C**		**D**		**E**	
Name	**Mix incl. nuclear**		**Current plans + Gas**		**RE + Gas**		**Medium RE + Gas**		**No Imports**	
	Capacity (MW)	Energy (TWh/a)	Capacity (MW)	Energy (TWh/a)	Capacity (MW)	Energy (TWh/a)	Capacity (MW)	Energy (TWh/a)	Capacity (MW)	Energy (TWh/a)
Wind power	8,000	16.2	1,200	2.4	4,000	8.1	3,000	6.1	15,000	30.4
PV	9,000	15.9	1,000	1.8	4,000	7.1	3,500	6.2	25,000	44.1
Geothermal	750	4.1	0	0.0	0	0.0	0	0.0	3,500	19.3
Hydro power	250	0.0	12	0.0	12	0.0	12	0.0	500	0.0
Biomass	700	6.1	90	0.8	90	0.8	1,500	13.1	5,000	16.7
CSP	5,000	20.4	0	0.0	2,000	9.0	2,000	9.0	20,000	6.5
Nuclear	2,000	15.4	0	0.0	0	0.0	0	0.0	0	0.0
Coal	1,000	6.9	0	0.0	0	0.0	0	0.0	0	0.0
Oil	1,500	8.5	470	4.1	470	4.1	470	4.1	5,000	0.3
Gas	12,000	23.4	18,000	101.2	17,500	77.8	16,000	68.1	4,000	0.0
TOTAL	**40,200**	**116.9**	**20,772**	**110.34**	**28,072**	**106.9**	**26,482**	**106.7**	**78,000**	**117.4**

B: Storage, emissions, cost

Scenario		A	B	C	D	E
Batteries (energy)	GWh	9.0	0.0	2.0	2.0	40.0
Batteries (power)	MW	5,187	0	900	900	18,009
CO_2 emissions	Mt	15.2	26.7	20.6	18.4	0.3
LCOE	Fils/kWh	106.4	74.0	78.4	77.7	219.3

3 Multi-criteria analysis

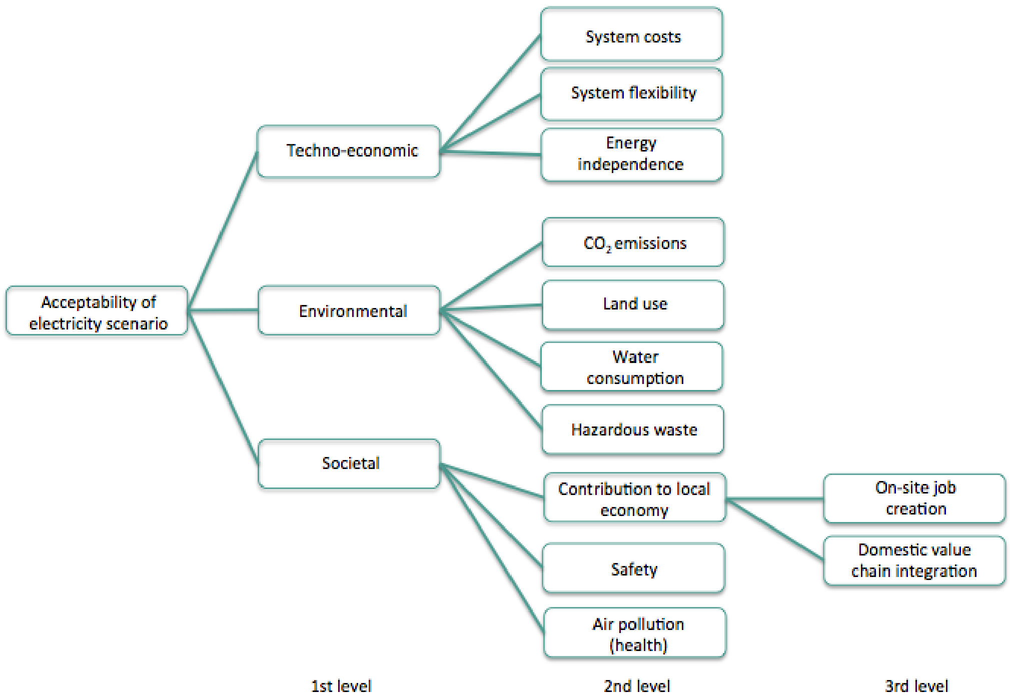
3.1 Background

Stakeholder participation is essential when developing robust pathways for the sustainable development of a future energy system. Therefore, within the MENA SELECT project, the long-term electricity scenarios for Jordan described in Chapter 2 are evaluated in a participatory process. A multi-criteria analysis (MCA) (Zopounidis & Pardalos 2010) serves to systematically identify and consider the importance assigned by national and local stakeholders to a range of social, techno-economic and ecological implications. The identified stakeholder weightings, in turn, are linked to the characteristics of the scenarios discussed. As a result, this process allows identifying those development pathways that are expected to receive broad support from the stakeholders involved.

The above scenario assessment was carried out on the second day of the workshop. First, all stakeholders were introduced to the MCA methodology, the criteria deployed as well as the stages of the intended process. 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 of the project. The mathematical methodology AHP (analytical hierarchy process) was applied to calculate the weighting based on a pairwise comparison of the criteria (Saaty & Sodenkamp 2010). The definitions of all criteria taken into account can be found in Table 2 of the Annex.

Figure 2

The criteria set



Source: Wuppertal Institute

3.2 Weighting process and stakeholder group identification

The weighting process consisted of two steps: An individual weighting by each participant as well as a group weighting within four groups of participants.

In the first step, each participant weighted all criteria at each level of the hierarchy with the help of a questionnaire that was handed out to them. They were asked to fill it in while paying attention to a Powerpoint presentation which included the criteria categories (techno-economic, environmental, societal) as well as a short description of the sub-criteria. The participants then had to mark their weightings for the criteria set in question in silence, without any discussion and then to individually check their weighting for inconsistencies.

In the second step, participants 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;

/ Environmental group: Higher preference for environmental criteria;

/ Societal group: Higher preference for societal criteria;

/ Equal preference group: Equal preferences among the three categories of criteria.

Each group received a group questionnaire, into which each member had to enter their individual weightings. Then, the whole group was asked to discuss different opinions and to decide upon a group weighting that all group members could identify with. A sheet with criteria descriptions was distributed among the stakeholders so that they could refer to the criteria during the discussion.

3.3 Discussion and results of the weighting processes

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

The different groups used different techniques to reach a group consensus. The 'techno-economic' group calculated the mathematical average of the individual weightings followed by short discussions as to whether each group member agreed with the result. Answers by members of the 'equal preference' and 'societal' groups did not diverge much to begin with, and the group members managed easily to agree upon a group answer. In these groups, there were no major disagreements. Despite the fact that weightings by the members of the 'environmental' group were highly divergent, they succeeded in finding a consensus within the group.

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	Environmental group	Societal group	Equal preference group	Mathematical average
System costs	15	2	1	3	4
System flexibility	21	2	4	1	5
Energy independence	31	2	9	10	12
CO_2 emissions	1	24	1	4	4
Land use	0	3	1	3	2
Water consumption	4	24	8	12	13
Hazardous waste	4	24	5	24	14
On-site job creation	1	0	4	1	1
Local value chain integration	4	1	1	3	3
Safety	15	15	46	13	27
Air pollution (health)	5	4	20	26	14
Total	100	100	100	100	100

As it can be deduced from Table 2, the group weightings reflect the respective groups' category priority, i.e. the 'techno-economic' group valued techno-economic criteria more than others, the 'environmental' group ranked environmental criteria higher, and the 'societal' group gave more importance to social aspects of energy systems. However, the 'equal preference' group did not consider the categories to be equally significant: Environmental and societal criteria dominate techno-economic aspects. In the mathematical average, safety stood out as the most significant criterion.

3.4 Finding a consensus

In addition to the group weighting results presented above, the possibility to agree on a joint consensus weighting among all participants was explored in a plenary discussion. Finding a consensus in a large group of heterogeneous stakeholders is a difficult task that is very likely to fail. Therefore, within the methodology applied, this can be regarded as an optional step of the multi-criteria assessment. Such consensus weighting—if available—can be integrated into the subsequent ranking stage, but is not required to complete the multi-criteria analysis.

The mathematical average weighting served as a starting point. After having discussed the average weighting, the stakeholders were given the opportunity to suggest changes to this weighting in case it did not reflect their judgment.

Some stakeholders expressed dissatisfaction with the criteria, especially concerning the paired comparison (with regard to the criteria that are weighted against each other). They also criticized the fact that at the weighting current local context was not taken into account. However, both aspects are core components of the AHP methodology: The hierarchical structure and pairwise comparison of the criteria make the task less complex by reducing a multidimensional decision issue to one single dimension. Focussing on the stakeholders' general preferences is an important aspect of the weighting stage of an MCA, since it allows the weighting to be applied on energy systems that undergo major structural changes over time compared to the status quo.

One stakeholder was surprised to see such a low figure for on-site job creation. Bearing in mind that there is a severe underemployment issue in Jordan, job creation should be weighted higher. Another stakeholder considered that system costs should be valued at more than four per cent. Finally, the participants felt that the average results did not represent their real preferences: Some participants assumed that the cost percentage might have been ranked so low because of an aversion against nuclear energy (which they presumed would be chosen in case low costs were a priority).

Some stakeholders suggested changing the results. One put forward to fill the consensus figures by hand voting. This was not a feasible solution. Another suggested that each preference group would only weight the criteria that fall into their category, i.e. the techno-economic group only weights techno-economic criteria and so forth. It was not possible to translate this ex-post suggestion into practice, either. Finally, it was suggested to calculate the mathematical average taking individual answers instead of the group answers into account, thereby counteracting the distorting effects of the different group sizes.

The majority of stakeholders could not identify with the mathematical average (seven against, five in favour, one abstention). Attempts at finding a consensus as to the adaptation of the results were not successful, as some questioned the idea of changing the average figures, which they perceived as an inappropriate adjustment of the applied methodology. No consensus could be agreed upon. As mentioned at the beginning of this section, this does not negatively influence the results of the workshop. It only means that the ranking of scenarios was based on group weighting results only rather than on an additional consensus weighting. The ranking results displayed in the following show that even divergent (intermediate) weighting results may result in the same (final) scenario preference.

3.5 Ranking of the scenarios

The different criteria weightings were applied to the five scenarios developed on the previous workshop day (see Chapter 2.3). This allowed ranking the scenarios according to the stakeholders' preferences established throughout the weighting process. As presented in Table 3, the different weightings all lead to similar scenario priorities. In all stakeholder groups, the scenario "No imports" ranks first. The techno-economic, environmental and societal groups' preferences display the same scenario ranking, which is also reflected by the mathematical average. However, the equal preference group portrays a different prioritization: The "Mix incl. Nuclear" scenario (the only one containing nuclear power and coal) ranks second instead of last.

Table 3

The ranking of the five scenarios according to the different weightings

	Techno–economic group	Environmental group	Societal group	Equal preference group	Group average
No imports	1	1	1	1	1
Medium RE + Gas	2	2	2	3	2
RE + Gas	3	3	3	4	3
Current plan + Gas	4	4	4	5	4
Mix incl. Nuclear	5	5	5	2	5

The equal preference group thereby prioritizes a more diverse mix of energy resources—knowing that the "Mix incl. Nuclear" scenario is the only one to include nuclear power and coal but representing a much higher share of renewable energies as compared to the "Current plans + Gas", "RE + Gas" and "medium RE + Gas" scenarios. Prioritizing a more balanced set of energy resources over the more gas-focused and renewables-exempt scenarios "Current plans + Gas", "RE + Gas" and "medium RE + Gas" corresponds with the more or less balanced category preference of the equal preference group.

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 using an MCA turns out to be in accordance with the stakeholders' criteria weightings and preferences. Even though the stakeholders could not agree on a single set of common weighting results, they could, however, relate to the final scenario rankings. As a final result of the MCA, the scenario "No imports" proved to comply best with the preferences of the workshop participants. This scenario features a future electricity system that relies mainly on renewable energy sources that are minimally supplemented by domestic fossil fuels.

4 Results of workshop discussions

The following section sums up the main threads of discussions during the stakeholder workshop. The results of all discussions are grouped into different topics.

4.1 Electricity cost

All of the workshop participants agreed on the importance of low electricity costs per kilowatt hour as a key parameter for the future electricity system.

They mentioned that due to high wind speeds especially in the Dead Sea Valley, wind energy is already the cheapest way to produce energy in Jordan's present system.

All efforts that are currently made in the electricity sector are cost-driven. That is why the focus for new solar power plants lies, for example, on the construction of solar photovoltaic (PV) power plants rather than on concentrated solar power (CSP) plants. Even though CSP plants would be more beneficial in terms of additional storage capacity, PV is much cheaper than CSP and therefore favoured by the decision-makers.

4.2 Renewable energies in detail

The workshop participants mentioned that wind and solar energy are both generally accepted by the population and political decision-makers and stressed the comprehensive experience with small-scale off-grid PV systems in particular during the discussions.

Currently, the government focuses on the expansion of large-scale wind farms and solar PV systems. This might change in a few years, as soon as CSP will be as cheap as PV or at least substantially cheaper than it is today. The main advantage of CSP compared to PV is the additional storage capacity. In times with high solar radiation and low electricity demand, surplus electricity can be stored in the form of heat. In times of high electricity demand and low solar radiation, the previously stored heat can be used to produce electricity.

The participants suggested combining both PV and CSP in terms of land use to adequately use the high solar radiation in specific areas like the Ma'an municipality. This area is known as the region with the highest solar radiation in Jordan with approximately 220 to 400 sunshine hours per month (World Weather & Climate Information, 2016).

Another important discussion was about a possible future electricity production from waste-to-energy. Nearly all of the participants argued against using agricultural biomass for biogas production because of the high water demand during the production. Water should not be wasted for electricity production as it is extremely scarce in Jordan, and food security is considered as much more important than electricity production. However, waste-to-energy was seen as a good alternative to produce electricity as there are high amounts of waste in Jordan; this would also meet the environmental goal of waste reduction. The main barrier to the large-scale introduction of waste-to-energy in Jordan today is the missing separation of waste. The costs of implementing, managing and maintaining such waste sorting systems need to be added to the costs of existing waste-to-energy systems where such structures already exist.

4.3 Regulatory framework

The workshop participants had different views and opinions on existing laws and regulations concerning the self-consumption of electricity from decentralized PV applications.

Some participants argued that the existing laws enabled just few people to install and operate their own small-scale PV applications. Others retorted that it is possible to install decentralized PV applications anywhere in Jordan without any problems. Their perception was that existing difficulties within these implementation processes are not based on the regulatory framework but on wrong practices of the responsible authorities. These different views on the current regulatory framework led to the conclusion that the current practical implementation of the rules is not transparent enough.

4.4 Conventional energies in detail

Conventional energies play a crucial role in Jordan's current electricity system, which mostly relies on oil and gas. Lacking domestic reserves of both resources have led the government to examine reliable future alternatives to decrease energy dependence on other countries. But the problem of all types of conventional energies is that each have their own bottlenecks and disadvantages.

One currently much-discussed option for the Jordanian system is the introduction of nuclear energy. However, nuclear energy is not a favourable option for most of the workshop participants. Despite the fact that much research has been done during the last years and a construction site for a nuclear power plant has already been identified, geological problems, a lack of cooling water reserves or financial support are just some factors that have delayed the construction for a couple of years. Yet, the government continues to pursue the construction plans expecting to produce cheap electricity with this technology. The workshop participants mentioned a range of unresolved issues, including plant decommissioning, nuclear safety concerns, missing nuclear waste repositories and the related cost uncertainties. For these reasons, most of the participants opposed the construction of such types of power plants.

Another conventional technology that is currently not used for large-scale electricity production is coal-fired power. As the country itself cannot resort to own resources, NEPCO is considering the import of coal to meet the increasing electricity demand. However, the workshop participants were relatively sure that importing coal on a large scale will not be possible in Jordan as logistical problems (no free space to build coal hubs at the Jordanian coast) will prevent these plans.

Additionally, the workshop participants pointed out that a focus on coal would go against the government's commitment to reduce CO_2 emissions by 14 per cent by 2030. If this goal were to be met, emission-intensive technologies like coal-fired power plants would have to be excluded from future electricity production.

Besides the reduction of CO_2 emissions, the workshop participants mentioned yet another important governmental strategy for the future: that of securing energy independence. Although the combined goals of high energy independence with CO_2 emission reduction might be achieved by the use of domestic renewable resources, the government also pursues the use of polluting and carbon-intensive domestic shale oil resources in its future system. The workshop participants pointed out, however, that even though huge amounts of domestic shale oil resources are to be assumed, the extraction and electricity production would be very expensive and of low calorific value.

4.5 Requirements for future electricity systems

The most important aspects of a future electricity system highlighted by the workshop participants during the workshop's general discussions consist of low electricity costs, job creation and safety issues. Nevertheless, they did not reject any technology completely as they recognized the necessity of finding the cheapest future electricity production system. Even if some technologies are expensive today, possible future cost reductions might increase their economic viability.

The workshop participants also agreed on the need for a diversity of renewable energy technologies in the future and mentioned the currently high political acceptance of all kinds of renewable energies. The only problem that all of the participants acknowledged is the currently missing large-scale potential of electricity storage which is needed in energy systems with very high amounts of fluctuating renewable energies. Compared to countries like Germany, the storage requirements in Jordan were expected to be higher due to a lack of transfer capacities to neighbouring countries. If large electricity storage capacities are available in the future, the integration of high amounts of fluctuating renewable energy capacities will be possible.

Participants also rated job creation as a very important factor and pointed out that different kinds of technologies will create different qualities of jobs.

They were concerned that only few jobs would be created for the Jordanian population if wind energy was used, as foreign investors and workers would do the planning, construction and maintenance of the wind farms. This problem could be solved if foreign investors were obliged to employ and train Jordanian workers.

As concerns safety issues, the workshop participants as representatives of the Jordanian population emphasized that negative experiences, such as the interruption of the Egyptian gas supply, ought to be avoided. They, therefore, stressed that the future electricity system had to be resilient with regard to supply shortages. Despite the government's efforts in the fields of nuclear, coal, and oil resources, the participants were aware of the necessary support of the international community concerning cost-intensive projects. With an expected lack of international funding for large fossil or nuclear projects that are expected to have severe environmental impacts, it is doubtful that such projects will be realized.

5 Conclusion & Recommendations

From the workshop results described above and the summary of workshop participants' expectations and preferences the following conclusions can be drawn:

- The question of power storage will be key for Jordan's future power system. Due to water scarcity, pumped hydro power was not considered to be an option. From today's perspective, battery or thermal storage can be of crucial importance in the future, especially if substantial amounts of fluctuating renewable energy sources are to be integrated into a power system with limited interconnections to neighbouring countries.
- Energy independence is an important objective for Jordan's future power supply.
- The most favourable power system is based on substantial shares of renewable energy sources, in particular solar PV and CSP. This mainly corresponds to the quantitative evaluation of the developed scenarios that resulted in a high acceptance for a generation mix with considerable shares of additional renewable technologies such as wind, biomass and geothermal power.
  The main conventional power generation type considered to play a role in Jordan's future power system is natural gas while coal-fired power plants are regarded as irrelevant for Jordan's future power system.
- Shale oil is regarded as a domestic energy source that might supplement a national energy system with high shares of renewables and the aim of low dependence from foreign sources.
- Nuclear power is regarded as an unpopular technology in Jordan's future power supply despite the fact that the country is currently pursuing a national strategy to develop this energy option. According to Jordan's national energy strategy of 2007, six per cent of its primary energy supply should be covered by nuclear power as of 2020 (World Nuclear Association 2017).
- Water scarcity also strongly influences the perception of different electricity generation technologies. The participants suggested to limit the potential of biomass to waste-to-energy, as they considered agriculture to be reserved for food production only.

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

- To achieve a high level of energy independence, Jordan should particularly focus on its abundant 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 Jordan'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 to establish an electricity system based on high shares of renewable energy should be investigated 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. The reduction of storage demand is especially important with regard to the limited availability of storage options such as pumped hydro power.

6 Next steps and other project activities

The scenarios developed with the spreadsheet model during the workshop will be utilized as inputs to the *RENPASSG!S* model developed by EUF. The *RENPASSG!S* model has already been provided to interested parties. Another workshop took place mid-March 2017 in Amman, Jordan, in which interested parties were 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. Central results will also be presented during a scientific conference in 2018.

Within the framework of the MENA SELECT research project and apart from the workshop activities in Jordan, further research and workshops with local stakeholders have been conducted in the states of Morocco and Tunisia.

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8 Annex

Figure 1

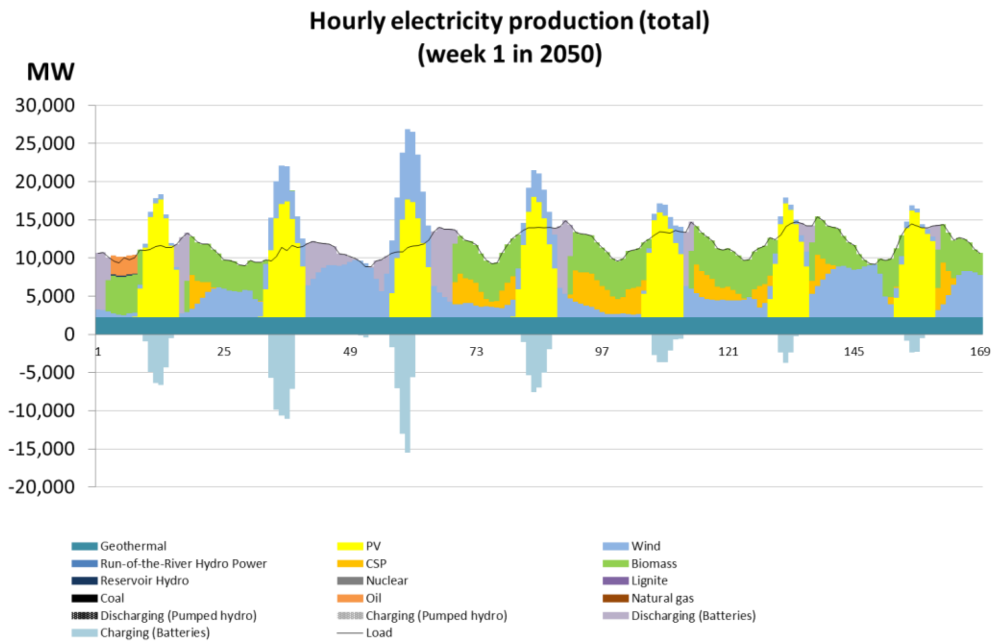
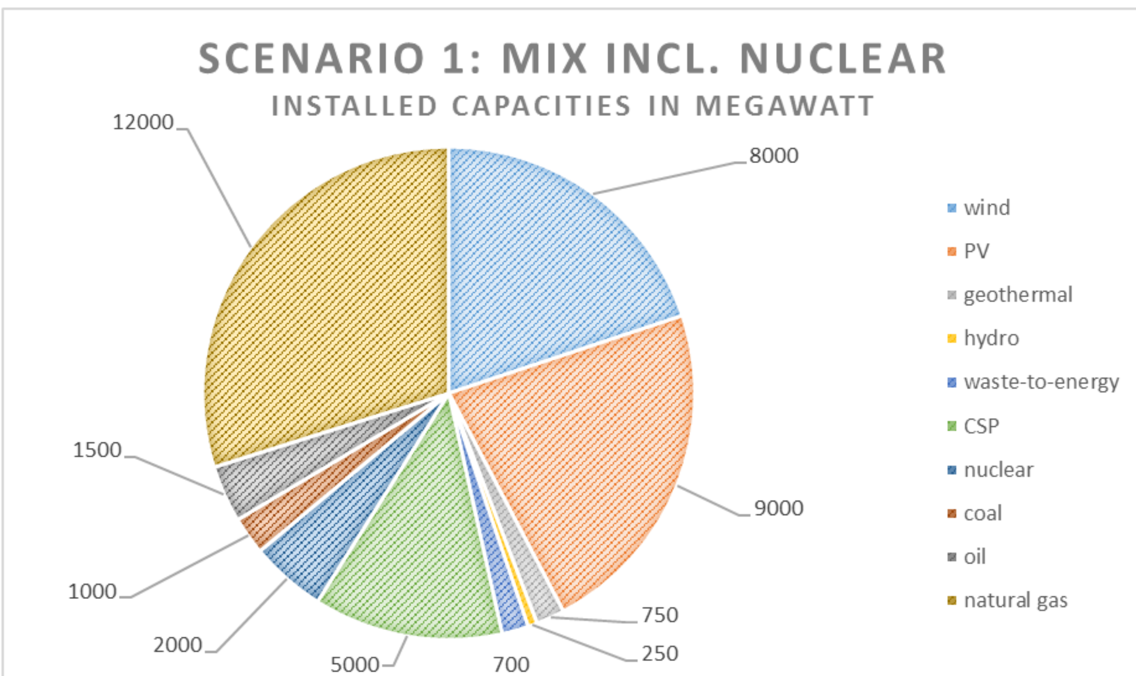
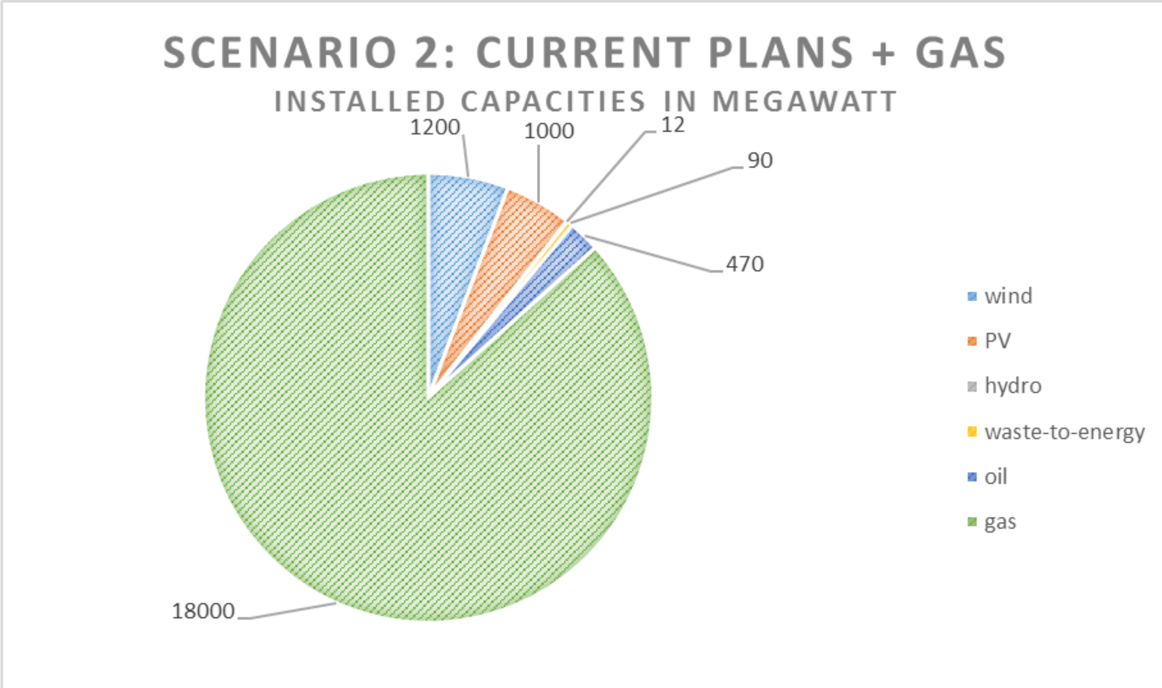
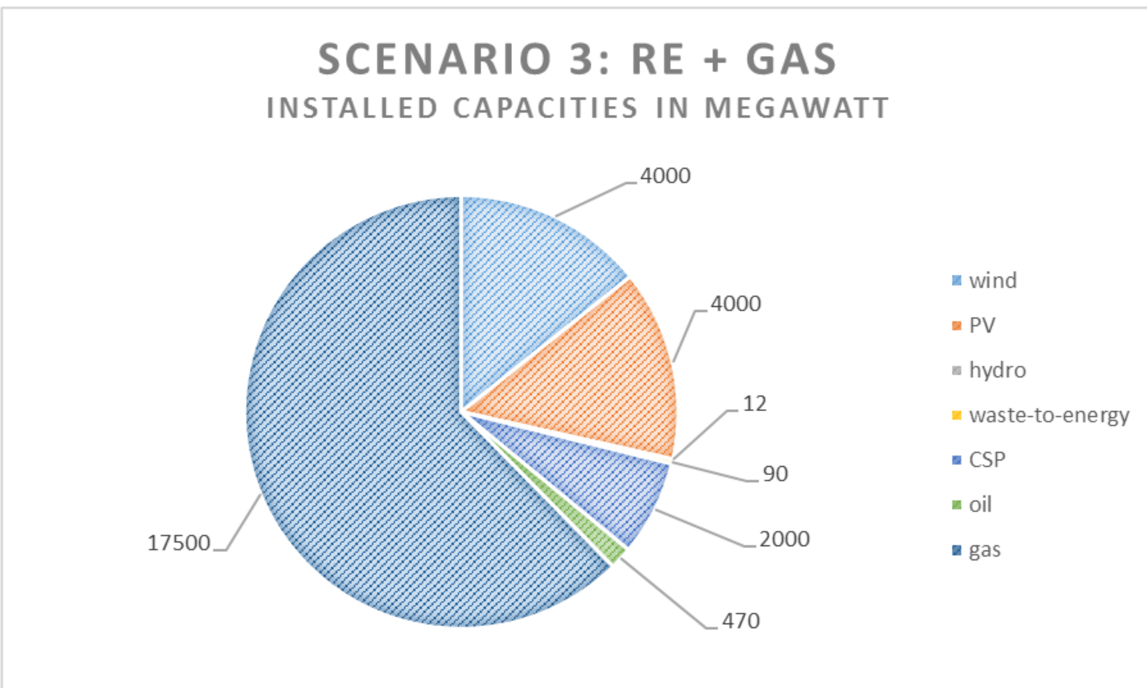
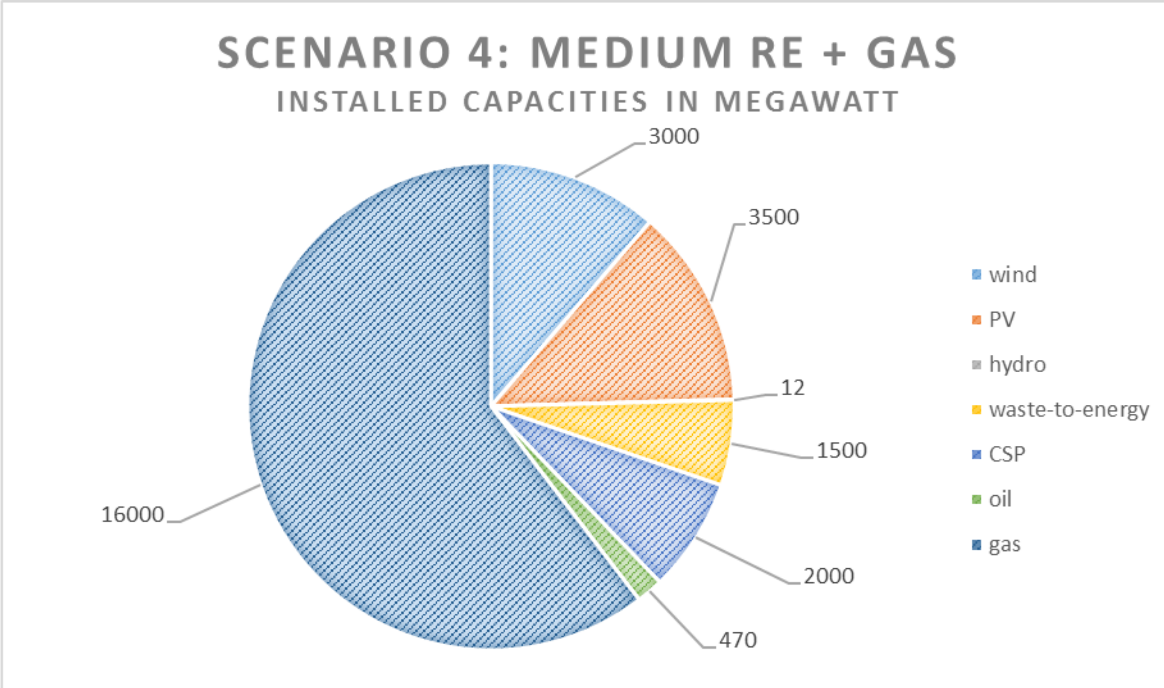


Figure 2




SCENARIO 2: CURRENT PLANS + GAS
INSTALLED CAPACITIES IN MEGAWATT
1200
1000
12
90
470
18000
wind
PV
hydro
waste-to-energy
oil
gas


SCENARIO 3: RE + GAS
INSTALLED CAPACITIES IN MEGAWATT
4000
4000
12
90
2000
470
17500
wind
PV
hydro
waste-to-energy
CSP
oil
gas


SCENARIO 4: MEDIUM RE + GAS
INSTALLED CAPACITIES IN MEGAWATT
3000
3500
12
1500
2000
470
16000
wind
PV
hydro
waste-to-energy
CSP
oil
gas

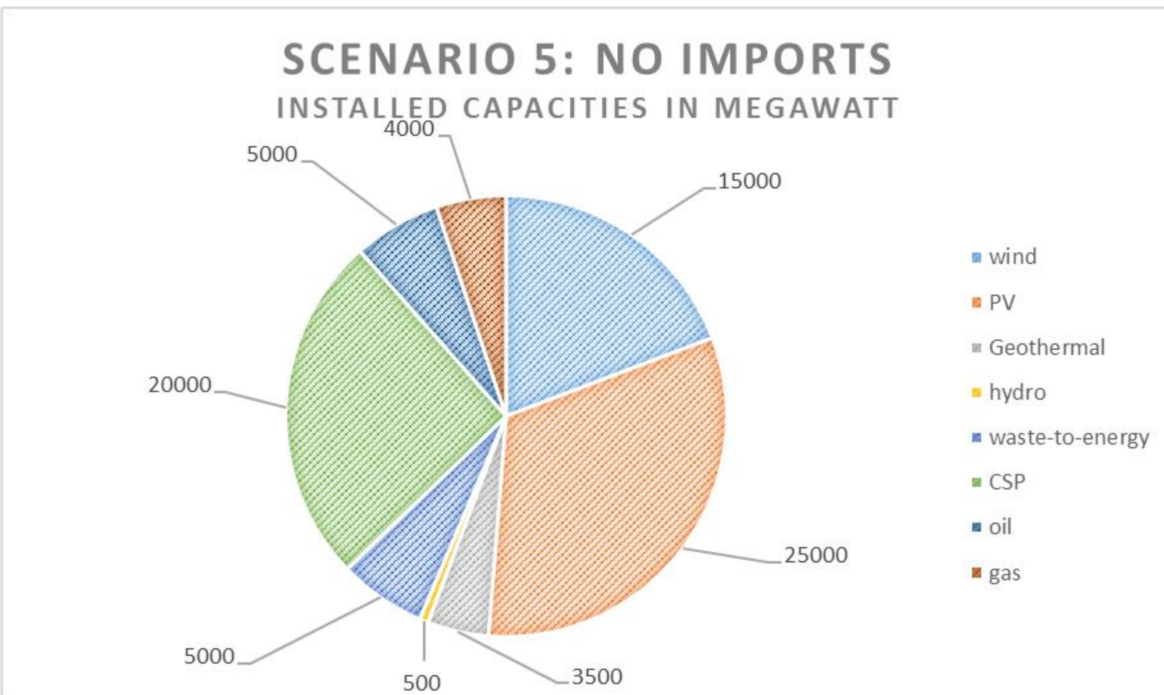

SCENARIO 5: NO IMPORTS
INSTALLED CAPACITIES IN MEGAWATT
4000
5000
15000
20000
25000
5000
500
3500
wind
PV
Geothermal
hydro
waste-to-energy
CSP
oil
gas

Table 1

Indicator values of each criterion for each scenario (based on installed capacity and electricity generation in the target year 2050)

Category	**Techno-economic**			**Societal**				**Environmental**			
Criteria	**System costs**	**System flexibility**	**Energy independence**	**Safety**	**Air pollution (health)**	**Contribution to local economy**		**CO_2 emissions**	**Hazardous waste**	**Land use**	**Water consumption**
						On-site job creation	**Local value chain integration**				
Unit/ Scenario	Mio. €	Scale 1-5	Scale 1-5	E-09 Fatalities /MWh	Mt	Scale 1-5	Scale 1-5	Mt	Scale 1-5	ha	Mio m^3
Mix incl. Nuclear	14 448	3.8	2.8	18	0.26	3.9	2.3	15.17	2.8	59 700	41.7
current plans + Gas	10 048	4.6	1.9	3	0.92	3.7	1.6	26.65	3.9	36 880	33.9
RE + Gas	10 645	3.9	2.2	3	0.72	3.8	2.0	20.63	3.4	47 240	29.5
medium RE + Gas	10 549	4.2	2.2	3	0.63	3.8	2.0	18.43	3.4	42 090	26.4
No imports	29 770	3.8	4.1	5	0.01	4.2	3.0	0.26	1.1	100 200	3.6

Table 2

Criteria definition

Techno-economic criteria	These criteria analyze the technical and economic characteristics of the electricity system. They take electricity production costs, dependency on energy imports and production volatility into consideration.
Environmental criteria	These criteria analyze the environmental characteristics of the electricity system. They take water consumption, land use, CO_2 emissions and management of hazardous waste into consideration.
Societal criteria	These criteria analyze the socio-economic characteristics of the electricity system. They take the system's effects on public health, the risk of serious incidents and the promotion of local economy into consideration.
System costs	The costs of the electricity system include production, grid extension and storage costs.
System flexibility	The electricity system's capacity to react rapidly and flexibly to changes in electricity demand.
Energy independence	Future capacity of the scenarios to make use of local resources in order to reduce energy dependency.
CO_2 emissions	Direct CO_2 emissions of all power plants during the observation period.
Land use	Soil occupation caused by the operation of all power plants (on-site).
Water consumption	Direct freshwater consumption during the operation of all power plants (cooling, steam cycle, cleaning).
Hazardous waste	Quantity and quality of hazardous waste produced by all power plants.
Contribution to local economy	The scenarios' capacity to integrate the local economy into the electricity system.
Safety	The number of fatalities as a result of serious accidents during the operation and maintenance of power plants.
Air pollution (health)	Air quality deterioration resulting from atmospheric pollutants that can bring about health risks.
On-site job creation	The scenarios' capacity to create on-site jobs during the construction and operation of power plants.
Domestic value chain integration	The scenarios' capacity to encourage the emergence and/or development of national industries and of indirect jobs during the entire life cycle of power plants.

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The responsibility for contents and views expressed in this publication lies entirely with the authors.

PROOFREADER
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DATE OF PUBLICATION
January 16, 2018

With financial support from
Federal Ministry for Economic Cooperation and Development