International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2021, 11(4), 14-23.

A Review on Prospective Energy Models: The Moroccan Case

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Received: 01 February 2020 **Accepted:** 20 January 2021 **DOI:** https://doi.org/10.32479/ijeep.8505

ABSTRACT

Nowadays, energy modeling is among the most required tools for the optimization of the energy system performance on a regional, national and global scale. The need for studies of energy models is justified by the increasing energetic demand, the evolution of power generation technologies and the transition to modern economics for developing countries. The aim of this study is to provide different aspects, techniques and characteristics of the existing energy models in literature. A better understanding of each model framework and requirements may lead to a better analysis of the Moroccan energy system description and criticism of its performance and ability to cope with the government international engagements concerning greenhouse gases emissions and also national engagements mostly the need to overcome the demand-supply related issues.

Keywords: Energy Modeling, Multi-agents Models, Moroccan Energy System
JEL Classifications: C53, Q42, Q56

1. INTRODUCTION

The increased energy demand in the domestic power sector is the major factor to consider forthcoming energy planning activities that can be based on an organized modeling and simulation of the energy demand evolution. Additionally, distributed power generation, integration of renewable resources and the need for a smart grid in Morocco can further be considered as fundamental issues.

Energy models are a valuable aid to decision making. They allow the evaluation in the long term of several possible scenarios of evolution of the energy system. The evolution of knowledge, technology and computing powers has thus favored the emergence of a large number of energy models developed and used independently by different institutions. While these models are certainly not prophetic tools, their contribution remains undeniable (Assoumou, 2006): they make it possible to formalize a coherent vision of the many interactions of the world of energy, and to avoid the direct experience of inappropriate choices.

Energy planning is based on prospective models for the numerical analysis of energy scenarios. These tools make it possible to evaluate the response of the energy system to alternative policies, constraints or operating conditions.

1.1. Demand Forecasting Issues

The future demand of electricity forecasting is essential for long-term planning of future generation facilities repowering, retrofitting and transmission optimization.

Due to the fact that excess power could not be easily storable, the underestimation of electricity demand may lead to supply shortages and forced power outages which will have negative socio-economic impacts (Steinbuks, 2017).

Additionally, the energy demand overestimating may lead to overinvestment in generation capacity which will increase electricity prices due to the fact that financial viability has to be maintained by recovering costs needs. Forecasting long-term electricity demand also includes other factors such as underlying population growth, changing technology, markets, and current weather conditions. In developing countries, this problem can be particularly challenging due to elusive data, political influences and historical electricity demand which is more volatile due to macroeconomic and political instabilities.

1.2. Reliability Issues

Reliability of supply is an essential requirement for the operation of electrical systems. The reliability of the system relies on two main missions (Drouineau, 2012):

- Ensure the normal operation of an electrical system, which is being responsive to demand and passing the peak. Fluctuations in production or consumption are predictable. Such a regime is ensured by a sufficient level of installed capacity and adequate activity of the plants, depending on their availability
- Ensure reliable system management to deal with exceptional incidents and unavailability, and to ensure a return to stable supply conditions. In this case, the fluctuations are unpredictable.

1.3. Environmental Issues

Environmental concerns related to power generation appear when large amounts of pollutant chemicals are released by mining industries while searching for fossil reserves needed for electricity production. In this matter, coal has a significant role due to its important pollutant characteristics as its combustion produces high amounts of environment harmful wastes especially large quantities of carbon and sulfur dioxide (Khatib, 2014).

Most of the effects of these products on environment can be divided into three cases. The first case is that of a local impact when fuels combustion resulting gazes and solids travel to relatively small distances (few hundreds of kilometers).

The second case corresponds to the regional impact which is translated in the ability of high emissions of sulfur dioxide to travel bigger distances and also to lie in the atmosphere for a longer time (few days). The third impact is global where CO_2 emissions major responsible for global warming also as other agents attend higher levels of condensation in the atmosphere.

Considering these goals, there are few models in literature that deal with the Moroccan energy system aspects (demand forecast, Green House Gases [GHG] mitigation, Integrated Assessment Models [IAM]…). In order to produce a Moroccan energy model, first we have to understand the main characteristics of energy modeling, the differences between the existing types of models (MARKAL, Med-Pro, LEAP, POLES, etc.) and their degrees of suitedness to the Moroccan particularities.

In section 2 modern energy systems and technologies will be presented. Section 3 will be dedicated to the presentation of some energy models while section 4 will discuss their applications across the world. In the last section, the Moroccan energy system will be briefly presented also as the existing models.

2. MODERN ENERGY SYSTEMS AND TECHNOLOGIES:

2.1. Modern Energy Systems

2.1.1. Smart grids

Smart grids are a synonym to the electric networks that include intelligent components allowing interactions between suppliers and consumers, interactions that ensure the security and sustainability of the supplied electric power (Kremers, 2013). The main quality of this type of networks is the possibility of information exchange between both the supplier and the consumer through the network itself. The Supervisory Control and Data Acquisition system (SCADA) is the key element that ensures this process and is used to control the whole electric system. Smart grids are commonly used in power networks for decades and there exist other technologies related to them which are the following: smart metering, electric vehicles, distributed generation, demand side management, energy storage and dynamic pricing.

2.1.2. Micro-grids

Like smart grids, micro-grids are designed to be implemented and used in parallel with the existing power networks. This system is composed of distributed energy systems that allow electricity supply for small groups of consumers located in relatively close distances.

Micro-grids also include Renewable Energy Sources (RES) and due to this fact they are presented as a part of the Hybrid Renewable Energy Systems (HRES).

2.1.3. Island systems

An example of these systems is the interconnected continental power grid such as the North-American power grid which is characterized by its wide geographic extension (thousands of kilometers) and high number of control systems.

This type of systems offers better frequency stability compared to small systems. Their main advantage as an isolated network is the ability to provide opportunities to measure the impact of significant integration of RES.

2.2. Presentation of Power Generation Technologies

Starting the 21st century, world faces important challenges concerning energy supply (Bazmi and Zahedi, 2011).

For a sustainable energy in the near future, low energy per unit of GDP and low carbon emissions will be required. The GHG emissions from power generation are a direct consequence of the main processes in related to the power generation. Despite the significant role of electricity in the economic development of societies, it is very important to ensure a sustainable development for a livable future for human beings and where their needs can be met without harming natural ecosystems. In this context, different technologies are used to provide electric energy. Their characteristics are presented in Table 1 as follows:

Among other technologies, the Carbon Capture and Storage (CCS) technology represents a significant tool for carbon mitigation by

Table 1: Power generating technologies. Adapted from (Bazmi and Zahedi, 2011)

Technology	Annual generation (TWhel/y)	Capacity factor (%)	Mitigation potential (GtCO2)	Energy requirements (KWhth/KWhel)	CO2 emissions (g/KWhel)	Generation costs (US$/KWh)	Barriers
Coal	7,755	70–90	-	2.6–3.5	900	3–6	Greenhouse gas emissions
Oil	1,096	60–90	-	2.6–3.5	700	3–6	Resource constraints
Gas	3,807	≈ 60	-	2–3	450	4–6	Fuel price
Carbon capture and storage	-	n.a.	150–250	2–2.5+0.3–1	170–280	3–6+0–4	Energy penalty, large scale storage, late deployment
Nuclear fission	2,793	86	> 180	0.12	65	3–7	Waste disposal, proliferation, public acceptance
Large hydro	3,121	41	200–300	0.1	45–200	4–10	Resource potential, social and environmental impact
Small hydro	≈250	≈50	≈100	n.a.	45	4–20	Resource potential
Wind	260	24.5	≈450–500	0.05	≈65	3–7	Variability and grid integration
Solar PV	12	15	25–200	0.4/1–0.8/1	40/150 – 100/200	10–20	Generating cost
Concentrating Solar	≈1	20–40	25–200	0.3	50–90	15–25	Generating cost
Geothermal	60	70–90	25–500	n.a.	20–140	6–8	Uncertain field capacity
Biomass	240	60	≈ 100	2.3–4.2	35–85	3–9	Efficiency, feedstock availability, cost

retaining significant shares of the actual electricity production infrastructure and developing existing expertise and techniques. Despite the fact that carbon capture technologies are well studied, this kind of technologies is still to be proven for a large commercial context.

2.3. Some General Power Generation Costs

2.3.1. The levelized cost (LCOE)

The Levelized Cost of Electricity (LCOE), also known as Levelized Energy Cost (LEC) is used to evaluate the cost-effectiveness of different power generation technologies. The LCOE is an estimation of the generated energy price per unit based on the lifetime generated energy and costs. Risks and different actual financing methods available for the different technologies are not included as defined in (Branker et al., 2011).

2.3.2. Levelized avoided cost of electricity (LACE)

The direct comparison of LCOE across technologies to evaluate the economic alternatives when a new capacity is needed can be misleading; therefore a better evaluation can be obtained by considering the avoided cost which is a method that provides a proxy measure for the annual economic value of a candidate project for power generation. It can be summed over its financial life and converted to a level annualized value that is divided by average annual output of the project to develop its LACE (as defined in (U.S. Energy Information Administration, 2017).

Other costs include: the enabling costs, the environmental impacts costs, the usage life spans, the energy storage and the recycling costs.

3. SOME INSTITUTES AND WORKSHOPS

3.1. Institutes

Energy institutes across the world play a significant role when it comes to energy modeling. They conduct and provide numerous case studies and data concerning a variety of regions on the globe. Here are some of these institutes:

- MASEN: Moroccan Agency for Solar Energy
- AMEE: Energy Efficiency and Renewable Energy development Agency
- SIE: Energy Investment Company
- IAE: International Energy Agency
- IAEA: International Atomic Energy Agency
- IIASA: International institute for applied system analysis
- IPCC: Intergovernmental Panel on Climate Change
- IRENA: International Renewable Energy Agency
- GIZ: German Cooperation Agency
- ADEME: Environment and Energy Agency
- IRESEN: Solar and Renewable Energy Research Institute
- GEF: Global Environment Facility
- IFDD: Francophone Institute for Sustainable Development
- SEI: Stockholm Environment Institute
- EEA: European environment Agency
- IEEE: Institute of Electrical and Electronic Engineers
- The Wuppertal institute.

3.2. Workshops

Workshops about energy modeling are very numerous, here are some well-known ones:

- World Energy Outlook: High-level Workshop on Energy and Development
- Digitalization and Energy
- IEA Energy Statistics Course
- IEA Unconventional Gas Forum
- G20: Energy End-Use Data and Energy Efficiency Metrics initiative
- IEA-IETA-EPRI Annual Workshop on Greenhouse Gas Emission Trading
- IEA-ESAP/EPRI Annual Expert Workshop: Challenges in Electricity Decarburization Optimizing the Path to 2050
- High-Level ESAP Plenary Meetings
- Climate-Energy Security Nexus: Emerging Best Practices and Lessons for North America.

4. SOME ENERGY MODELING SOFTWARE

4.1. Introduction

The energy modeling goal is to make complex systems easier to understand, this can be done by arranging significant quantities of data and frameworks for testing hypotheses. On one hand, energy system models tend to analyze the behavior of an entire energy system on a national, regional and global scale while on the other hand these models are driven by exogenous macroeconomic trends (Heaps, 2002).

Energy economy models are specifically required to measure the impact of energy systems on the wider economy. The other models such as partial system models attempt to measure the impact on a local scale.

Energy policy models use different aspects depending on the modeler views, goals and available data:

- Optimization Models: Identification of least-cost configurations based on various constraints in order to select adequate technologies
- Simulation Models: Simulation of consumers and producers behavior under various signals in order to reach market clearing demand-supply equilibrium
- Accounting Frameworks: Explicit specifications of outcomes by users as a main function in order to manage data and results
- Hybrids Models: Combination of the approaches above
- Multi-agent models: Based on multi-agent approaches for both modeling and simulation by considering energy systems as complex systems.

In this part, MARKAL, LEAP and Med-Pro are going to be discussed aiming to understand their characteristics and multi-scenario analysis behaviors. Other main energy models existing nowadays include: POLES, EFOM-ENV, ENERPLAN, ENPEP, MARKAL-MACRO, MESAP, MESSAGE-III, MICROMELODIE, and RET screen.

4.2. MARKAL

A brief description of MARKAL characteristics would indicate the following aspects (Loulou et al., 2004).

- The time horizon: The user can choose to divide the time horizon into a number of time periods with the same number of years
- Technology explicit model: Technologies in MARKAL are represented by input and output parameters (technical and economical)
- Multi-regional: Some existing MARKAL models include a limited number of regional modules, this limit is justified by the difficulty of large size linear programs solving
- Partial equilibrium: MARKAL calculates both all the possible flows related to the energy market in order to guarantee the fact that the energy produced matches the amounts needed by the consumers.

The MARKAL objective is to minimize the total cost of the system through the defined time horizon under the following constraints:

- Energy Service Demands Satisfaction
- Capacity Transfer
- Use of capacity
- Balance for Commodities
- Peaking Reserve
- Emissions.

4.3. Long range Energy Alternatives Planning System (LEAP)

The Long-range Energy Alternatives Planning system (LEAP) is an energy system and GHG mitigation policies analysis software tool for energy policy analysis developed at the Stockholm Environment Institute (SEI) (Heaps, 2008).

A brief description of LEAP's characteristics (Stockholm Environment Institute, 2014) would indicate the following aspects:

- Time frame: LEAP's time frame involves medium and long-term horizons. Its time horizon is divided into annual periods representing a large number of years. Most forecast case studies involve periods between 20 and 50 years
- Scenario Analysis: Through LEAP, alternative scenarios can be created, analyzed and evaluated by the user in order to compare energy needs also as the economic and environmental impacts
- Decision Support System: LEAP is seen as a Decision Support System (DSS) in a way that it can provide Data management and reporting options
- Graphic views: This tool provides the ability of visualizing, interpreting results and detecting errors by displaying calculus in different forms from simple graphs to complex maps
- Energy balance: The energy balance in LEAP adopts the same standards of most international and national energy policies organizations
- The Technology and Environmental Database: The Technology and Environmental Database (TED) offers an easy access to the main characteristics of a wide number of power generation technologies from different types and generations.

4.4. The MEDEE Med-Pro Model

Med-Pro is another type of electric system and GHG mitigation policies analysis software that belongs to the MEDEE models family which consist in analyzing the demand side including the different end-use sectors (Enerdata Data Management, 2016).

As a MEEDEE family model, Med-Pro includes the following features:

- Simulation of energy demand
- Different energy balances
- GHG emissions forecast
- Production of future GHG inventories
- Forecast of electricity loads
- Assessment of energy and climate change policies.

5. OTHER MODELS

5.1. Prospective Models

Energy modeling first started in the 1970s, when the evolution of computer science, mathematical modeling, the first global oil crises and the environmental issues emergence were the major factors to reconsider the energy resources exploitation. Most of these models were first created and used by the developed countries in order to cope with the economic challenges at the time (Bhattacharyya and Timilsina, 2010).

1972: Meadows produced a global model studying world economic and energetic interactions pushing to development limits concluding that the major issues were the sustainability of the power supply and the dependence of the economic growth on energy resources.

1974: Hudson and Jorgenson represented the relationship between the macroeconomic trends model and the industrial energy demand model where each component contributed to the demand estimations.

1976: Hoffman and Wood in the USA introduced to the world the Reference Energy System (RES not to be confused with Renewable Energy Sources) which is a referential note book of the energy system that takes into consideration the totality of the components that can be present in an energy network underlying the complexity of most energy systems resulting from the evolution in time of different factors influencing the energy markets. The main quality of the RES consisted in using mathematical optimization in order to add more flexibility to the energy systems enabling them to use a wide set of different technologies. As a result of this new approach in the time, models like BESOM which is a linear programming model emerged and which later versions included MARKAL.

1980-1995: Hogan and Manne focused on the role of energy demand elasticity in the relationship between capital and energy while Brendt and Wood completed the study by measuring the impact in the short term.

The most important question asked at the time was about the role of the Top-Down and Bottom-Up approaches in analyzing both technologies and markets evolution.

Then the lights were spotted in a different direction and studies began to show interest in energy related environmental issues. This period was marked by the birth of the long term modeling. As an example, the TEEESE model of India was developed.

Other models appeared including the Asian Pacific Model (AIM), Second Generation Model (SGM), Regional Air Pollution Information and Simulation (RAINS), Integrated Model of Climate, POLES, MEDEE and LEAP which was chosen as a standard model for international use by the United Nations Framework of Convention on Climate Change Reporting.

1997: In Australia, the Australian Energy Planning System Optimization Model (AEPSOM) had been developed by Sardar to analyze self-sufficiency, conservation and sustainability while in China, Zhijun Xie and Michael Kuby had developed an optimization model for power generation based on coal.

2003: Cormio used the energy flow optimization model (EFOM) to present his study of the integration and the promotion of renewable energy sources. The approach used was the bottom-up approach with environmental issues consideration (Jebaraj and Iniyan, 2006).

2005: Chen used MARKAL-MACRO to create a Chinese base scenario of GHG emissions and energy system forecast in the horizon of 2050. The study showed that it would be a decrease of carbon emission at an annual rate per GDP of 3% in between 2000 and 2050 (Chen, 2005).

2007: Rafaj used the Global Multi-regional MARKAL Model (GMM) to study the role of including the external costs to power production costs in order to evaluate the effect of this approach on energy systems. Rafaj concluded that this approach would increase power generation costs favoring the use of natural gas combined cycles, nuclear and renewable technologies (Rafaj and Kypreos, 2007).

2008: Adams built an econometric model for energy market in China which the main objective was to evaluate the future Chinese energy demand and imports to the year 2020. The main conclusion was that Chinese imports would increase at considerable levels due to the growing high tech industry and motor vehicle population (Adam and Shachmurove, 2008).

2009: Swan and Ugursal presented in their paper a review of several energy modeling approaches in the purpose of analyzing the residential sector demand across the globe. The study was based on two different approaches (top-down and bottom-up) using different sets of input parameters (Swan and Ugursal, 2009).

2012: Soria presented a various range of energy planning policies considering three major fields which were energy, transport and environment. The main objective of this study consisted in evaluating the impact of the power generation on the climate change for the European Commission offering flexible options and techniques including the use of RES (Soria, 2017).

2014: Bosseboeuf proposed a model for electrical appliances consumption in France focusing his study on the evolution of the energy market forecasts resulting from the adoption of different policies (Bosseboeuf et al., 2017).

In the same year, Callonec presented his vision of the French energy transition for the ADEME (French Environment and Energy Management Agency). This study consisted in using a macroeconomic model taking into consideration different end-use sectors also as economic factors such as employment (Callonnec et al., 2017).

2016: In Argentina, Sbroivacca used a various set of models including LEAP, TIAM-ECN, and GCAM aiming to measure the evolution of the primary energy consumption under certain boundaries for CO_2 emissions and pricing in between 2010 and 2050. This study showed that for Argentina new carbon pricing policies would cause a decrease in the amount of generated power based on classic fossil fuels that would be compensated by other sources of energy (Di Sbroiavacca et al., 2016).

Emodi presented different scenarios of Nigeria's energy system's future evolution in the horizon of 2040 using LEAP while Salazar focused on the use of bio-energies considering both economic and environmental factors in developing countries (Emodi et al., 2017), (Salazar et al., 2016).

Rahman developed a framework model in order to provide a global analysis of the Bangladesh energetic policies while Hong measured the impact of the South Korean energy policies for the transportation sector on both the energy market and the environment in the horizon of 2050 (Rahman et al., 2016), (Hong et al., 2016). Table 2 shows characteristics of some of these models.

The table presents several models from different countries; therefore, these models vary considering their methodologies and purposes. In order to understand the differences of the energy models and choose the adequate ones for a certain situation, a classification method is significantly necessary. The classification method should focus on the following questions (Shina et al., 2005):

- Projecting demand
- Mapping supply options
- Matching demand and supply
- Assessing the impacts
- Appraising the different options.

5.2. Multi-agent Models

On one hand, agent based models (ABM) are known for being able to represent the complexity of systems such as electricity systems (Van Beeck, 1999). On the other hand the ABM choice is justified by the fact that classic simulation techniques are compromised by the number and degree of complexity of interactions of the different actors in distributed energy systems. Kremers presented an overview on energy systems related ABMs including (Kremers, 2013):

2001: A Multi-Agent System (MAS) was applied for micro-grids control systems by Tolbert.

2005: Hatziargyriou Albert presented a MAS capable of capturing a various set of options introducing a global representation of micro-grids control systems.

2010: Tranchita proposed different modeling approaches in order to identify new operational risks for smart grids introducing the Information and Communication Technologies (ICT) that were integrated into the network.

2014: (Yilmaz et al., 2014) presented a variety of studies using Java Intelligent Agent Component (JIAC) methodology technique aiming to promote the use of smart grids and other technologies such as Electrical Vehicles (EVs) and Virtual Power Plant (VPP).

2016: Hu presented a multi-agent based simulation in order to measure the impact of the promotion of EVs on energy systems (Hu et al., 2016).

2017: Hanga focused on the Energy Storage Units (ESUs) using an ABM to measure the power generation variations on the energy system (Huang et al., 2017).

Coelho also mentioned some other multi-agent models in his overview including an ABM model consisting on interaction between different components in the system in order to facilitate the implementation of new technologies. A second model presented by Coelho consisted on the ZigBee (specification of high level communication protocols) based protocols which is a process of decision making taken by different agents in the system (Coelho et al., 2017).

Table 2: Comparison of some existing energy models

Reference	Year	Activity sectors	Model	Main function	Principal objective	Geographical coverage
Shina el al., 2005	2005	TPE, PFE, industry, transport, residential, commercial, public and other (All sectors)	LEAP	Accounting framework	Landfill gas electricity generation forecast	National (Korea)
Assoumou, 2006	2007	Residential, tertiary and transport	MARKAL	Optimization	Electricity prospective modeling	National (France) and regional (EU)
Adams and Shachmurove, 2008	2008	Transport, residential and others	Chinese energy model	Accounting framework	Energy consumption forecast	National (China)
Swan and Ugursal 2009	2009	Residential	Several models	Optimization and simulation	Energy consumption reduction	International
Soria, 2012	2012	Industry, household, residential and transport	POLES	Simulation	Policies impacts on energy demand satisfaction	Regional (EU and Latin America) and global
Gallonec et al., 2014	2014	All sectors	Med-Pro	Accounting framework	Energy demand forecast	National (France)
Kumar and Madlener, 2016	2016	All sectors	LEAP	Accounting framework	$C0_2$ emissions forecast	National (India)
Emodi et al., 2017	2017	Industry and transport	LEAP	Accounting framework	Energy demand and emissions forecast	National (Nigeria)
Salazar et al., 2016	2016	All sectors	LEAP	Accounting framework	Energy demand and emissions forecast	Internationnal
Hong et al., 2016	2016	All sectors	LEAP	Accounting framework	GHG emissions forecast	National (Korea)

6. MOROCCAN ENERGY MODELS

6.1. Introduction

Studies of the Moroccan energy system as shown in Table 3 include a study on the national energy system and the implementation of Carbone Capture Storage (CCS) infrastructures in one technical-economic model using the MARKAL-TIMES model of Morocco, Portugal and Spain considering geographic boundaries (Kanudia et al., 2013). Merrouni presented simulation results of a relatively small photovoltaic installation taking advantage of the sunny climate of the city of Oujda (Merrouni et al., 2016).

(Carrasco et al., 2016) focused on photovoltaic rural electrification techniques in order to promote an initial project in the kingdom while (Nouri et al., 2016) developed a technical framework in order to compare the potentials of wind power in two different geographical locations in Morocco.

6.2. The Moroccan Energy Supply and Demand

Morocco's primary energy supply increased significantly since the 1990s. Table 4 demonstrates the contribution of each technology to the total primary energy supply in percentage (International Energy Agency, 2014).

The kingdom's energy consumption is growing at a considerable rate. Table 5 shows the transition of this consumption from 1992 to 2012 expressed in thousands of Tons of oil equivalent.

6.3. Morocco's National Energy Strategy

The Moroccan National Energy Strategy (NES) was first planed in 2009 aiming to increase the share of renewable installed capacity to 42% in 2020 but this goal was revised in 2015 with a new objective in the horizon of 2030 of a 52% share.

This new policy is also led by other major factors rather than environmental issues or energy efficiency, the need for acquiring new expertise and the creation of employment opportunities can also be seen as significant economic directives for the kingdom and can be feasible relying on the transition to RES thanks to the high wind and solar potential in the country.

6.4. The Moroccan Energy Mix model (MOREMix)

6.4.1. Purpose

In the framework of collaboration between the German Society for International Cooperation (GIZ) and the Kingdom of Morocco in executing its energy development strategies, new energy planning models have been developed by the German Aerospace Center (DLR) such as REMix-CEM (Renewable Energy Mix Capacity Expansion Model) in order to encourage the relative Moroccan institutions and agencies in achieving their purposes.

These models offered a critical evaluation of the Moroccan electricity system which the main goals consisted in increasing the energy supply in order to cope with the parallel demand and ensuring the sustainability of this supply (Kern et al., 2014).

6.4.2. Scenarios

The project consisted in generating different scenarios in order to represent various strategic alternatives characterized by free, forced or environmental directives. The goal here was to measure the impacts of these directives on the general system in order to better understand the evolution of power generation costs. The different scenarios are presented in Table 6.

6.5. Morocco LEAP Study

6.5.1. Purpose

Using the software LEAP, this study by Roauz aimed at evaluating the Moroccan energy system and measuring the impact of different policies on its evolution. The study is based on three main steps: In the first step, the Moroccan energy system in its integrality was decorticated. In the second step, a set of various scenarios were generated in order to provide estimations of the system evolution in the horizon of 2040. Finally in the third step, in each scenario, results are obtained for specific years in between 2012 and 2040 in order to be criticized based on specific terms.

6.5.2. Scenarios

6.5.2.1. The reference scenario

In this scenario, the considered features are those according to the year of the study. Some features as population growth remained unchanged while oil and natural gas products were considered and changed values within the time line of the study.

Both passenger and goods transportations were presented also as the industry sector with their respective shares of the final energy demand of 33% and 22%.

6.5.2.2. New policies scenario

The new policies scenario involves new policies and energy planning directives intended by Moroccan authorities. As we have seen previously in the Moroccan strategy section, this study uses the same targets as for example the reach of 42 % of renewable share of future installed capacities in 2020. Targets for other technologies shares in the power generation system are presented in Table 7.

Table 3: Moroccan energy models

Reference	Year	Model	Main function	Paradigm	Principal objective	Geographical coverage
Kanudia et al., 2013	2013	MARKAL	Optimization	Bottom-up	Optimization of CCS contribution to mitigation	International (Morocco, Spain and Portugal)
Raouz, 2015	2015	LEAP	Accounting framework	IAM	Energy system forecast	National (Morocco)
Kern et al., 2014	2015	REMix-CEM	Optimization	Bottom-up	Renewables integration forecast	National (Morocco)

Source: Compiled by the authors

Table 4: Morocco primary energy supply, adapted from (International Energy Agency, 2014)

Total primary energy supply 2012			
Energy source	**Ktoe**	**PJ**	**%**
Crude oil and oil products	12702	531.81	67.6
Coal	3024	126.61	16.1
Natural Gas	1067	44.67	5.7
Bio-fuels and waste	1386	58.03	7.4
Hydro	140	5.87	0.7
Geothermal, solar etc.	63	2.64	0.3
Electricity (net imports)	416	17.42	2.2
Total	18798	787.05	100

Table 5: Morocco final consumption, adapted from (International Energy Agency, 2014)

Comparison of total final consumption 1992 and 2012 (in thousand Tones of oil equivalent)						
Year	**Coal**	**Oil products**	**Natural gas**	**Bio-fuels and waste**	**Electricity**	**Total**
1992	366	4305	18	1066	819	6574
2012	8	10537	67	1358	2370	14341

Table 6: Exemplary scenarios and sensitivity analysis for specific strategies, adapted from (Kern et al., 2014)

Business as usual with sensitivities: Free development strategies
- Change in fossil fuel prices for oil, NG, LND, and coal
- CO_2 prices
- Financial boundary conditions (equity/dept shares and conditions)
- Others

Business as usual with forced implementations strategies: Forced development strategies
- Forced gas entry (of LNG)
- Forced distributed PV
- Others

Specific climate policy with sensitivities: Climate policy
- Fluctuating renewable (PV and wind) versus capacity solar power (CSP)
- Advanced battery storage with ambitious reduction of Li-Ion battery storage prices
- Reduced demand due to energy efficiency gains
- Modification of the national and regional load curves due to production and consumption changes
- Evaluation of specific storage technologies (pumped storage, batteries)
- National energy independency

6.5.2.3. GHG mitigation scenario

As part of the Moroccan energy transition, the environmental aspect is considered and translated in GHG mitigation. In the emissions scenario, several parameters are taken into account:
- Transportation: Promotion of EVs also as use of new forms of diesel which are friendly to the environment
- Industry: At this level the limitation of oil exploitation is seen as an alternative measure
- Power plants: New plants are considered in this scenario in addition to those of previous scenarios
- Electricity generation: The integration of renewable sources in the system would contribute to the decrease of fossil fuel use in power generation which share is expected to be around 10% in 2040

Table 7: Summation of future plans of capacity in different energy areas, adapted from (Raouz, 2015)

Technology	**Target**		
	Year	**Total installed quantity (MW)**	**Investment cost (US $) (Million $)**
Solar (thermal)	2015	480	251
Solar (thermal	2020	1500	786
Hydro	2020	402	251
Wind	2020	1000	200
Coal	2017	380	91.3

6.5.2.4. Oil shale scenario

The exploitation of national resources in Morocco would help the country to overcome its large foreign energetic dependency. This scenario represents the possibility of exploitation of domestic oil shale based on recent discoveries which would prevent possible sever consequences of global oil prices changes.

6.6. Morocco's CCS Infrastructures Study

6.6.1. Purpose

The Moroccan GHG's mitigation study conducted by Kanudia aims at representing the national energy system and the implementation of Carbone Capture Storage (CCS) infrastructures in one technical-economic model using the MARKAL-TIMES model of Morocco, Portugal and Spain considering geographic boundaries.

6.6.2. Scenarios

The model used sets of half a million variables and equations taking into account country regions and sub-regions interactions in several ways in order to meet GHG's mitigation targets.

The main drivers of the model are:
- Economic growth
- National mitigation levels
- Storage capacities
- CCS availability
- National CO_2 pipelines networks
- Possibility to transport across country borders.

The scenarios of this study are shown in the Table 8.

7. DISCUSSION

In this study, different energy modeling tools were presented with descriptions and indications of their main characteristics, approaches and behaviors taking into consideration a classification based on models functional properties (simulation, optimization and accounting models).

The main qualities of energy systems in developed countries consist in the fact of that supply often matches demand and electricity transport rarely produces significant failures. It is also clearly observed that energy policies provide better circumstances to the development of the electric systems in rural arias (Urban et al., 2007).

To the contrary, the energy systems of developing countries such as Morocco we face the following issues:

Table 8: Scenarios definition for the TIMES-COMET model, adapted from (Kanudia et al., 2013)

Descriptive name	GDP Growth	Mitigation level (%)	Storage Potential	National Routes	Cross-Frontier
Set 1: Emission side					
Conservative CCS	High	40	Low	Gas	Nat
High Mitigation	High	80	Low	Gas	Nat
No-CCS	High	40	-	-	-
Low Economic Growth and High Mitigation	Low	80	Low	Gas	Nat
Set 2: Transport and storage infrastructure side					
Conservative CCS	High	40	Low	Gas	Nat
Cross-Frontier	High	40	Low	Gas	Reg
Free Routes	High	40	Low	Free	Nat
Optimistic Storage	High	40	High	Gas	Nat

- Transition from traditional to modern economics: The country is recently in a transition from an agriculture based economy to a new industrialized economy and several projects took place e.g. Tanger Med, connecting to the European electric grid through Spain, aircraft construction etc.
- Integration of variable renewable energies: In Morocco, hydro-thermal models based on Load Duration Curves (LDC) were often used in a period when integration of RE was still new to the country and the environmental balance was not a predominant concern. On one hand, this type of models didn't require high computational effort but on the other hand load synchronization wasn't guaranteed and the integration of ER couldn't match this type of modeling.
- The need for a smart grid in Morocco: Taking into account the geographic location of Morocco, the integration of the country's network in wider intercontinental connections that could link Europe to North Africa and the Middle East remain an important project that could see the light in the current century. In order to be ready to this kind of international strategic projects, the Moroccan grid should be more flexible in terms of intelligent communication within the network which could be realized thanks to smart grids.
- Multi-Agent approaches: Nowadays, micro-grids open a large horizon of opportunities to solve current issues of most energy systems and specially those of developing countries. Given the distributed nature of these types of smart energy systems characterized by the presence of a large numbers of communicating and decision making actors, the multi-agent systems paradigm remains the most adequate mean to cope with the integration of such complex systems.

8. CONCLUSION

One of the most efficient aspects of optimization models rests in the ability to ensure the enlargement of the solutions search space using many integrated types of analysis adding more flexibility and diversity in terms of scenarios generation but still, this type of models is not the perfect tool for simulating real time behaviors of energy systems.

On the other hand, simulation models are not explicitly concerned by optimality but the amount of required data can be time consuming in a negative way and can produce redundancies leading to controversial behaviors. In the meantime accounting models don't require much data to create their scenarios but their ability to provide optimal solutions in terms of least cost for technologies investments needs major improvements.

The optimization of the integration of renewables in the MOREMix project requires high temporal resolution in order to verify its compatibility with the real curve load. Additionally, the study of CCS infrastructures of Kanudia proved the flexibility of the technology in terms of coherence with the transport systems such as pipeline networks but Morocco still has to invest in new technologies in order to limit emissions at the sources.

The integration of renewable energies in Morocco compromises its economic stability also as its social activities and behaviors. But in the other hand it has the power of changing the Moroccan way of thinking towards its environment and its economic progress.

Taking into account these differences, a suitable model for Moroccan energy system should include the ability to deal with its particularities and strategy to achieve governmental targets (installed capacities and time lines) such as the increase of the renewable contribution to power generation and also has to respect time horizons (the horizons of 2020, 2030 and 2050).

Another aspect is that of the impact of energy policies and the need to adopt new laws aiming to cope with international standards of investments in the energy sector.

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