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The use of model based energy scenarios to support policy development

In this text, "model based energy scenarios" is used about computer-generated results describing potential developments of the electricity system in a country or a region. The methods and the assumptions must be transparent and the results must be understandable and verifiable. Scenarios can be input driven or goal driven.

Computer models as tools

It has an analytical purpose, when we use computer models to describe potential futures. The idea is not that the computer shall make policy. The result from a group of scenarios will help to qualify the political discussion.

Electricity systems are large systems where interaction take place though synchronous AC systems, e.g. covering distances of more than 2,000 km (e.g. from West Denmark to Portugal). The balance between demand and generation must be maintained at the level of microseconds and extra input of electricity at one point must be balanced by reducing generation elsewhere. These features makes it relevant to study the impact of new technologies like wind and solar power in models covering large areas, e.g. large synchronous areas.

Figure 1. Transparency requires that all input data is published and can be reviewed, and that methods are documented and are easy to understand. If this is fulfilled, results can be fully understood.

With a transparent set-up the discussion can change from "for or against" a certain technology to a discussion about the assumptions. If parties can agree on the assumptions (including input data) and understand the methods, then consensus about the results is realistic.

Input data

Input data includes data about future values, e.g. the future cost of fuels, the future investment costs of technologies, including generation technologies like wind power, PV and nuclear power. Such data may be debated and important sources can be *technology catalogues* e.g. from the International Energy Agency, U.S. Energy Information Administration or the Danish Energy Agency[1].

[1] IEA, Technology roadmaps: www.iea.org/roadmaps/
IEA, World Energy Outlook: www.worldenergyoutlook.org/
IEA and NEA (Nuclear Energy Agency) (2015): Projected costs of generating electricity.
Future investment costs: www.worldenergyoutlook.org/weomodel/investmentcosts/
U.S. Energy Information Administration (EIA):
www.eia.gov/analysis/studies/powerplants/capitalcost/pdf/updated_capcost.pdf
Danish technology catalogue: www.ens.dk/node/2252
Irena Mexico study. See page 92 for technology costs:
www.irena.org/DocumentDownloads/Publications/IRENA_REmap_Mexico_report_2015.pdf

Technology type	Available (Year)	CAPEX incl. IDC ($M\$/MW_{el}$)	Fixed O&M ($\$1000/MW_{el}$)	Variable O&M ($\$/MWh_{el}$)	Efficiency (%)	Technical lifetime (Years)
Steam Coal - Subcritical	2020-2034	1.8	45	3.8	35%	30
Steam Coal - Subcritical	2035-	1.8	45	3.8	35%	30
Steam Coal - Supercritical	2020-2034	2.2	63	5.3	40%	30
Steam Coal - Supercritical	2035-	2.2	63	5.3	40%	30
CCGT	2020-2034	0.8	25	2.1	59%	30
CCGT	2035-	0.8	25	2.1	61%	30
Gas turbine	2020-2034	0.4	20	1.7	38%	30
Gas turbine	2035-	0.4	20	1.7	40%	30
Geothermal	2020-	4.3	43	3.1		30
Medium Speed Diesel (MSD) Engine	2020-	1.6	22	1.8	45%	30
Low Speed Diesel (LSD) Engine	2020-	2.4	10	0.8	46%	30
Nuclear	2020-	5.7	140	0.0	33%	60
Solar PV	2020-2034	1.9	24	2.0		25
Solar PV	2035-	1.5	23	1.9		25
Wind - onshore	2020-2034	1.5	22	3.7		20
Wind - onshore	2035-	1.4	21	3.5		20

Figure 2. Example of technology data about future investment costs etc. from IEA. Data used for the 2014 Master Plan for Eastern African Power Pool. Note that variable fuel cost for e.g. coal or natural gas units typical is in the order of US \$ 50-100 per MWh_{el}. In this perspective, the shown O&M costs are relatively small.

Future data about fuel and technology costs are intrinsic uncertain and it can be relevant to use scenarios to show the impact of alternative values, e.g. with higher and lower values. Such sensitivity analyses can illustrate the robustness of results.

Methods: Optimal dispatch and optimal investments

The need to balance electricity system in the short time scale and the possibility to import and export electricity over long distances makes the dispatch problem suitable for model studies. Optimal dispatch of generation in large systems with limited transmission capacity requires the use of computer models.

Optimal dispatch is well defined: If the marginal generation costs is known for each generator, one solution will have the lowest total costs. The marginal cost of traditional power plants is defined as the fuel price divided by the efficiency. Wind and solar power have high investment cost, but marginal generation costs close to zero. These technologies will produce when the sun is shining or the wind is blowing[2]. Hydro plants with reservoir also have a low marginal cost. However, the optimal dispatch of such hydro plants must consider that the units are restricted by the inflow of water. Optimal dispatch of hydropower means optimal use of the available water across a longer period, e.g. a

[2] In situations with large *must produce* generation the electricity price may be negative and it is relevant to curtail wind and solar.

year. The optimal use of hydropower is to optimise (maximise) the value of the electricity generated.

In the simplest set-up, each hour is considered independently, start-up and stop costs are ignored. These costs could be included in the modelling to make the dispatch more realistic, since power plants that are running in one hour are likely to continue generation in the next hour. Using such *unit commitment costs* will increase computer time and the more detailed dispatch is often not needed in studies of future situations as the change in yearly cost may not change significantly. Simulation to be used in the daily operation can be more detailed than in future scenario analyses. In future scenario analyses, unit commitment may not be applied and representative weeks can be included instead of the full number of hours of each year (8760).

Scenarios may include model based investments in generation and transmission. Model based investment may take place in a simplified way, e.g. the model may invest if the annualised costs of investments is less that the benefit in the same year. The set-up can be called myopic because the future use of the investment is not included.

Scenarios

Scenarios can be defined to support the political discussion. They are not meant as predictions, but as possible futures. Models are simplifications of real life and the absolute results may not always be accurate. However, the difference between two scenarios may be more accurate, e.g. changing an input parameter will give differences in dispatch as well as investments.

The reference may be a frozen policy scenario: All framework is as today. Any planned change is ignored. Alternatively, it may include expected changes in the framework. In Figure 3 a set-up with 21 scenarios is illustrated. In the case all scenarios are one-step away from the reference (one parameter is changed). In this way, it is easy to analyse even this high amount of scenarios. In other studies, scenarios must be analysed is steps (see Figure 4).

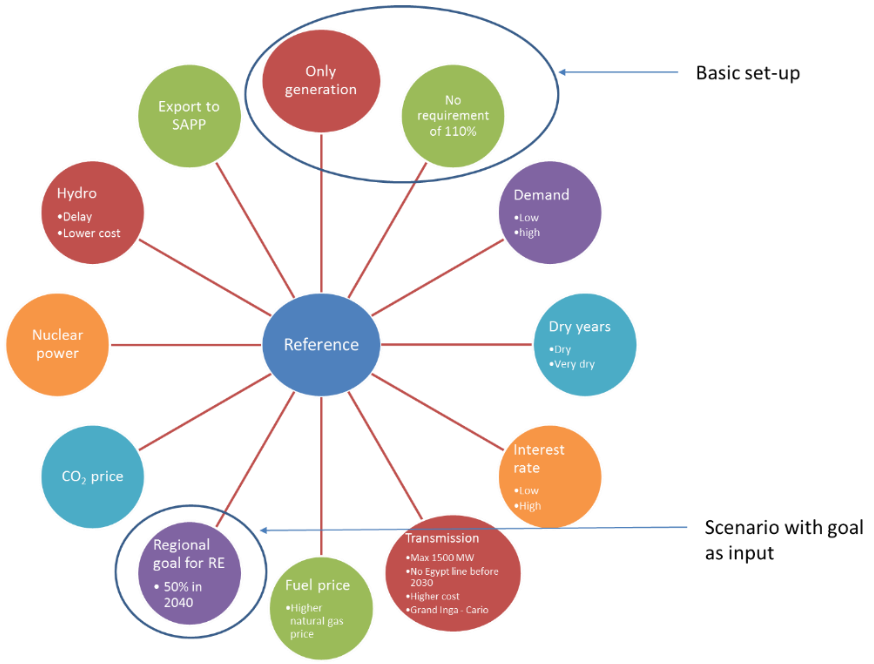

Figure 3. A reference and 20 alternative scenarios:
17 parameter variations (e.g. about demand, hydro inflow or interest rate)
1 goal scenario (50% renewable energy in 2040).
2 basic variation (Only generation, where no investment take place in transmission, and No requirement of 110%, where the requirement that each country should have local generation capacity corresponding to minimum 110% of the peak demand),

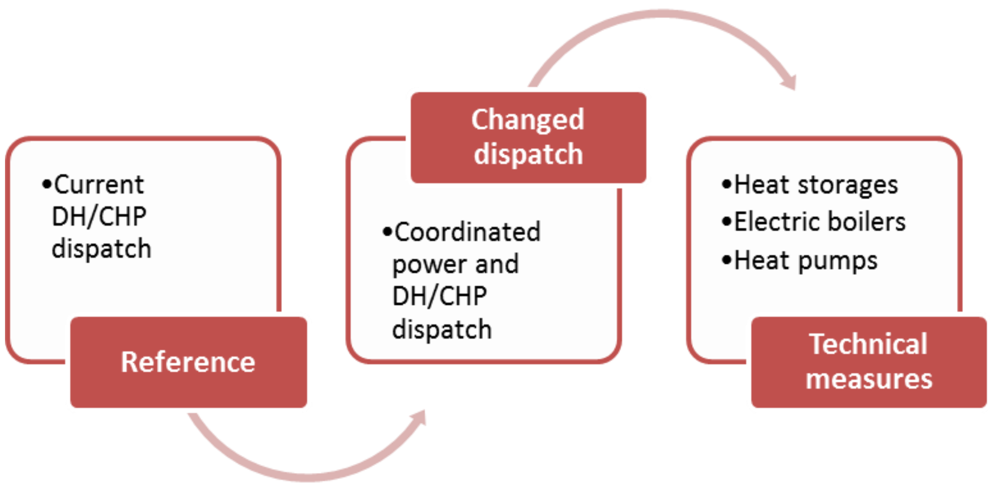

Figure 4. A two-step approach of the design of five scenarios: Reference can be compared with Changed dispatch and this can be compared with three scenarios where one technical measure is introduced. In the reference the current dispatch, include some specific tariffs that do not represent the marginal cost of the plants.

Results

Model results may include:

- Electricity generated (MWh). This may be per generator for each hour. These results can be aggregated per type of technology (coal, wind, solar, etc.) and to yearly values.
- Investment (MW) in generation and transmission. Investment may be shown per area, per type of technology or may be aggregated.
- Economic data, e.g. operating costs (fuel and maintenance), unit commitment costs, investment costs. Data may be shown per type of market participants (e.g. end-users, generators and TSO). In addition, externalities can be included. In many cases, only the total costs may be presented.

Discussion

The model based scenario results have been used in many studies. The benefit of this approach is the more detailed analyses. The value of a specific technology, e.g. wind power, is described for the specific location and with a specific capacity. Other approached, as the levelised cost of electricity, LOCE, compare technologies in more general terms.

Distribution of costs and benefits can be illustrated with the models, e.g. across countries or regions or between end-users and generators.

Goal driven scenarios can illustrate the total costs of e.g. requiring a certain amount of renewable energy or a specific reduction of the CO_2 emission.

In this text, focus has been on model-based scenarios. Please note that the scenario technique can be used in many ways. In some cases scenarios is used to describe possible futures in a qualitative way, see ENTSO-E (2015), Danish Energy Agency (2014) and EcoGrid (2009).

Appendix: Possible scenarios to illustrate the options for the Mexican electricity system

Based on the discussion on the workshop and meetings at SENER 7 – 10 September 2015, a number of scenarios is formulated.

- **Reference**: Prodesen, SENER (2015). The reference is modelled in Plexus and the goals for clean energy are included as restrictions. Total costs (fuel costs, investments costs and other O&M costs), New capacity (generation and transmission) and CO_2 emission can be listed and used as a reference for the following scenarios:

- Same, but with **strict definition of committed investments**. A strict definition could be only to include future plants, where construction has begun. In all other cases it would be possible to change direction without huge costs. This would give the model more room to invest in least cost options. The idea is *not* that no other parameters than costs is important, but to highlight what can is possible with the cost perspective.

- Reach the same CO_2 emission as the Prodesen-reference (year by year) by use of a **CO_2 price** instead of the goals for clean energy. This will give lower total costs, since possibilities in the tradition sector (oil, coal, and natural gas) can also be used to reach the goal. The CO_2 price should be understood as a planning price – not necessary as a CO_2 tax. The central issue is that investment and operation is done as if CO_2 had a price.

- **How to meet the conditional CO_2 target?** The unconditional CO_2 target is 22% reduction of the baseline (973 Mton) in 2030. The conditional goal is a 36% reduction. How the electricity sector should contribute to this has not been decided. For the purpose of this analyses it could be analysed how the sector could reduce its emission with 18% compared to the prodesen-reference (the 36% is equal to 623 Mton compared to 759 Mton for the 22%, equal to 18% less).

- **Focus on power exchange** North/South. The reference has (with good arguments) focus on the Mexican system. To illustrate the possibilities with more interaction with nearby countries this scenario could study the possible interaction with USA, Guatemala, Belize, Honduras, El Salvador and Cuba. Exchange with others areas can be attractive if there is a difference in the marginal price of generation electricity. Whether this is attractive to exploit is related to the costs of the needed interconnectors (AC/DC and distance) as well as the size of the other systems. This scenario could also include a sub-scenario where a part of a strong expansion of wind generation in Baja California could be exported to California, USA.

In combination of these scenarios it was also suggested to include parameters like:

- A **higher natural gas price** (sensitivity analyses)
- A **lower electricity demand**.
- The impact of the ongoing **reform**.

Other scenarios can have the focus on the development of renewable energy:

- **Focus on wind power expansion.** Given the detailed input the model can optimise both the location and type of wind power turbines. By the type is meant the ratio between rotor area and the generator size. Low wind turbines has a relative smaller generator compared to high wind turbines. The extra investment in high wind turbines (the larger generator) may not always be optimal. The extra generation that is possible with the larger generator only occur at high wind speeds – and in some cases the marginal electricity in these cases is low. Instead of locating all wins turbines in the best location – the model will balance the potential with the marginal benefits – on location and on turbine type.

- A scenario with **strong expansion of de-central generation**, e.g. roof-top PV and micro hydro. In some countries the de-central generation technologies has reached a significant volume (e.g. Germany and Denmark). This scenario can illustrate the impact of such a development in Mexico (e.g. consequences for the investment in generation and transmission, as well at the marginal reduction in fuel and emissions). The economy and the likelihood of such a development could also be analysed.

- A scenario with **strong expansion of biomass** based generation. This could include a maximum use of residuals, like residuals from coconuts, coffee and bagasse. Generation from biomass based generation can be dispatched (in contrast to wind and solar) and can play a positive role in high RE scenarios.

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Examples of scenario studies:
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www.ea-energianalyse.dk/themes/energy_scenarios.html

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