GUIDELINE: PREDICTING EFFECTS OF RENEWABLE ENERGY INTEGRATION

Abstract

The goal of this guideline is to present an introduction to the methodology of predicting the future energy system behaviour and provide a five-step guide on analysing the integration of renewable energy and its effects on the current energy system. Following these steps you will analyse the effects (technical, economic, environmental, etc.) that renewables bring to the existing system. The results will enable the utilities, policy makers and design engineers to take appropriate actions to ensure an efficient, reliable, and predictable operation of the system.

What is it?

An optimal design of the system that integrates renewable energy requires a balanced combination of technologies. This document aims to guide the utilities, researchers or engineers towards designing an optimal configuration of their (renewable) energy systems. Based on presented recommendations you should design energy systems, which will suit your objectives and operate reliably at predicted costs. Reliable supply and anticipated costs of (renewable) energy should facilitate the engagement of energy consumers in renewable energy adoption.

Conventional energy systems can usually withstand the integration of smaller shares of renewables. Nevertheless, increasing the share of renewable capacity escalates technical problems (such as unpredicted voltage levels and energy flows, inefficient ramping of power plants, congestion, etc.) in energy systems. Most notably the intermittency of renewable energy production from sources such as solar PV and wind cause a mismatch between energy production and demand. Computer simulations of the physical behaviour of an energy system with a large share of intermittent renewables can provide insights its technical and economic feasibility (time frames of the analyses may vary from daily to 20 years, or more).

Figure 1 Renewable energy systems more and more include intermittent solar and wind technologies (source: www.homerenergy.com)

When to use?

You can use this guideline, for example, if you are part of a utility that is planning to increase the share of renewable energy in your future energy system, especially if you are trying to assess the link between large renewable capacities and the mismatch of energy production and demand within a grid (or its part). Utilities might find the following tools to best suit their needs: GTMax, PERSEUS and ProdRisk (Connoly et al, 2010). Engineering companies could find this guideline useful to design small energy systems, such as hotel complexes on islands or energy self-sufficient communities. This guideline (methodology) has been used also by researchers, consultants and policy makers.

Designing tourist complexes on islands (INEA, SI)

Electricity supply of a tourist complex in Cabo Verde was designed by using the 5-step methodology discussed in this guideline to define the optimal system configuration for a private investor. Due to high prices of electricity, low power quality and frequent grid failures (black outs) in Cape Verde, efforts were put into mitigation of negative effects using available renewable energy sources (RES). Cape Verde's geographical location and weather patterns enabled utilization of solar and wind energy. Two different scenarios have been analysed: grid only system (served as a reference) and grid connected renewable energy system, using solar and wind energy (new conceptual system design). The results of using computer simulations have enabled a design where 80% of electricity demand was supplied by RES. Due to constant wind speeds the favourable design included only wind turbines, while designs with photovoltaic panels have not been found economically efficient. Using the described methodology has also helped the consulting company to expand their professional services while solving the technical limitations of electricity supply and engaging smart customers/ tourists in the eco-tourism sector.

Proposing Danish alternative energy plan (IDA Energy Plan 2030, DK)

An example of this is the Danish Society of Engineers, which has conducted a comprehensive analysis based on the step-by-step methodology described in this guideline. They have presented the alternative plan of renewable energy integration in a document entitled the Danish Society of Engineers' (IDA) Energy Plan 2030 (IDA, 2006). The results have been presented to the government and have (likely) contributed to the Danish national pro-renewable energy focus. The Energy Plan 2030 contains 11 vital recommendations for Danish energy policy that must be implemented if the visions presented in the plan are to be realized. The report's most important conclusion is that the development of a renewable energy system is both technologically and economically favourable. But this development requires political will and a marked change in the course of energy policy,

More information: http://www.fritnorden.dk/nf2007/energyplan2030.pdf

The interventions described below in this guideline can be primarily adopted in the first stages of project and/or product development, i.e. in the planning phase. You should use the results of the analysis performed by following the 5 steps of this guideline as:

- For grid operators: a way to allocate benefits (less CO_2 production, less fossil energy sources consumed, etc.) and disadvantages (higher costs of energy, more complex system designs, etc.) that integrating renewables would bring to your grid,
- For investors/utilities: a base for assessing future investments in renewable energy,
- For engineers/researchers: a starting point for designing (renewable) energy systems.

What do you need to do?

We advise you to pursue an optimal design of the entire energy system (not only of individual components). An optimal design is defined by a correct combination of technology types and their capacities. Results of calculations vary with respect to the structure of the existing system, required specifications, restrictions and regulations, availability of renewable energy sources, price of technology and costs, etc.

The renewable energy integration can be approached in various ways such as experimental, empirical and a design based on mean values (average, peak requirements, etc.) and numerical simulation. The latter is gaining in relevance, since it enables a relatively thorough and accurate approximation to the actual system performance and will also be described in this guideline. The numerical tools for renewable energy design can be diverse (in calculation algorithms, time frames of analysis, granularity, etc.). Nevertheless, they all follow the same procedure of analysis, which is presented in this guideline as a step-by-step guide (see Figure 2).

1. Prediction of energy consumption types and profiles

The first step to take would be to define energy consumption in the system – this could be electrical energy only, but also energy used for heating and transport. In general energy consumption is defined by a load profile (averaged consumption with respect to the time). More accurate results are achieved with a lower granularity of inputs and outputs (for example an hourly period over the course of one year rather than daily averages). The shorter time scales reveal the dynamic properties of the system, like the number of operating hours, fuel consumption, availability of renewable energy sources, load factors, full load hours, etc. These indicators reveal otherwise hidden information on dynamics of energy system performance.

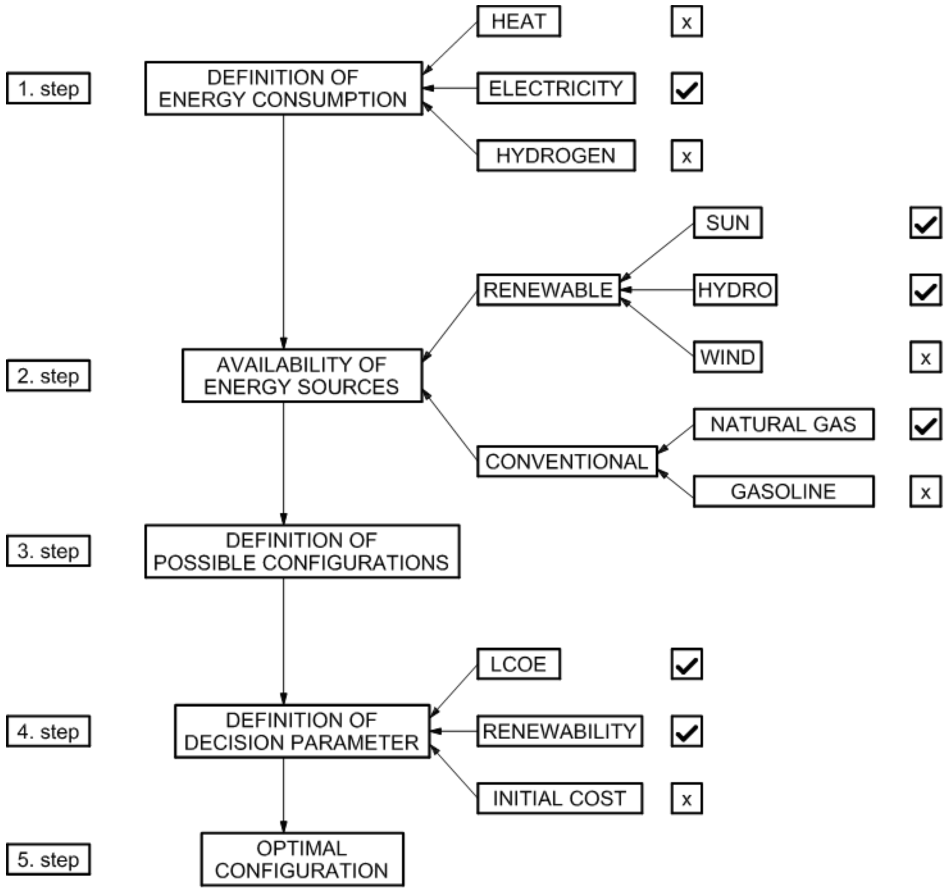

Figure 2 Example energy system design procedure (Lacko et al, 2006)

2. Availability of energy sources

After having quantified the demand it is necessary to quantify the potential supply of the energy system. Energy sources can be conventional (natural gas, gasoline, coal etc.) and renewable (sun, hydro, wind, biomass, biogas, etc.). For each individual energy source the available capacity, availability and fuel price have to be defined, optionally location could be taken into account. Existing infrastructure should also be included (e.g., distribution grids, storage, etc.) by including investment or operating costs. In order to allow for an estimation of the amount of renewable energy available from each source the following variables need to be added to the model, usually as hourly averages (also monthly, daily):

- Wind energy: speed
- Solar:
  - Global horizontal radiation (the total amount of solar radiation striking the horizontal surface on the ground)
  - Extraterrestrial horizontal radiation (the radiation hitting a horizontal surface at the top of Earth's atmosphere)
  - Clearness index (a dimensionless number between 0 and 1 indicating the fraction of the solar radiation striking the top of the atmosphere that makes it through the atmosphere to strike the Earth's surface)
- Water: river's volumetric water flow rates
- Biomass: price of fossil and bio-fuels (availability of fuels is usually considered unlimited in the models).

3. Definition of possible configurations

The goal of this step is to search for the available technologies on production and consumption side that are technically acceptable by an investment project. The result is a list of potential technologies with respect to available (renewable) energy sources, where one source may feed several different technologies (e.g. photovoltaic and solar-thermal panels can both be powered by solar energy source, etc.). Several commonly analysed technologies are listed in Table 1. Besides listing the technologies you should also define possible rated power of each technology. Furthermore, you should outline the operating characteristics, such as fuel curve, energy efficiency curve, maximum or minimum power limits, of the energy production units, as well as define their economic parameters (e.g. cost of investment, cost of operation, cost of maintenance, etc.).

Table 1: List of common technologies by energy source

Energy source	Technology (power plant)
Wind energy	Wind turbine
Solar radiation	Photovoltaic panels, solar thermal panels (heat only)
Water	Conventional hydro-(dam), run-of-river hydro-(diversion), pumped-storage hydro power plant
Coal	Coal thermal-, combined heat and power
Natural gas	Gas thermal-, combined heat and power, gas boiler (heat only)
Nuclear	Nuclear thermal-, combined heat and power
Oil	Oil thermal-, internal combustion engine gen-set, combined heat and power, boiler (heat only)
Geothermal Biomass	Geothermal power plant, geothermal heat plant (heat only) Boiler
Electricity*	Heat pump (heat only), electric (resistive) heater (heat only)

** not an energy source, but used as an energy input in the process of designing energy systems*

4. Definition of decision parameters

The decision parameters describe the target goals, which the end user wants to achieve with the selected renewable system configuration. Along with the most common parameter (energy cost), the decision parameters could also be: renewable energy ratio, amount of CO_2 emissions, fuel (primary energy) savings, operating and maintenance costs, initial cost, etc.

5. Optimal configuration

There are numerous tools available for such exercises, each specialising in a specific type of analyses. The selection of the appropriate tool is based on the decision parameters, type of analysis (as described in Table 2) and your objectives. The energy tool types are presented along with a list of corresponding software tools. Depending on the character of your optimisation goal you should select the suitable software tool. Different options of optimisation goals to choose between are simulation, scenario, equilibrium, top-down, bottom-up, operation optimisation and investment tools, or their combinations. For detailed information on the process of choosing the appropriate tool see (Connoly et al, 2010).

Result of such a numerical simulation should consist of an optimal system configuration (mix of technologies and their capacities), accurate operating characteristics (number of starts/stops of devices) and energy production and consumption data, for example exact operating hours and load factors. Although the listed energy tools consider many technical characteristics, these mostly do not include specialised smart grid functionalities, such as load shifting potential “finders” (as described in the S3C tool How to estimate your load shifting potential) or other demand side management options. Those present an option for future development of the tools or imply the need for additional external (custom made) specialised "add-in" smart grid algorithms.

Table 2: Energy tools listed by type (Connoly et al, 2010)

Tool	Type						
	Simulation	Scenario	Equilibrium	Top-down	Bottom-up	Operation optimisation	Investment optimisation
AEOLIUS	Yes	–	–	–	Yes	–	–
BALMOREL	Yes	Yes	Partial	–	Yes	Yes	Yes
BCHP Screening Tool	Yes	–	–	–	Yes	Yes	–
COMPOSE	–	–	–	–	Yes	Yes	Yes
E4cast	–	Yes	Yes	–	Yes	–	Yes
EMCAS	Yes	Yes	–	–	Yes	–	Yes
EMINENT	–	Yes	–	–	Yes	–	–
EMPS	–	–	–	–	–	Yes	–
EnergyPLAN	Yes	Yes	–	–	Yes	Yes	Yes
energyPRO	Yes	Yes	–	–	–	Yes	Yes
ENPEP-BALANCE	–	Yes	Yes	Yes	–	–	–
GTMax	Yes	–	–	–	–	Yes	–
H2RES	Yes	Yes	–	–	Yes	Yes	–
HOMER	Yes	–	–	–	Yes	Yes	Yes
HYDROGEMS	–	Yes	–	–	–	–	–
IKARUS	–	Yes	–	–	Yes	–	Yes
INFORSE	–	Yes	–	–	–	–	–
Invert	Yes	Yes	–	–	Yes	–	Yes
LEAP	Yes	Yes	–	Yes	Yes	–	–
MARKAL/TIMES	–	Yes	Yes	Partly	Yes	–	Yes
Mesap PlaNet	–	Yes	–	–	Yes	–	–
MESSAGE	–	Yes	Partial	–	Yes	Yes	Yes
MiniCAM	Yes	Yes	Partial	Yes	Yes	–	–
NEMS	–	Yes	Yes	–	–	–	–
ORCED	Yes	Yes	Yes	–	Yes	Yes	Yes
PERSEUS	–	Yes	Yes	–	Yes	–	Yes
PRIMES	–	–	Yes	–	–	–	–
ProdRisk	Yes	–	–	–	–	Yes	Yes
RAMSES	Yes	–	–	–	Yes	Yes	–
RETScreen	–	Yes	–	–	Yes	–	Yes
SimREN	–	–	–	–	–	–	–
SIVAEL	–	–	–	–	–	–	–
STREAM	Yes	–	–	–	–	–	–
TRNSYS16	Yes	Yes	–	–	Yes	Yes	Yes
UniSyD3.0	–	Yes	Yes	–	Yes	–	–
WASP	Yes	–	–	–	–	–	Yes
WILMAR Planning Tool	Yes	–	–	–	–	Yes	–

Do's and don'ts

- **Perform numerical analysis.** Computer analysis enables more detailed calculations. Such results will provide you with much more information on behaviour of the system you are considering to implement.
- **Take time to learn your tool.** Most tools, which are presented in Table 2 offer online tutorials and libraries of best practice examples or training exercises on their websites. Some tools can be learnt for basic usage within a week.
- **Use accurate input data.** The analysis will be as accurate as the input data, therefore spend some effort to obtain good quality data.
- **Conduct sensitivity analyses.** Analyse the sensitivity of the results to different objectives. It will provide you a broader understanding of your energy system.

Further reading

- Connolly, D., Lund, H., Mathiesen, B. V., Leahy, M. (2010). A review of computer tools for analysing the integration of renewable energy into various energy systems, Applied Energy 87 (2010), p. 1059-1082.
- Lacko, R., Pirc, A., and Mori, M. (2010). *Step by step numerical approach to a self-sufficient micro energy system design*, Int. Journal of Engineering Research and Applications 4 (2014), pp. 1-10.
- The Danish Society of Engineers (IDA) (2006). The Danish Society of Engineers' Energy Plan 2030 (2006), summary available (in English) in February 2015 at http://www.fritnorden.dk/nf2007/energyplan2030.pdf