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Methodology to Elaborate a Roadmap for a 100% Renewable Energy Mix in Isolated Grids Using GRIDSOL's SRH-M

Jorge Servert[1,a)], Eduardo Cerrajero[1], Robert Valencia-Chapi[1], Juliette Marti[1], José Estebaranz[2], Eirini Stavropoulou[3], Maria Kourasi[3], Aris Dimeas[4], Mattia Baldini[5]

[1]*Investigación, Desarrollo e Innovación energética S.L. (IDIe). C/ Segre, 27. 28002, Madrid, Spain.*
[2]*Cobra Industrial Plants & Energy. (COBRA). C/ Cardenal Marcelo Spínola, 6. 28016, Madrid, Spain.*
[3]*Hellenic Electricity Distribution Network Operator (HEDNO). Perraivou 20 St. 11743, Athens, Greece.*
[4]*National Technical University of Athens (NTUA). Iroon Polytechniou 9 St. 15780, Athens, Greece.*
[5]*Technical University of Denmark (DTU). Anker Engelunds Vej 1 St. 2800, Lyngby, Denmark.*

[a)] Corresponding author: jservert@idie.es

Abstract. A fully renewable electricity sector is in our future but finding the path that minimizes the cost of this transition is no easy task. The GRIDSOL project has developed a methodology to prepare Sustainable Roadmaps of Energy Generation Systems (SRoEGS) [3], aimed at determining the best way for a region to reach a highly renewable generation mix, while taking into account a comprehensive set of conditions such as: security of supply, availability of land, use of water, etc. This methodology can incorporate in the decision-making process a wide range of additional inputs set by the stakeholders, assessing environmental, social and economic impacts of the development plans to ensure their sustainability from a holistic point of view. The results of a case study show that simply adding cheap renewable generation to the mix is good enough if the RE content target is low (up to 25%) but, if a truly significant RE fraction (over 60%) is desired, tailoring the deployment to the available resources and, most importantly, determining the storage requirements at the system level (i.e. developing larger, shared standalone BES facilities instead of including smaller ones in individual plants) helps keeping the costs to a minimum.

INTRODUCTION

During the last years, energy markets worldwide have started a trend towards decarbonization, increasing the installed generation power of renewable energy (RE) technologies such as photovoltaic (PV), wind, concentrated solar power (CSP), geothermal, and biomass. However, choosing the path to follow for this transition is not trivial, as it must find an equilibrium between grid stability, security of supply, cost of generation and cost of backup. This equilibrium depends on local factors such as demand profiles, availability of renewable resources, infrastructures, and policies, so each region must find the path that better suits its necessities.

Adding to this, each technology has its inherent advantages and disadvantages. PV and wind have led the development and installation of RE technologies worldwide, already reaching economic competitiveness against traditional fossil-fueled power plants in certain markets [1]. However, these Variable Renewable Energy sources (VRE) are hard to control, requiring backup technologies (such as storage and flexible generation) to guarantee grid stability. The long-term target of decarbonizing the electric sector will, therefore, require additional flexibility and dispatchability [2] from RE generation. Dispatchable renewables (CSP, biomass, geothermal) have the most desirable qualities of both previous groups, except the low cost (yet). Biomass, especially when using residual sources (waste-to-energy), can reach grid parity, but its size is usually limited by fuel availability.

The GRIDSOL project has developed a methodology to prepare Sustainable Roadmaps of Energy Generation Systems (SRoEGS) [3], aimed at determining the best way for a region to reach a highly renewable generation mix,

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while taking into account a comprehensive set of conditions such as: security of supply, availability of land, use of water, etc. This methodology can incorporate in the decision-making process a wide range of additional inputs set by the stakeholders, assessing environmental, social and economic impacts of the development plans to ensure their sustainability from a holistic point of view.

This methodology is supported by the Smart Renewable Hub Modeler (SRH-M), an optimizer tool developed in GRIDSOL's work package on "Modelling of non-dispatchable RES and Synchronous Generation in Smart Renewable Hubs", led by IDIe.

METHODOLOGY FOR SUSTAINABLE ROADMAPS OF ENERGY GENERATION SYSTEMS (SROEGS)

The driving element in the roadmap is the security of supply. In order to ensure that the energy mix determined by the SRH-M is adequate, a comparison between the hourly demand of the system and the hourly generation of the renewable and non-renewable plants is carried out, and a parameter of Firmness (understood as the fraction of the hours in a year where generation reaches at least 95% of the demand) is calculated [4].

Parameters of the Roadmap

Once the time horizon is selected (e.g. 2050), the following parameters are defined for each roadmap:

- Demand Scenario i.e. a forecast of the hourly demand of the system. As an example, these can be:
    - Base-case demand: evolution of demand is only affected by the evolution of demographics and energy efficiency [5].
    - Economy-driven demand: as above, but the evolution in the relevance of the economic production sectors (Primary, Secondary and Tertiary) is also considered.
    - Paradigm-changed demand: as above, but paradigm-changing elements (e.g. change in social acceptance of nuclear energy, electric mobility) are also considered.
- Business Scenario i.e. assessment of external factors that might affect the optimization of the energy mix and/or the expected cost of electricity for the consumers [6]. Some examples of this would be:
    - Cost of CO2 emissions and its evolution over time.
    - Mandatory quotas for certain technologies.
- Evolution of the existing generation park: phasing out of older plants and technologies.
- Other constraints: use of land or water, grid connection requirements.

The inputs data are summarized in Table 1. All values have been optimized for each of the different scenarios previously exposed.

TABLE 1. Input parameters.

	Nomenclature	Value	Unit
Total Power Installed	-	215 → 2066	MW
Wind Power	W	14 → 788	MW
Photovoltaic Power	PV	14 → 788	MW
Battery Energy Storage System Power	BESS	0 → 188	MW
Steam Turbine Power (CSP)	ST	0 → 115	MW
Fossil Fuel Power	FF	187	MW
Thermal Energy Storage	TES	0 →20	h
Solar Multiple	sm	0 → 2	-

Hypotheses

In this work, both investment (CAPEX) and operation (OPEX, fossil fuel prices) costs are considered constant in time.

The demand growth is assumed to be linear, taking into account both the Base-case population growth and simplified estimations for the adoption of electrical mobility (60% of replacement rate by 2050). The Fossil Fuel power is fixed, being its value the one currently on the island. The installed CSP power is constant upon time after its installation. The minimal Firmness value will be 95%.

Analyses Carried Out

Using the SRH-M software developed in GRIDSOL, in the selected location, the operation of the generation mix, either the existing one or the one optimized using SRH-M, is simulated (Fig. 1) and managed with the target of addressing the hourly energy demand profiles from the Demand Scenarios. The required investment program and expected costs of electricity are estimated.

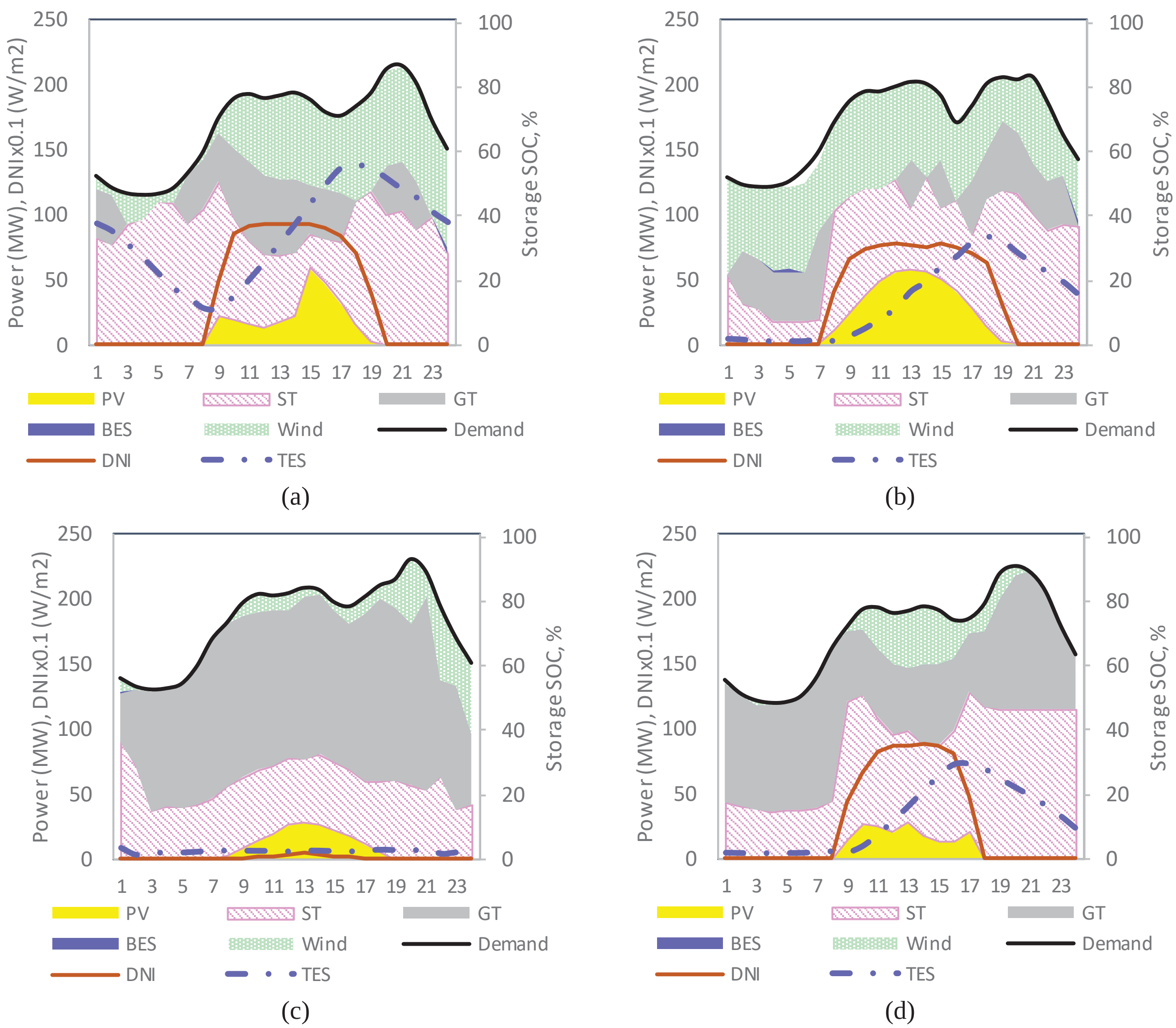

FIGURE 1. Production profile around each season's change day, current (2017) mix. a) Spring b) Summer c) Autumn d) Winter.

RESULTS AND DISCUSSION

In order to have a comparison reference, optimized energy mixes are compared against technology-driven variations, i.e. adding a single technology or combination of technologies to the current mix until the same RE content is obtained. In the following figures, the technology-driven variations are dismissed when the total RE curtailment exceeds 50%.

The results shown in Fig. 2 suggest that PV and Wind have the lowest initial cost but, when a large share of renewable generation is desired, time-of-delivery becomes an issue: unit costs of energy delivered to the grid increase due to curtailment, with batteries slightly moderating the cost escalation until, for very high RE content scenarios, the LCOE skyrockets. Combining both PV and Wind with batteries allows for a renewable content above 85% with an LCOE similar to the current scenario; an all-renewable system, however, requires a more comprehensive mix that GRIDSOL can define.

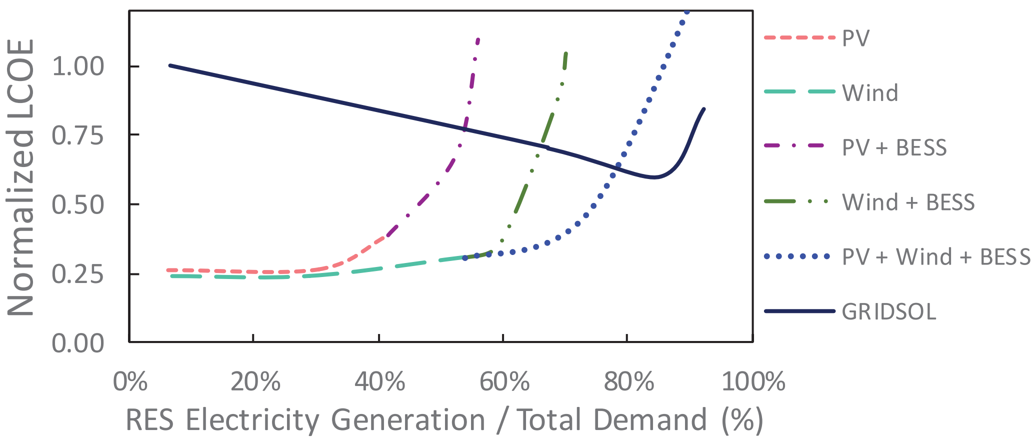

FIGURE 2. Normalized LCOE vs RES Electricity Generation / Total Island Demand.

Figure 3 shows the evolution of the system's LCOE when additional renewable power is added on a technology-based approach and compares it to GRIDSOL's optimization. With our approach, the combination of PV and Wind happens earlier, as well as the use of batteries, following the path of minimum LCOE. For higher RE content, CSP with TES plays a major role in keeping the overall system costs down.

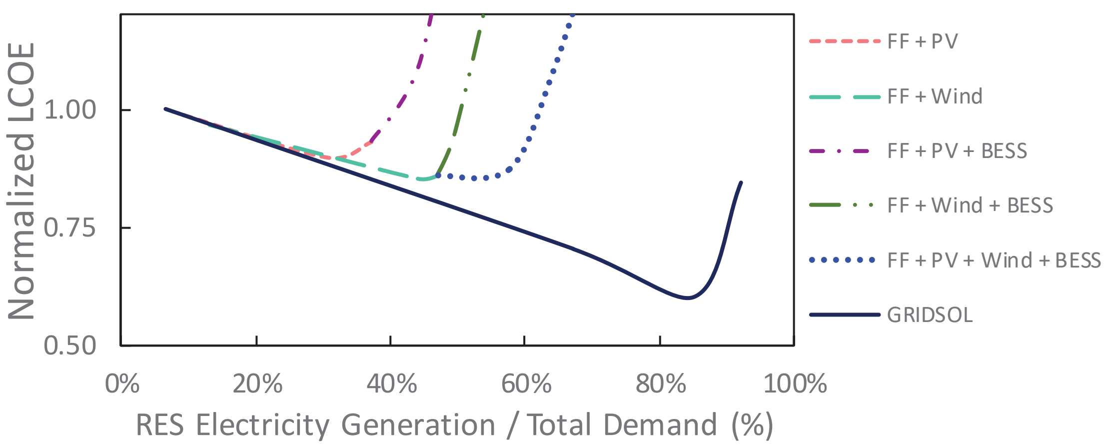

FIGURE 3. Normalized LCOE vs RES Electricity Generation / Total Island Demand.

Development of Roadmap for Future Demands

As the system evolves, driven by the changes in demand and technology improvements, the optimum energy mix changes too. The SRH-Modeler can define the lowest cost path by finding the optimum energy mix for each future scenario, using past and future results as boundary conditions. This way, both existing and new plants are assumed to finish their useful life before being replaced.

When carrying out the optimization for the different time horizons (2020, 2030, 2040 and 2050), the RE growth has been found to follow a logarithmical/sigmoid curve which denotes a saturation limit when the RE content approaches 100%.

Figure 4 represents our suggested evolution for the system, aimed at reaching 95% of renewable content by 2050, if the CSP is installed in 2020. Most new plants are PV and Wind, but batteries are included from early on, despite their cost, to take advantage from the cheap generation. CSP has been kept constant since 2020, assuming its development to be more complex in island contexts due to land availability limitations. Given the limited productivity of PV and Wind (in terms of kWh/kW per year), the total installed power required to serve the demand grows significantly, which might require improvements in transmission and/or distribution grids.

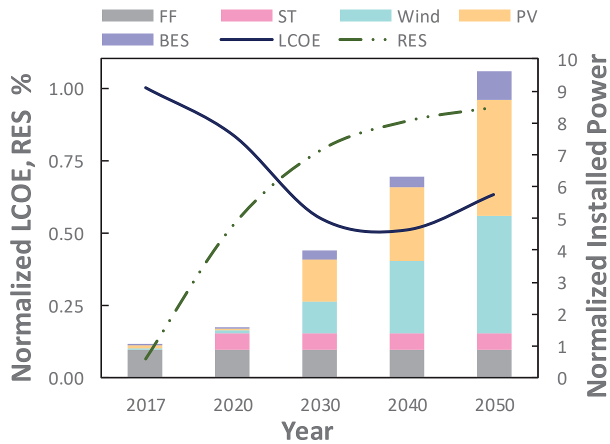

FIGURE 4. Normalized LCOE and Renewable Energy Percentage vs Year. The CSP would be installed in 2020.

Figure 5 represents our suggested evolution for the system, aimed at reaching 95% of renewable content by 2050, if the CSP is installed in 2030 instead of 2020. The main difference is that, for the Fig. 4, the slope of the LCOE curve was concave in the portion between 2017 and 2030, and in Fig. 5, for the same portion, the slope is convex. This is due to the use of PV and Wind instead of CSP in 2020, in the Fig.5 scenario.

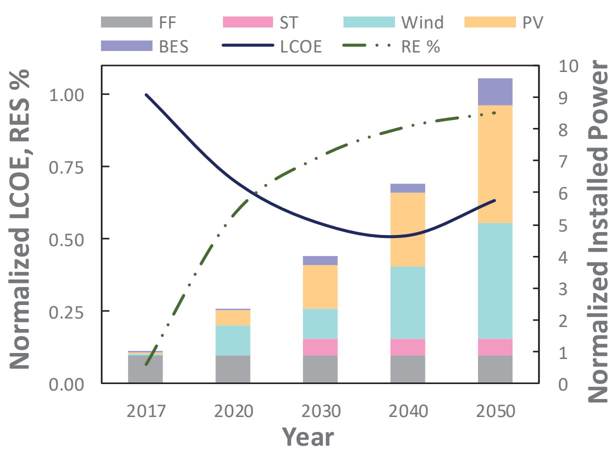

FIGURE 5. Normalized LCOE and Renewable Energy Percentage vs Year. The CSP would be installed in 2030.

It must be noted that, while the option represented in Fig. 5 has a lower cost than the one in Fig. 4, lowering the generation LCOE for this period, the total installed power increases more than twofold, and it is questionable whether the grid infrastructure would be able to keep the pace.

CONCLUSIONS

A fully renewable electricity sector is in our future but finding the path that minimizes the cost of this transition is no easy task.

In isolated grids, where security of supply is the key driving factor, GRIDSOL proposes to extrapolate the tools used for Smart Renewable Hubs, originally postulated as multi-technological hybrids inside a larger grid, to find the optimum energy mix that minimizes the cost of generation in the system.

Simply adding cheap renewable generation to the mix is good enough if the RE content target is low (in our case, up to 25%) but, if a truly significant RE fraction is desired, tailoring the deployment to the available resources and, most importantly, determining the storage requirements at the system level (i.e. developing larger, shared standalone BES facilities instead of including smaller ones in individual plants) helps keeping the costs to a minimum.

Neither the inertia necessities nor the technical constraints have been considered quantitatively; future works will include them in the analysis.

This sort of roadmap is a useful tool for policymakers, utilities or other stakeholders willing to assess the future development of isolated grids, or any other system where which security of supply is a must.

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