Zdravko Kravanja (Editor), Proceedings of the 26th European Symposium on Computer Aided Process Engineering – ESCAPE 26
June 12th -15th, 2016, Portorož, Slovenia

Renewable electricity integration at a regional level: Cantabria case study

Antonio Dominguez-Ramos[a], Charalampos Triantafyllidis,[b] Sheila Samsatli,[b] Nilay Shah,[b] Angel Irabien[a]

[a] *Unversidad de Cantabria, Chemical and Biomolecular Engineering, ETSIIyT, Avda. Los Castros, s.n., 39005 Santander, Spain*

[b] *Imperial College London, Centre for Process System Engineering, South Kensington London SW7 2AZ, United Kingdom*

Abstract

Sustainability Energy Programs (SEPs) determine the operative way in which the different energy vectors must be provided to final industrial, domestic or transport customers, as target demands for each final form of energy. In order to reduce the current huge regional electric deficit of the Cantabria region (northern Spain) due to imports from neighboring regions, a restructured, integrated system based mainly on wind on-shore power for 2020 is envisaged by the SEP of Cantabria. In this work, results of a Resource-Task Network model for the electricity grid have been developed as a previous step to feed the STeMES model for a better temporal resolution that can consider energy storage. A MILP optimization problem is solved for the minimization of the total cost of the electricity network capable of supplying the electricity demand in Cantabria for the 2020 horizon, using as a starting point the 2014 generation, transformation and distribution structure.

Keywords: electricity, grid, RTN, Cantabria, renewable energy

1. Introduction and context

In Spain, most of the executive power is in hands of the autonomous communities, and only few capabilities remain in the central government. In this work, the Autonomous Community of Cantabria, located in the northern coast of Spain, is selected as a case study. The Cantabria regional government is responsible for strategic energy planning. It can be appreciated in the document entitled “Sustainability Energy Programme for Cantabria 2014-2020” –SPEC– (Cantabria Regional Goverment 2014) that the region features a clear net electricity importer profile. The SPEC supposes the need to increase the installed power based on the contribution of different renewable energy sources especially by means of wind on-shore power. The predicted installed power is around 700 MW by 2020. Consequently, electricity imports are expected to be reduced from 3.272 GWh in 2014 to 1.565 GWh in 2020, which is around 52% reduction. On the other hand, few mentions in the SPEC of energy storage technologies are made, options that clearly can play a vital role to promote the sustainability of the energy system (Liu, Li et al. 2010). The stated problem is the current cost per unit of stored kWh. While pumped-storage power stations can help to diversify the power portfolio, technical space availability has become a serious issue in Spain.

Increasing the installed power of renewable energies such as wind or solar implies that many more peaks of power will appear. The possibility of storing those power peaks into different chemical products and fuels from the reduction of CO_2 is well-known (Centi, Quadrelli et al. 2013).

Therefore, it is necessary to develop a mathematical model capable of dealing with the planning of energy infrastructures to take into account the future needs of electricity and fuels. Because of the interest in the ER technology, the electricity network will be the focus of this work. One the main problems that arise with the planning of energy infrastructures is the geographical domain that is intended to be covered. Those models range from national to urban levels. However, as it happens in the SEPC, the real actions regarding energy infrastructures are taken on a regional basis. Even if regional programs are coherent with national targets which in turn does so with european ones, intrinsic regional considerations maybe not included. On the other hand, the temporal domain is also critical. Most of the reviewed models lack the appropriate temporal resolution which is critical when storage must be accounted for. Only the STeMES model is able to consider hourly operation over an entire year and simultaneously optimize the design of the network of conversion, storage and transport technologies (Samsatli, Samsatli 2015a). However, the initialization of this very model requires care and good quality data sets thus a model capable of taking into account simultaneously both the regional features for the geographical domain as well as the principal infrastructures in a yearly resolution is necessary according to the normal period of time derived from the previously mentioned described planning. The novelty of this work is the description of a model for an electricity grid network, which can help at the initialization of a more complex model. Anyway, because of the simplicity of the described model, it can be easily managed by technical staff in order to help at regional energy programming without the need of advanced skills.

The aim of this work is the development of a mathematical model with yearly temporal resolution to determine the prediction of electricity infrastructures (generation, transformation and transmission) to fulfill the targets of the SPEC. The obtained results can be fed to the hourly temporal resolution model STeMES (Samsatli, Samsatli 2015a). The model considers a Resource-Task Network approach (Samsatli, Samsatli 2015b). It has been completed for 2 scenarios: a) No restrictions on the imports b) a decrease of a yearly 10% in the imports from 2014.

2. Development of the electricity grid network model in Cantabria

Figure 1 depicts the Resource-Task Network (RTN) diagram for this work. Tasks are related to technologies for generation and/or transportation of electricity at different voltage levels. Boxes are used to represent technologies, while circles represent the 3 existing resources. In the left side of Figure 1, the 4 selected generation technologies produce the resource “electricity at 220 kV”. This resource can be transformed into “electricity at 400 kV” by means of the “substation HV/MV”. The resource “electricity at 220 kV” is transformed into the resource “electricity <220 kV” at the technology “substation MV/LV” to supply the demand (electricity is only consumed below 220 kV as long as the <220 kV grid is not modelled here).

1	3	5	8	6
	2	4	7	9
		10		

Figure 1. Distribution of the 10 shires in the Cantabria region

The storage of electricity is simulated thanks to the technology “pumped-storage”, which is responsible to produce “electricity at 220 kV” from “electricity at 400 kV. This way, installed power for this technology can be considered properly (no net power generation). The 2 types of transmission lines (single and double circuits) are responsible for the import/export of the resources “electricity at 220 kV” and “electricity at 400 kV” within neighbor shires. Cantabria was divided into 10 square cells (23 km per side) representing the 10 existing shires, for which an installed power (4 technologies and pumped-storage) and transformation capacity (2 technologies) was defined. The transmission infrastructure (4 technologies) between shires was also defined. Figure 2 shows the approximated distribution of cells within Cantabria.

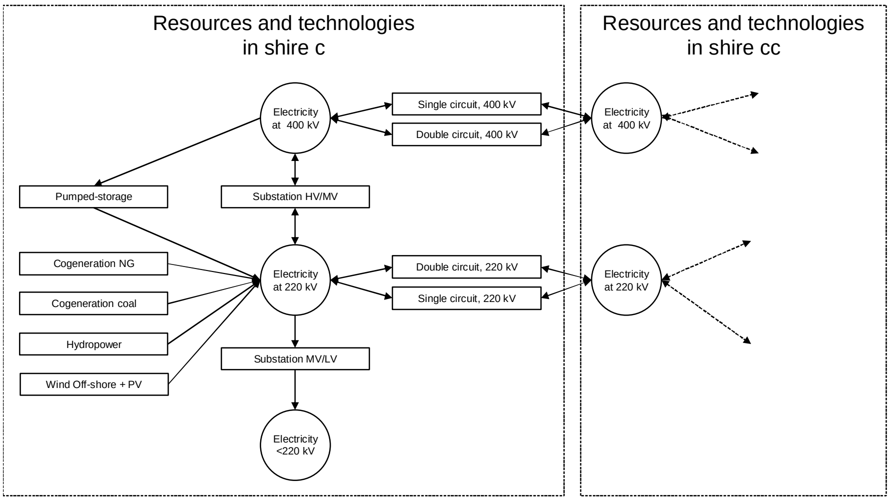

Figure 2. Resource-Task Network diagram for the connection of the 3 resources modelled in this work: electricity <220 kV, electricity at 220 kV, electricity at 440 kV between two neighbor shires c and cc. Only 2 resources are transported between shires

Because there is no data for the consumption of electricity on a shire basis, the total electricity demand in Cantabria for 2014 was used and disaggregated, so that in each shire, the consumption is proportional to the population (62% of the population is concentrated in shires 4 and 5). Table 1 shows the installed power and transformation capacity in each shire for 2014 (Cantabria Regional Goverment 2014).

3. Mathematical model

GAMS v24.2.3 was the selected platform for the RTN model. This mathematical model is formulated so it can be solved as a MILP optimization problem using CPLEX. The objective function is a total cost function for the period 2014-2020, which considers the infrastructure as overnight cost of the power facilities (generation and transformation) and the transmission network, the fuel cost, the operation and maintenance cost and imports from neighbor regions. This total cost must be minimized. The core of the model is a resource balance as shown in Eq. (1).

$$E_{r,i,tm} = \sum_j MU_{j,r} P_{i,j,tm} + IM_{r,i,tm} \sum_{PL,ii} Q_{r,PL,ii,i,tm} - \sum_{PL,ii} Q_{r,PL,i,ii,tm} - D_{r,i,tm} \quad (1)$$

Being *r* the set of resources, *i* the shires (*ii* all the other shires), *tm* the year, *j* the technologies and *PL* the type of power line. $E_{r,i,tm}$ represents the excess of a resource *r* in each shire *i* at the period *tm*; $MU_{j,r}$ is the resources transformation matrix for each technology *j* and resource *r*; $P_{i,i,tm}$ is the available power in shire *i* from technology *j* (generation or transformation) installed at a period *tm* (which accounts for the installed power and capacity factor); $IM_{r,i,tm}$ is the import of resource *r* from other regions by shire *i* at a period *tm*; $Q_{r,PL,i,ii,tm}$ is the transmission of resource *r* using the type of power line *PL* between the shire *i* and the shire *ii* at the period *tm*; and $D_{r,i,tm}$ is the demand of the resource *r* in a shire *i* at a period *tm*.

Table 1. Installed power and transformation capacity on a shire basis for Cantabria in 2014

	Shire									
Technology (power / transformation) Demand	1	2	3	4	5	6	7	8	9	10
Cogeneration NG	0	28	1	160	11	0	6	89	0	0
Cogeneration Coal	0	0	0	44	0	0	0	0	0	0
Hydropower	5	58	0	21	0	0	2	0	8	8
Pumping-storage	0	0	0	0	0	0	0	0	0	361.9
Wind on-shore + PV*	0.0	0.2	0.0	0.1	1.4	0.1	0.2	0.4	32.6	3.2
Total installed power	5	86	1	225	13	0	8	89	40	373
MV/LV	100	200	100	200	800	100	100	400	100	600
HV/MV	100	100	100	100	600	100	100	600	200	400
Total transformation capacity	200	300	200	300	1400	200	200	1000	300	1000
Total electricity demand at <220 kV	5	20	15	78	225	44	25	49	15	15

*PV contribution is minimal

The main assumptions of this work are highlighted below:

- Generation of power only takes place at 220 kV thus $MU_{j,r} = 1 \; \forall \; j \in [GEN], r = Electricity \; at \; 220 \; kV$, being GEN the subset of generation technologies
- Capacity factors for generation technologies are constant until 2020 under the selected values for the Cantabria region
- Import of electricity at 400 kV and 220 kV from neighbor regions is possible only by shires 1, 6 and 10 thus $IM_{r,PL,i,tm} = 0 \; \forall \; i \notin [1,6,10]$
- Increasing installed power only is possible for wind on-shore, keeping 2014 capacity factor thus $P_{i,j,tm} \geq P_{i,j,tm-1} \; \forall j$ = Wind on-shore
- Power can be transmitted only between neighbor shires $Q_{r,PL,i,ii,tm} \leq Y_{r,PL,i,ii,tm} Qmax_{r,PL}$ being $Y_{r,PL,i,ii,tm}$ the availability of infrastructure for the

transmission of the resource *r* using the type of power line *PL* from the shire *i* to the shire *ii* at the period *tm* and $Qmax_{r,PL}$ the maximum power of resource *r* that can be transmitted by the type of power line *PL*. Therefore, power cannot be transmitted if there is no infrastructure to do so and a maximum value is set up. To avoid inconsistencies, the $Y_{r,PL,i,ii,tm}$ infrastructure matrix must be symmetrical.

Therefore, given as inputs to the model:

- The expected evolution of the electricity demand in Cantabria for the period 2014-2020 (6.1% per year)
- The distribution of the 220 kV resource demand in each shire (see Table 1)
- The distribution of the initial power and transformation capacity in each shire (see Table 1)
- The capacity factor for each technology (highlighting 25% for wind power)
- The investment, operation and maintenance prices for generation and transformation (assuming constant 2014 values) (not shown here for simplicity purposes)
- The price of the importation of electricity (averaged as a generic $\$_{2014}$ 50/MWh)

The output of the optimization of the corresponding mathematical problem delivers:

- The total cost for supplying the electricity demand in Cantabria for each year in the period 2014-2020
- The requested wind on-shore power for further utilization in the STeMES model
- The imports of electricity from neighbor regions

4. Results

Results were obtained in less than 1 s by means of a Intel(R) Core(TM)2 Duo CPU E8500 @ 3.16 GHz and featuring 3.25 GB RAM.

From an economic point of view, the most adequate solution in the horizon 2020 for the scenario a), considering the set of values used in this work, is the installation of 641 MW of wind on-shore power in 2015 (all in shire 5), which is logical as this is the most demanding shire. On the other hand, increasing imports up to 3,274 GWh by 2020 (mainly by shire 10) is observed. This situation is possible assuming a generic price of $\$_{2014}$ 50/MWh for the imports of electricity at both levels 220 kV and 400 kV. As it was assumed that pumping-storage uses electricity at 400 kV to deliver electricity at 220 kV, there is always a minimum importation of 1.704 GWh (as long as the resource electricity at 400 kV can be only imported). The total cost for supplying the demand in the period 2015-2020, which includes the capital cost of the wind on-shore power facilities as well as the operation of all the power generation facilities is around $\$_{2014}$ 2.87bn.

To fulfill demand subject to import targets as in scenario b), an annual decrease of 10% for the imports is assumed. In this case, a noticeable increase in the installed wind on-shore power is presented: from the 38 MW available in 2014 in all shires, in shire 5, 653 MW are added in 2015, 127 MW in 2016, 135 MW in 2017, 143 MW in 2018, 142 MW in 2019, and 74 MW in 2020. Shire 8 increases 10 MW in 2019 and 60 MW in 2020. The total cost for supplying the demand in the period 2015-2020 is around $\$_{2014}$ 3.80bn.

Therefore, the choice made for the price of the imported electricity must be subjected to further analysis.

Consequently, as long as the built-up of the wind farms are almost instantaneous, or at least they can be completed in one year, the proposed model suggest the immediate construction of wind farms in shire 5 in 2015, that is, as soon as possible. For the coming years, the additional demand of power is simply imported in scenario a. Restrictions to the imports in scenario b suggests that the compensation must be completed mostly by wind on-shore farms in shire 5. As long as each km^2 is capable of accepting between 1.25-2.5 MW, this installation of 1,344 MW will demand between 538 km^2 and 1075 km^2. The PSEC suggests around 480-755 km^2 as available area. Therefore the coupling with the technical available area in each shire must be performed, as a limit of 1000 MW per year is the only limit established. This clearly suggest a different distribution once actual technical available areas are defined. In both cases, considering the existing transmission network, there is no need of additional power lines and only a tiny increase in the transformation capacity.

5. Conclusions

A RTN mathematical model has been developed capable of describing the electricity grid in Cantabria for planning purposes. A yearly temporal resolution has been considered. In a scenario a), a yearly increase in the demand of 6.1% and a constant distribution of the existing population, the lowest cost given by the RTN model when imports from neighbor regions are fixed at $\$_{2014}$ 50/MWh requests the addition of 641 MW of wind on-shore by 2015 and total imports up to 3,274 GWh by 2020. In a scenario b), a yearly increase in the demand of 6.1%, a constant distribution of the existing population, and a decrease of 10% per year in the total imports, the lowest cost given by the RTN model proposes the installation of wind on-shore farms up to 1,344 MW by 2020 (keeping the capacity factor at 25%). Beyond 2020 is possible to suggest that i) the integration of other technologies such PV (Girard, Gago et al. 2016) or wind off-shore to reduce imports; ii) a larger penetration of biomass power together with carbon capture and utilization; iii) the promotion of a larger grid in the case there is not enough area to fulfill the targets of wind power penetration.

References

Cantabria Regional Goverment, 2014. *Sustainability Energy Program for Cantabria 2014-2020 (Plan de Sostenibilidad Energética de Cantabria 2014-2020).*

G. Centi, E.A. Quadrelli and S. Perathoner, 2013. Catalysis for CO2 conversion: A key technology for rapid introduction of renewable energy in the value chain of chemical industries. *Energy and Environmental Science,* **6**(6), pp. 1711-1731.

A. Girard, E.J. Gago, J. ordoñez, and T. Muneer, 2016. Spain's energy outlook: A review of PV potential and energy export. *Renewable Energy,* **86**, pp. 703-715.

C. Liu, F. Li, M. Lai-Peng, and H. Cheng, 2010. Advanced materials for energy storage. *Advanced Materials*, **22**(8), pp. E28-E62.

S. Samsatli, and N.J. Samsatli, 2015a. A general spatio-temporal model of energy systems with a detailed account of transport and storage. *Computers & Chemical Engineering,* **80**, pp. 155-176.

S. Samsatli, N.J. Samsatli, and N. Shah, 2015b. BVCM: A comprehensive and flexible toolkit for whole system biomass value chain analysis and optimisation – Mathematical formulation. *Applied Energy*, **147**, pp. 131-160.