Abstract

The European Union (EU) has identified different Climate and Energy Targets, in order to reach carbon neutrality within 2050. The main pillars of these targets are the reduction of greenhouse gases (GHGs), the increase of the energy efficiency and the increase of the share of renewable sources deployed for energy generation. An energy transition is therefore needed, since the energy sector in EU is responsible for almost 75% of the GHGs. Increasing the share of electricity (i.e., electrification) in all the sectors, coupled with cleaner generation sources, results to be crucial in order to make possible this transition. Cleaner generation sources are represented by Variable Renewable Energy Sources (VRES), such as Photovoltaic and Wind, that are characterized by negligible GHG emissions during the operational phase. However, the increasing share of VRES arise some issues for the energy systems, in particular for electricity grids. In fact, both photovoltaic and wind power plants depend on weather factors, causing a great oscillation on generation within the day and the seasons. Daily variability determines renewable overgeneration issues during some hours of the day and undergeneration (or lack of generation) in others; seasonal variability instead is caused by unbalance on seasonal generation.

Additionally, VRES are characterized by high intermittency, that can lead to frequency value deviation from the nominal one. Since that, arises the need for flexibility options in order to guarantee the proper working of electrical grids, represented by Energy Storage and Conversion Technologies, Demand-Side Management and Demand Response options. In particular, energy storage devices could store energy during excessive generation periods and release it when it is needed by the grid, other than being

support tools for frequency and voltage regulation. Energy Conversion Technologies could instead store electricity during overgeneration and convert it in other useful forms (e.g., H_2). However, only a part of these technologies is suitable for providing the services required by the electricity grids. The current thesis aims to investigate the suitability of these technologies in providing such services, to rank them according to specific attributes, as well as to provide specific indicators that assess their performances according to the service considered.

In detail, in Chapter 2 an evaluation of electricity services that are needed for the proper operations of the electricity system is carried out. The services are mapped according to their technical features. The technologies considered are subdivided in suitable, partially suitable and not suitable to provide the electricity services. Findings of this study shows how electro-chemical storage are the technologies able to provide the larger number of services and that there is a not dominant technology.

A comparative multi-criteria evaluation of Li-ion batteries is then reported in Chapter 3, that accounts for techno-economic, environmental and raw materials supply risk criteria. In detail, a flexible tool called STeP (Sustainable Technology Performance) is built in MATLAB®. The tool implements a Multi Attribute Value Theory (MAVT) method, coupled with the Analytical Hierarchy Process (AHP) for the weighting of criteria. The flexibility of the tool allows users to customize the model, through the variation of the weights and the numerical inputs. Results shows that Li-ion battery characterized by Lithium Iron Phosphate (LFP) as cathode active material have better performance than the other typologies analyzed. Finally, in Chapter 4 an evaluation of the best electricity services to provide for LFP Li-ion batteries is carried out. The analysis accounts for one economic indicator, that is the Levelised Cost of Storage, and six environmental indicators. Furthermore, a Supply risk indicator is exploited for the evaluation of the geopolitical risk of selected raw materials. The results show that the

Frequency Containment Reserve and the Congestion Relief and Investment Deferral result the best services to provide for these batteries, in order to minimize their impacts.