Developing Cost-Effective, Flexible, Reliable GWh-scale Energy Storage – An eStorage Project Update

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Introduction

The European Commission-backed eStorage project has been tasked with developing a cost-effective solution for the widespread deployment of flexible, reliable, GWh-scale energy storage across the EU and enhancing grid management systems to integrate a large share of power generation from renewable energy sources. Specifically, the eStorage project is:

- Further developing pumped hydro energy storage.
- Valorizing the flexibility offered by variable speed pumped hydro storage through the enhancement of a smart dispatch tool and modeling the additional pumped storage plant technical capabilities and constraints.
- Determining the potential to upgrade fixed speed pumped hydro power plants to variable speed and identifying promising sites for new pumped hydro storage plants.

The paper will highlight the project's results to date and give an overview of the results to come. Mid-way through the project's six-year program, there are already substantial results to report:

1. The first version of a smart dispatch software has been developed and is in its test phase. This software optimizes pumped hydro scheduling in near real time which improves grid stability by easing load balancing and reserve procurement.

2. A detailed database of existing pumped hydro storage plants in Europe has been developed which identifies opportunities for future upgrades of fixed speed pumped hydro to variable speed. A GIS (geographic information system) based model that identifies potential new and easily exploitable sites in Europe for the development of new pumped hydro energy storage plants has been created

If widely developed in Europe, this technology could provide up to 10 GW of additional regulation capability with no environmental impact and at a much lower cost than developing a new plant.

The eStorage project includes major players from the entire electric power "ecosystem," including Algoé, a management consultancy; Alstom, a leading power generation and distribution equipment, services and solution provider; EDF, a leading energy company; Elia, one of Europe's leading transmission system operators; Imperial College London, a science, engineering and business university, consistently ranked amongst the world's best and DNV GL, a business and technical consultancy for the energy market.

Background

By 2050, the European Union (EU) wants to reduce greenhouse gas emissions by 80 – 95% from 1990 levels. According to the EU, about two thirds of European energy should come from Renewable Energy Sources (RES) with electricity production being almost emission-free. Large-scale integration of RES into the EU electricity system cannot be done without making the system more flexible.

Pumped hydro energy storage plants and particularly variable speed pumped hydro are key technologies for providing flexibility to the electricity system. Pumped hydro plants store energy when there is a surplus in the energy system -- for example, a windy night when wind turbines are producing more power than is required by the system. However, a fixed speed unit can only provide power regulation while generating power but a variable speed unit has the added flexibility to regulate power not only while in generation mode but also in pumping mode. This provides, among others, the capability to store the surplus of wind energy at night while providing regulation capabilities.

The vast majority of pumped hydro units are fixed speed. This technology imposes a fixed power capacity per unit in pumping mode: the pump is either stopped or operating at full capacity. The result is that other types of flexible generation must be kept online when the pumps are in operation or some pumped hydro units must continue to operate in generation mode to provide power regulation while other units are pumping. The fixed operating speed also limits the ability of the hydraulic unit, when operating in turbine mode, to maintain high efficiency over a large head and flow range.

1.1 Benefits assessment of variable speed pumped hydro energy storage

One of the key benefits of upgrading to variable speed technology is that the power absorbed in pumping mode can be varied, which is not possible with fixed speed technology. This new functionality enables offering ancillary services such as primary, secondary and tertiary frequency reserve in pumping mode, corresponding to periods of low demand or high intermittent renewable generation.

The current price that RTE uses in France to compensate the electricity producer delivering capacity for frequency control is approximately 17 €/MWh. That price is contractually defined for 3-year periods. RTE organizes the secondary frequency control through mandatory bilateral contracts with producers that must reserve a requested volume for every 30 minutes.

1.1.1 Increased variability in European power system

The increasing share of intermittent renewable energy sources in the European Union's power mix is posing challenges because the range of variability could approach a level that is beyond what the system can absorb. For example, EDF R&D simulated the average daily production in 2030, based upon the EC Roadmap toward 2050 scenario. During winter in Europe, mean available capacity is 190 GW but, considering different climatic scenarios this can vary between 60 and 275 GW.

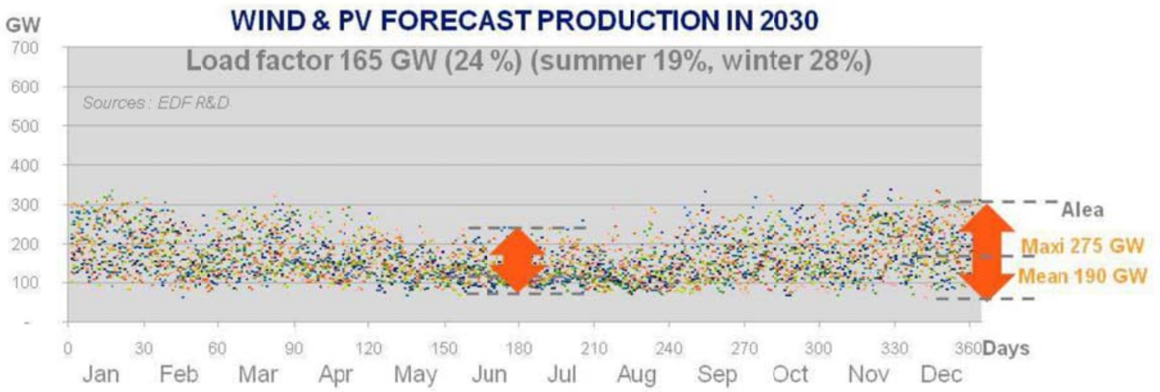

Figure 1: Wind and PV forecast wind production under EC Roadmap towards 2050 (HighRES) scenario

Another issue with intermittent RES is the predictability of power production. Although significant progress has been made recently, it is unlikely that meteorology will be able to deliver fully accurate second by second predictions of the output of wind and Photovoltaic (PV) plants. Considering the EU 27 has 650 GW of installed capacity of intermittent RES, a variation of just 1% between prediction and generation represents a variation in capacity of 6.5 GW that has to be compensated by the power system.

Currently, fluctuations in intermittent generation are mainly compensated by existing thermal or hydro power plants operating under partial load. Therefore, increasing intermittent feed-in will also lead to more balancing demands for thermal power plants which in turn means more time operating at partial load which decreases plant efficiency.

Moreover, in periods with low demand or high RES generation, thermal power plants cannot always be stopped which leads to wind or PV curtailment or negative prices on energy markets. Therefore, there is a specific need for additional flexibility in these periods.

2. IPSO software for smart dispatch

Intraday Plant and Storage Optimization (IPSO) is a smart dispatch software tool that improves the profitability of power generation companies by allocating generation and storage resources to meet TSO-agreed power production schedules for each trading period at the lowest cost for the power producer.

IPSO operates between the scheduling operations of the generation portfolio and the real-time control of generation operations. It computes optimized reference basepoints for *each minute* and for *each unit* in order to produce smoothed and optimized unit basepoint schedules and to allocate the contracted reserves at the portfolio level in the most economical way (Figure 2). Prior to IPSO, optimization was typically done every 30 minutes. Not only does this provide the generation company with more data to produce electricity at the lowest cost but it also helps them avoid penalties from any deviation in the reported schedules with the TSO over each trading period.

One of the goals of the eStorage project is to use smarter scheduling and dispatch techniques to take advantage of variable-speed pumped storage assets to provide as much balancing flexibility as possible while meeting the primary energy storage target.

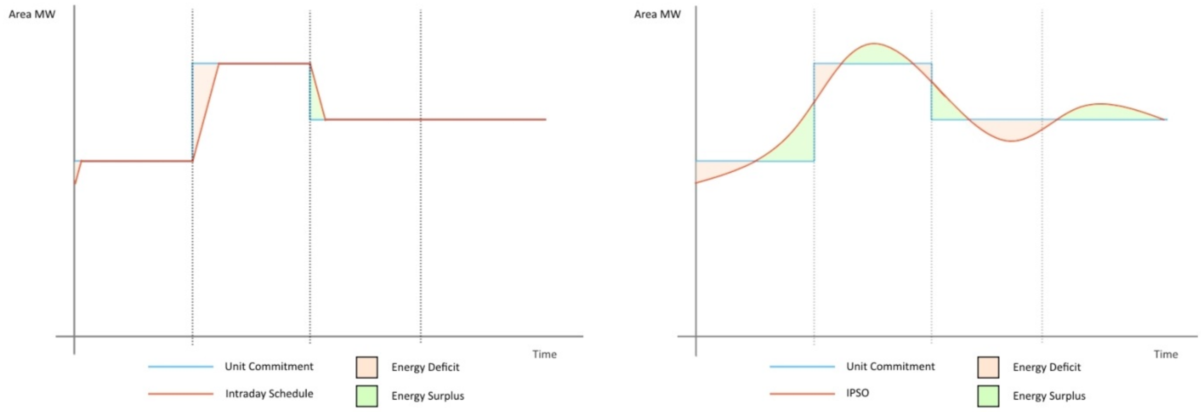

Figure 2 – Example of balanced area energy without and with IPSO

Such optimization permits fine rescheduling of the units based on the latest operating conditions. It also manages extra flexibility that can be used to cope with the power system imbalances, especially with significant deviations in intermittent generation forecasts.

IPSO is an optimization application and it provides plant dispatch information on a least cost basis. The objective function shows the penalization deviations between the trading period-based schedules input and the 1-minute schedules result that enables respecting as close as possible the contracted position and avoiding penalties.

IPSO uses data coming from the unit commitment tool that allocates unit load requirements on a trading period basis (usually 15 or 30 minutes) and the Automatic Generation Control (AGC) that reports the current state of the units from SCADA.

IPSO's basepoint schedules and reserve allocation schedules are used by the AGC to control the units through the SCADA system. The following diagram shows the interaction between IPSO and its typical environment.

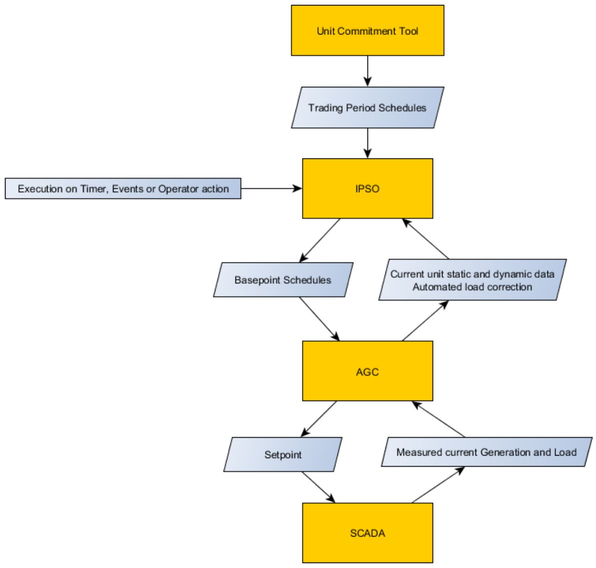

Figure 3: High level IPSO interactions

2.1 IPSO functionalities

The IPSO tool can operate in two different contexts. First IPSO can serve as an analytical tool for generation companies. Second it can be integrated into a generation company's system as a production component with external triggering to produce optimized setpoints.

The IPSO tool has two types of input data:

- Static Data and Dynamic Data: this includes the reported schedules defined by the EDF generation scheduling tool.
- Real-time Data: this includes the actual generation/pumping level which can be complemented with additional information such as the measured energy deviation and other hydro plant related data.

IPSO defines 1-minute based schedules while enforcing operational and technical constraints such as minimum and maximum power, ramp rates, forbidden zones and minimum switch time between generation and pumping mode, among others.

2.2 IPSO developments in eStorage

As part of the eStorage project, the IPSO software tool was improved to better model storage and variable speed pumped hydro to better take advantage of its quick ramping capacities and flexibility to provide services to the network, while being price competitive.

2.2.1 Intermittent generation assets

Intermittent generation assets such as wind or solar have also been included in IPSO's capabilities. Wind and solar energy resources were modelled using a specific dispatching mode: forecast, which is not centrally dispatched. In this mode, resources are described as an input generation forecast (as reported to the TSO) and the latest available intermittent generation forecast. Variable speed pumped storage units can be then used to compensate as much as possible for the deviations expected and/or observed between reported schedules and the latest generation forecasts.

2.2.2 Hydro plant efficiency model

A detailed hydro plant efficiency model was introduced within IPSO to refine the rescheduling of the pumped storage units using input for each trading period for up to three operating point characteristics. Each operating point is characterized by an efficiency factor, a maximum contribution to upward regulation and a maximum contribution to downward regulation. Such a detailed model allows increasing the supply of regulation services and optimizing the operation of the units around an operating point.

2.2.3 Hydro plant implicit energy model

Hydro plant energy was modelled implicitly in IPSO, using energy related parameters instead of elevation-related parameters. Each reservoir is modelled with maximum and minimum energy limits (representing maximum and minimum elevations) and the sum of all the inflows, outflows, generation and pumping provides the variation of the actual capacity of the reservoir. A target capacity at the end of the trading period can be expressed in MWh-equivalent and may vary within a defined range. In the case of pumped hydro storage plants, both higher and lower MWh limits corresponding to the elevation of the stored energy in the reservoir should be included. This allows IPSO to ensure consistency between medium-term strategy and energy balancing strategy.

3. Opportunities to upgrade fixed speed PSPs to variable speed and potential for new PSPs

3.1 Potential to convert existing fixed speed PSPs to variable speed in EU 15, Switzerland and Norway

The EU 15, Switzerland and Norway represent 81.7% of the total pumped hydro energy storage installed capacity in Europe or 42.7 GW out of a total installed base of 50.9 GW.

Motor generators are generally ageing faster than conventional hydro generators because they subjected to more cycles than their conventional counterparts which causes more fatigue as they are operate in turbine and pumping modes. Furthermore, motor generators were originally designed to operate with two or three starts and stops per day – one in pump mode during the night and one or two during peak times – the integration of more RES now requires these machines to increase their level of cycling with 10 starts and stops per day becoming usual.

Upgrading existing fixed speed pumped hydro energy storage plants to variable speed will increase plant efficiency and flexibility by allowing power regulation in both turbine and pumping mode. It will enable electric utilities to harness surplus power from intermittent sources like wind to fill pumped hydro storage plants' upper reservoirs faster, storing the surplus energy for later use when demand is high or when insufficient wind energy is available.

Considering the typical lifetime for a motor generator is 30 years then approximately 34.9 GW of motor generators for the EU-15, Switzerland and Norway will need to be refurbished by 2020 which is about 84% of the 42.6 GW pumped hydro installed base currently operating in this area.

The power absorbed in pumping mode by a variable speed unit can vary by 30%. Thus, converting 100 MW of fixed speed pumped hydro to variable speed will provide around 30 MW of regulation in pumping mode. This means that if the 34.9 GW of fixed speed generators older than 30 years are converted to variable speed then around 10.47 GW of additional frequency regulation capability in pumping mode could be obtained. Typically, such capacity would serve the regulation needs for wind generation.

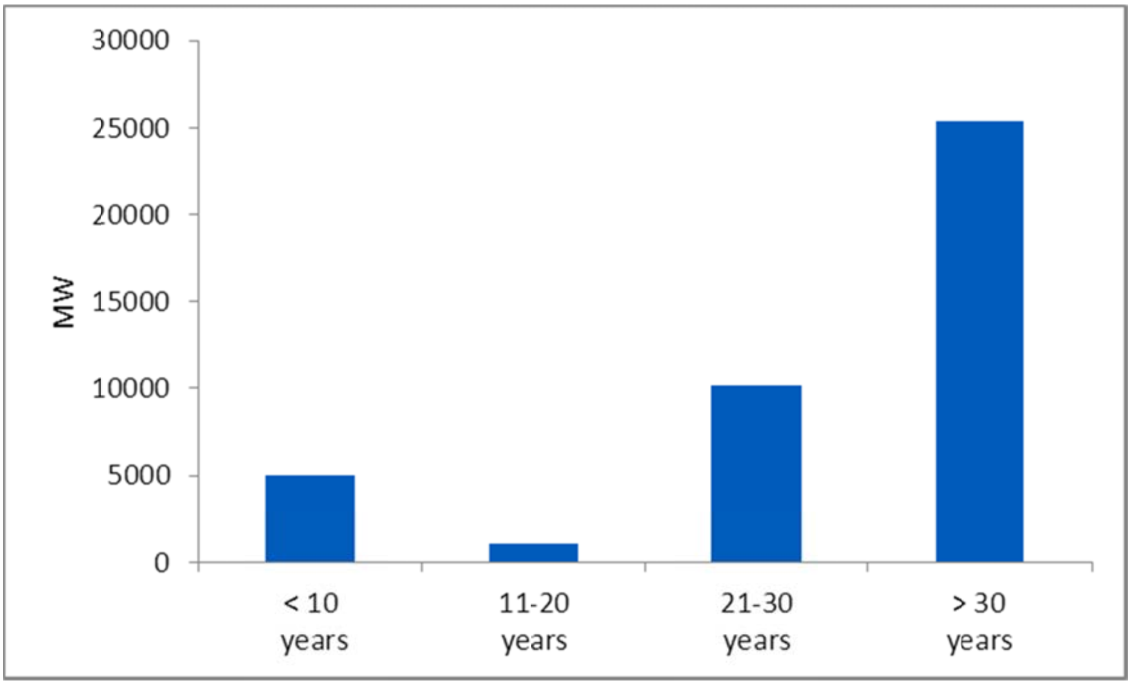

Figure 4: Age of units in 2013 for the EU-15, Switzerland Norway (Alstom, 2013)

The type of unit axis (vertical or horizontal shaft line) is an important parameter to consider with a variable speed upgrade because some of the components are larger and heavier, requiring more space in the powerhouse to accommodate the new equipment. The share for the different unit axis is presented in the figure below. Overall, horizontal machines represent 29% of the market and vertical machines 71%.

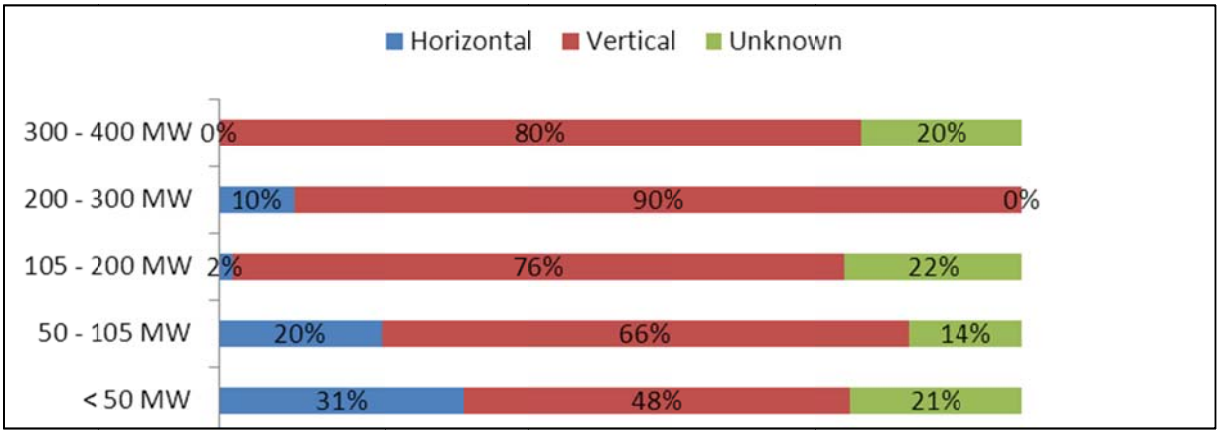

Figure 5: 12 Share of unit axis depending on the unit power output (MW) (Alstom, 2013)

3.2 Inventory of suitable locations for new PSPs in EU 15, Switzerland and Norway

The eStorage Project has created a Geographic Information System (GIS) model of potential and viable new pumped hydro locations in the EU-15, Switzerland and Norway, including the total theoretical storage potential (TW, TWh) of each site. This inventory provides a ranked list of potential sites in the region and an overview of possible total energy storage capacity per country, giving political and business leaders valuable information about the development of new pumped hydro energy storage projects.

Only existing pairs of water bodies with the following criteria were selected:

- Energy storage capacity of at least 1 GWh
- Maximum distance of 10 km between them
- At least 80 m difference in elevation
- Average downward slope of at least 5%

The selection criteria were weighted in a model to reflect the relative importance of the individual parameters:

- Energy storage capacity -- the amount of energy to be stored is most critical factor for deciding whether a water body pair is economically viable or not. This parameter is weighted with a value of two.
- Inverse slope -- distance between water bodies divided by the head is the inverse slope. The higher the inverse slope, the more attractive the pair is to develop. Nevertheless, this parameter is less important than the energy storage capacity and is weighted with a value of one.
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After the rankings were generated from the model, additional relevant characteristics were considered to refine the model manually and provide a more qualitative analysis. Relevant characteristics included:

- Distance to grid -- The availability of an appropriate grid connection is an important factor influencing the suitability of a potential pair. The distance to three different voltage classes was is included:
  - Low (150-220 kV)
  - Medium (220-400kV)
  - High (> 400kV)
- Overlap with restricted zones -- Certain areas are less- or unsuitable for the construction of new PSP infrastructure. This can be because of existing construction or regulations restricting certain activities. The following restriction factors have been identified:
  - Global or European conventions
    - World Heritage Sites (UNESCO)
    - Man and the Biosphere (UNESCO)
    - Wetlands of International Importance (Ramsar)
    - Natura2000
  - National protected areas (classified according to IUCN category system)
    - Strict nature reserve
    - Wilderness area
    - National park
    - Natural monument or feature
    - Habitat/species management area
    - Protected landscape/seascape
    - Protected area with sustainable use of natural resources
  - Urban land use
    - Industry
    - Residential
    - Cemeteries

The datasets used to create the most accurate GIS model possible are outlined in the table below.

Type of Data	Dataset
Water bodies	Corine Land Cover and OpenStreetMap water layer
Reservoirs and dams	DAMPOS and GRanD
Elevation	SRTM and ASTER
Grid data	Enipedia
Sensitive areas	OpenStreetMap

Table 1: Datasets used to create the GIS model

A GIS model alone is not sufficient to capture the complex and sometimes arbitrary process of potential site selection so a manual review of the sites complemented the data model. National hydro industry experts were asked to provide an expert judgement on the attractiveness of selected pairs.

Country	Suitable Locations Total	Suitable Locations in Country	Suitable Locations Cross Border	Suitable pairs related cross border pairs (powerhouse located within country of interest)	Total Energy Storage Capacity [GWh]
Austria	25	24	1	27	153.8
Belgium	1	1	0	1	1.6
Denmark	0	0	0	0	0.0
Finland	1	1	0	1	1.3
France	35	32	3	41	249.4
Germany	2	1	1	2	9.0
Greece	1	1	0	1	160.4
Ireland	0	0	0	0	0.0
Italy	64	57	7	64	435.0
Luxembourg	0	0	0	0	0.0
Netherlands	0	0	0	0	0.0
Norway*	382	376	6	442	17263.6
Portugal	10	5	5	4	277.6
Spain	95	87	8	97	720.7
Sweden*	62	56	6	68	217.4
Switzerland	37	30	7	39	456.9
United Kingdom	19	19	0	0	84.6
TOTAL*	836	780	56	787	

Table 2: Preliminary results for suitable new pumped hydro storage plants

* Totals cannot simply be added due to overlapping cross border pairs.

Conclusion

To achieve the EU goal of reducing greenhouse gas emissions by 80 – 95% requires cost-effective, flexible, reliable GWh-scale energy storage. The eStorage project, supported by the European Commission, is working toward this goal and has made great strides in the first three years of a six year program.

The eStorage project has developed and is testing software that will improve grid stability by facilitating load balancing and reserve procurement. The smart dispatch software, known as IPSO optimizes PSP scheduling in almost real time.

One plant alone will not provide the necessary storage flexibility to reach the EU's 2050 goal. Many more plants are needed and the eStorage project has identified pumped storage plants across Europe that are viable candidates to upgrade to variable speed, as well as surveying potential new exploitable sites for pumped storage.

Cost-effective grid-scale storage and flexibility are two key drivers for cutting greenhouse gas emissions and achieving the EU 2050 goal.

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The Authors

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Haike van de Vegte graduated as an engineer from the Technical University of Eindhoven in the Netherlands. Since 2011 he has conducted technical and economic assessments for energy storage projects and performed solar PV analyses for DNV GL. Haike Van de Vegte also has experience in energy efficiency improvement in the building environment, biogas technology assessment and Geographic Information Systems. He began his professional career in 2005 and has worked in the field of renewable energy and energy efficiency for Ecofys and OneCarbon and he worked for two years in Beijing, China.