Electricity storage needs for the energy transition: an EROI based analysis

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Context

High share of intermittent renewable energies increases the stress on the electricity market. Storage is part of the solution.

The **storage needs** for an electricity production based on 100% Renewable Energy (RE) is estimated at **100-300 TWh** for Europe[1]. However, the **potential** of the most common storage technology, i.e. pumped hydro storage, is **4 TWh** only [2]. Therefore, the use of other **storage** technologies, with different time scales, is **unavoidable** during the energy transition.

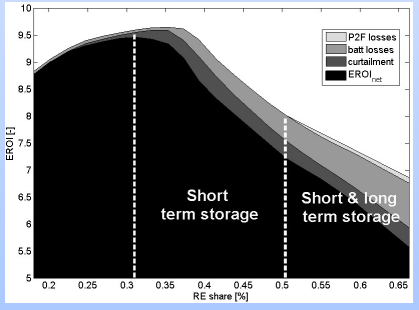
Objectives

Define the energy storage needs as a function of the share of renewable energy in the electricity mix (applied to the case of Belgium)

The different storage technologies are chosen to **maximize** the Energy Return on Investment (**EROI**) of the renewable electricity production. This metric is linked to the welfare of the populations and does not depend on policies, subsidies, lobbies, etc.

Results

- RE Intermittency requires a storage mix composed of **batteries** (high efficiency, short term storage) and, at high RE share, **PtG** (high capacity, long term storage) and RE **curtailment** (<4%)
- EROI of electricity production increases first and reach a **maximum** at **37%** RE share due to an optimal ratio between solar and wind energy. Beyond, it decreases due to a higher share of solar, curtailment, and storage losses.



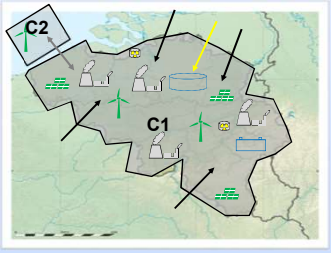
EROI of the Belgian electricity production as a function of the RE share. Max. reached at 37%.

Conclusions

- With more than **30-35%** of RE share, storage will be **unavoidable**. **Battery** storage will be required for **short term storage** and designed to shape PV production from day to night in summer.
- With more than **55-70%** of RE share, **seasonal storage** is required and **Power to Gas** (PtG) is a solution to shift overproduction of summer to winter. Nevertheless, this solution is energetically expensive (30% efficiency) but better than RE curtailment from the EROI viewpoint.
- Still, to face intermittency, RE **curtailment** is part of the solution. It reaches a **ceiling** of **3-4%**. This value is an optimum between building more RE or install more storage.
- The **EROI** is defined mainly by the **energy cost** of the RE technologies. Curtailment and storage play a non negligible secondary role.
- Remaining **fossil fuel** (i.e. gas) consumption in high RE penetration scenario is responsible for **95%** of the **CO2** emissions.
- Base load **nuclear** has no impact on the storage needs for the development of **RE**.

Our model

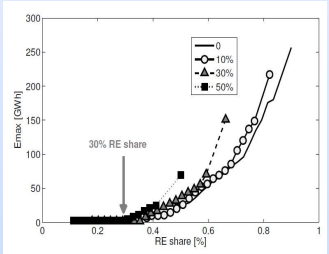
- The studied region is discretized by interconnected cells. Each **cell** is composed of **production** (RE, gas and nuclear), **consumption**, and **storage**. Storage is a mix of existing capacities (**pumping hydro storage**), short term storage (**batteries**) and long term storage (**Power to Gas**).
- The model balances, on an **hourly** basis and for a year, the electricity grid by **optimizing** the use of existing storage/**production**, installing more RE or **storage**, **curtailing** RE, using cells interconnection or **importing** from neighboring regions.
- Linear programming is used to solve this problem with more than $4 \cdot 10^5$ variables and $6 \cdot 10^5$ constraints



*Representation of Belgium with **2 cells**. **C1** is the mainland and **C2** is offshore wind parks*

Estimated storage needs

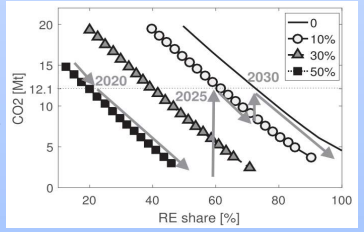
- With more than **30% RE** share, **short term storage** is required to shift solar overproduction of day to night and wind peaks. The storage is **designed** by daily solar shaping during summer.
- Reaching 50% RE in Belgium requires 50GWh of storage ⇔500k electric cars batteries
- With more than **55% RE** share**, long term storage** is required to shift summer sun overproduction to winter. **PtG** units are at **full load** day and night during **summer** thanks to solar and stored solar energy.
- Even if PtG **efficiency** is around **33%**, it is necessary and less expensive than more solar or wind combined with curtailment.



Required battery capacity depends on RE share.

Belgium transition: a scenario

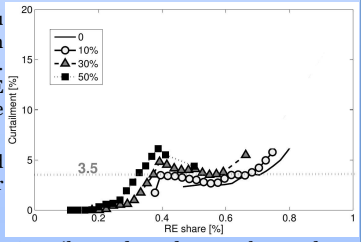
- Constant increase of RE share up to 80% in 2050.
- **Nuclear phase out** in 2025 is compensated by imports and gas power plants that temporarily **double CO_2** emissions.



CO2 emissions as a function of the RE and nuclear share. Belgium transition is represented by grey arrows.

Impact of RE share on curtailment

- **Curtailment** is **ceiled** by a plateau around **3-6%** which is an optimum between curtailment and storage. It is a balance between shaving RE production peaks and install storage to absorb them.
- The plateau value can be increased if RE devices get cheaper or decreased if batteries get cheaper



Curtailment depends on nuclear and RE share

1 D. Heide et al. 2010 & 2011, G. Plessman et al 2014
2 M. Gimeno et al. 2013