Data processing documentation

https://www.nature.com/articles/s41560-023-01355-z#MOESM8

Techno-economic effects on future's energy consumption

1. **Technology improvements**. Energy saving potential in future technology development for total enegry (both electricity and heat)

$$\Delta Ef_{tech,n,i} = \left(1 - f_{tech,i}\right)^{n}$$

- $\Delta Ef_{tech,n,i}$: energy efficiency improvement in year *n* for battery technology *i*
- $f_{tech,i}$: percent saving by technology *i (battery specific)*
- n: year number after 2020 (current year – 2020)

2. **Learning effects.** Learning effects result from experience in production, such as reducing scrap rates and using machines and tools more efficiently.

$$\Delta Ef_{learn,n} = n^{\log_2(1-f_{learn})}$$

- f_{learn}: savings by doubeling the cummulated output, 3 % (range 2%-4%)
- n: year number after 2020 (current year – 2020)

3. **Economies of scale**. By economies of scale, the effect is described that the effort (cost) to produce a product is reduced with increased scale in its production.

$$\Delta Ef_{econ,n} = MD_n{}^{\log_2(1-f_{scale})}$$

- f_{scale}: savings by doubeling the cummulated output, 3 % (range 2%-4%)
- MD_n: Percentage market increase in year n to 2021

4. **Use of heat pumps.** For improved energy sourcing, it is assumed that electricity is used instead of natural gas and that heat pumps are used for the generation of heat.

$$\Delta Ef_{HP,n,i} = \frac{E_{ele,i} + E_{NG,i} \times \left(\frac{60\%}{COP} \times \frac{n}{19} + 1 - 60\% \times \frac{n}{19}\right)}{E_{ele,i} + E_{NG,i}}$$

- $E_{ele,i}$: Cell specific electric energy consumption [kWh_prod/kWh_cell]
- $E_{NG,i}$: Cell specific natural gas energy consumption (heat demand) [kWh_prod/kWh_cell]
- COP: coefficient of performance of heatpumps to change from natural gas to electricity (take average value 2, range 1.5-2.5)
- 60%: Assumed market share of heat pumps in 2040 (from the paper)
- n: year number after 2020 (current year – 2020)

In our project:

Categories of battery considered

- LIB:
  - NCA
  - NMC532 & NMC622
  - NMC811 & NMC900
  - LFP
- PLIB (aggregrated due to lack of LCI: SIB, ASSB (polymer), ASSB (oxidic), ASSB (sulfidic), LSB, LAB

Scenario defination:

Scenario name	Market share of battery	Technology improvements
SSP2-Base BAU	Current LIB market share and technology status until 2040	none
SSP2-RCP19 1.5 Scenario	LIB and PLIB market mix share scenario from (Degen et al., 2023)	LIB & PLIB technology improvements LIB & PLIB learning effects LIB & PLIB economic of scale LIB & PLIB use of heatpump

Scenario data calculation:

Efficiency|Heat|LIBs: heat efficiency improvement in year n for LIB

Total heat efficiency improvement by technology improvements, learning effects, economic of scale and use of heat pump

$$\begin{aligned}\Delta Ef_{heat,n,i} &= \Delta Ef_{tech,n,i} * \Delta Ef_{learn,n} * \Delta Ef_{econ,n} * \Delta Ef_{HP,n,i} \\ &= \left(1 - f_{tech,i}\right)^{n} * n^{\log_2(1-f_{learn})} * {MD_n}^{\log_2(1-f_{scale})} \\ &* \left(\frac{E_{ele,i} + E_{NG,i} \times \left(\frac{60\%}{COP} \times \frac{n}{19} + 1 - 60\% \times \frac{n}{19}\right)}{E_{ele,i} + E_{NG,i}}\right)\end{aligned}$$

Efficiency|Heat|PLIB:

$$PLIB, \Delta Ef_{heat,n} = \sum_{i=1}^{6} MS_{PLIBi,n} * \Delta Eff_{heat,PLIBi}$$

- $MS_{PLIBi,n}$: market share of 6 kinds of PLIB *i* in year *n* from the paper data
- $\Delta Eff_{heat,PLIBi}$:efficiency improvement of each PLIB from the paper data

Efficiency|Electricity|LIBs:

$$\begin{aligned}\Delta Ef_{ele,n,i} &= \Delta Ef_{tech,n,i} * \Delta Ef_{learn,n} * \Delta Ef_{econ,n} \\ &= \left(1 - f_{tech,i}\right)^{n} * n^{\log_2(1-f_{learn})} * {MD_n}^{\log_2(1-f_{scale})}\end{aligned}$$

Efficiency|Electricity|PLIBs:

$$PLIB, \Delta Ef_{ele,n} = \sum_{i=1}^{6} MS_{PLIBi,n} * \Delta Eff_{ele,PLIBi}$$