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FlexPlan

RC France & Benelux workshop| 6^{th} March 2023

RC France & Benelux – Modelling and results

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Agenda

FlexPlan

- Introduction
- Grid modelling
- Scenario data
- Results and analysis

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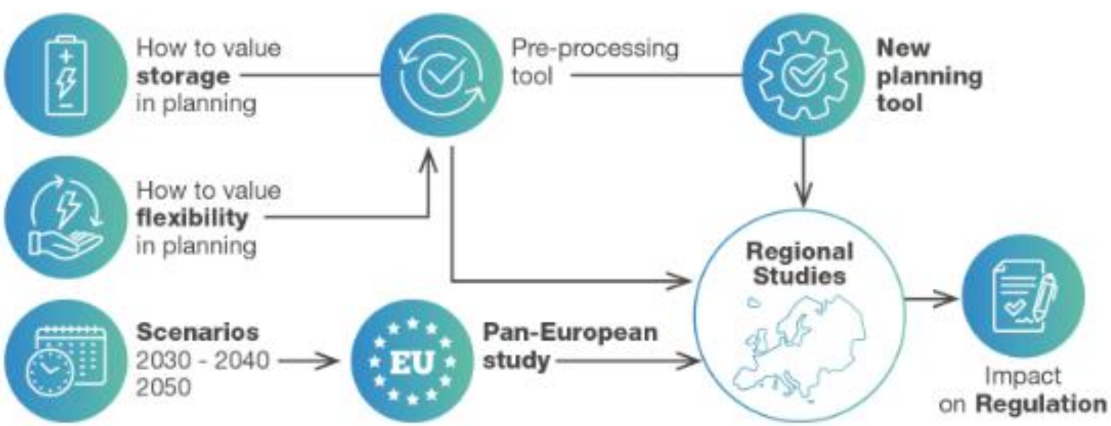
The FlexPlan project

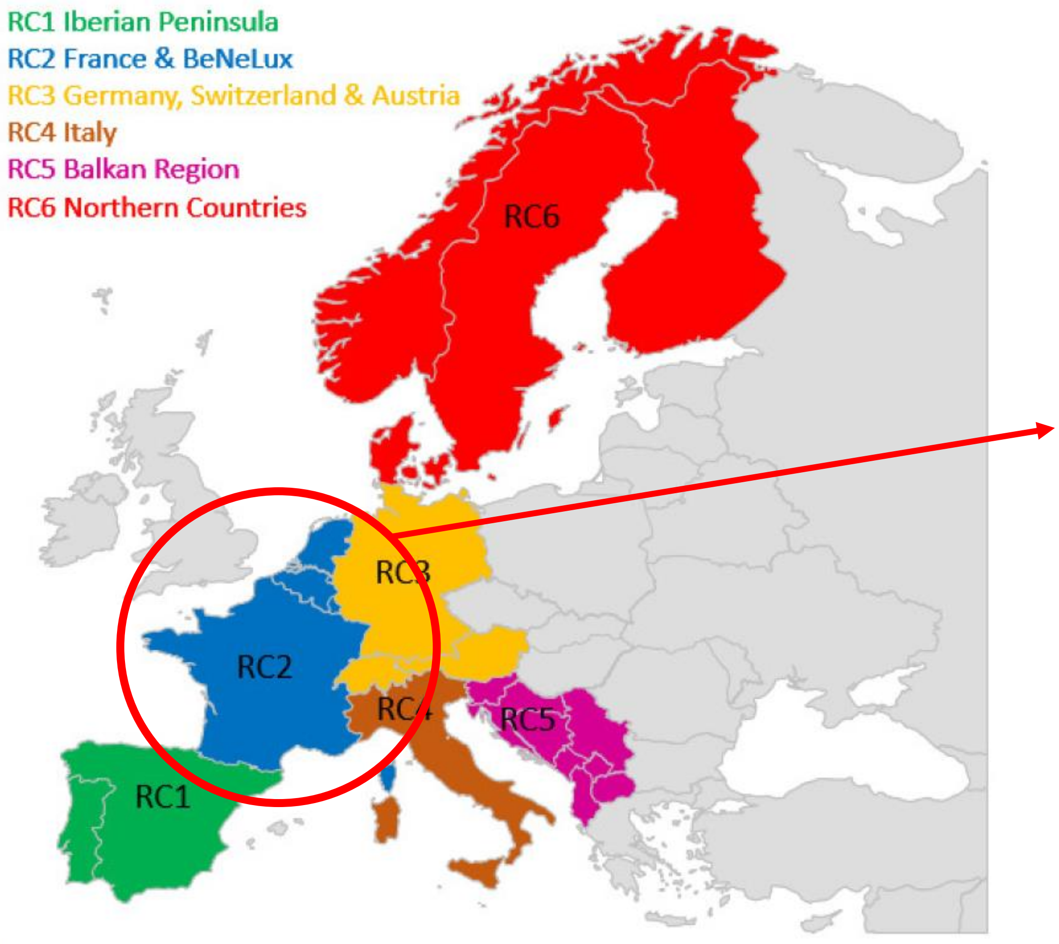
FlexPlan

Main objective: Establishing a new grid planning methodology considering the opportunity to introduce new storage and flexibility resources in electricity transmission and distribution grids as an alternative to building new grid elements



The FlexPlan project

- Regional cases



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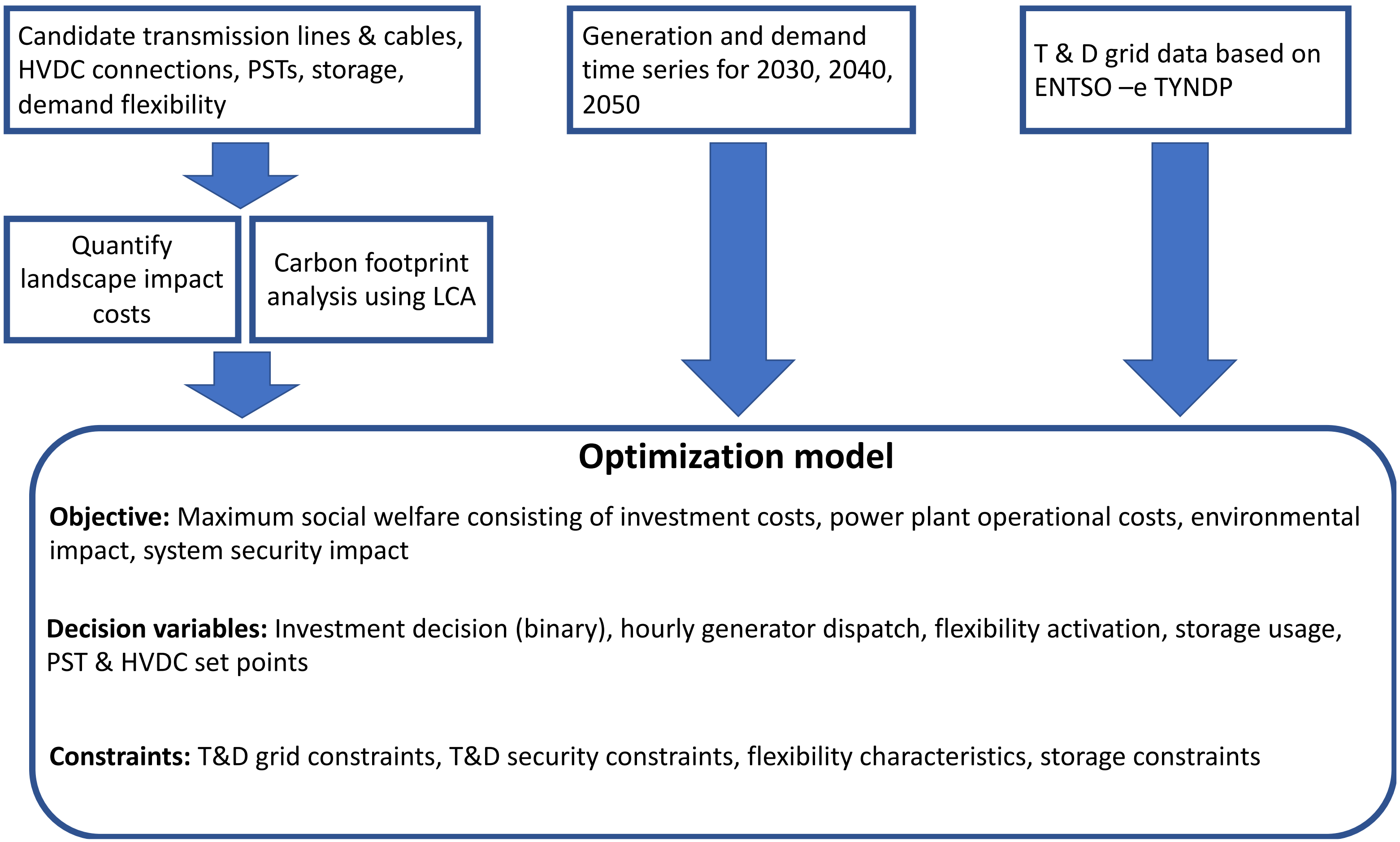
RC2 France & Benelux

The FlexPlan planning methodology



Optimization objective – General structure

- The maximum social welfare objective formulated as a cost minimization
  - Quantification of potential benefits not straight-forward without market assumptions
  - Danger of double counting benefits / costs due to complex flow of money
  - Eventually, all cost needs to be borne by consumers in some in way
- Objective function structure:
  - $\min \sum_y [\sum_t [\sum_i (C_{y,t,i}) + \sum_{y,j} \alpha_{y,j} (C_{y,t,j}) + \tilde{U}_{y,t,c} \Delta t \sum_c C_{u,t,y}^{voll} \, \Delta P_{u,c,t,y}] + \sum_j \alpha_{y,j} I_{y,j}]$

Operational cost of existing equipment

Operational cost of candidate equipment

Expected cost due to outages

CAPEX of candidate equipment

i… set of existing equipment
j… set of candidate equipment
α… binary decision variable
t….set operational time points (8760h)
y... set of planning horizons (2030, 2040, 2050)

  - Environmental impact cost considered as part of operational and CAPEX cost

Detailed formulation of the objective function

$$
\min \sum_{s} \pi_s \left\{ \sum_{y \in S_y} f_y^{d,o} \left\{ \sum_{t \in S_t} \left[\begin{array}{c}
\sum_{g \in S_g} \left[C^{aq}_{g,y} + \left(\theta^{CO_2} G^{pf} + \theta^{f}\right)\eta^{f}_{g} \right] P_{g,t,y,s} + C^{res,curt}_{g,y} \Delta P^{res}_{g,t,y,s} + \\
\sum_{j \in S_j} \left[C^{abs}_{j,t,y} P^{abs}_{j,t,y,s} + C^{inj}_{j,t,y} P^{inj}_{j,t,y,s} \right] + \sum_{j \in S_{jc}} \left[C^{abs}_{jc,t,y} P^{abs}_{jc,t,y,s} + C^{inj}_{jc,t,y} P^{inj}_{j,ct,y,s} \right] + \\
\sum_{u \in S_u} \left[C^{nce}_{u,t,y} \left(P^{ref}_{u,t,y,s} - P^{nce}_{u,t,y,s} \right) + C^{ds}_{u,t,y} \left(\Delta P^{ds,up}_{u,t,y,s} + \Delta P^{ds,dn}_{u,t,y,s} \right) + C^{lc}_{u,t,y} \Delta P^{lc}_{u,t,y} \right] + \\
\sum_{n \in S_n} \left(C^{EE}_{n,t,y} EE_{n,t,y,s} + C^{LL}_{n,t,y} LL_{n,t,y,s} \right)
\end{array} \right] + \right. \right.
$$

$$
\left. \left. f_y^{d} \left[\begin{array}{c}
\sum_{j \in S_{jc}} \alpha_{jc,y} \left(I^{E}_{jc,y}\left(E^{max}_{jc}\right) + I^{P}_{jc,y}\left(P^{max}_{jc}\right) + FP^{CO_2}_{jc,y} \right) + \sum_{u \in S_u} \alpha_{u,y} \left(I_{u,y} + FP^{CO_2}_{u,y} \right) + \\
\sum_{lc \in S^{ac}_{lc}} \alpha_{lc,y} \left(I_{lc,y} + FP^{CO_2}_{lc,y} + LS_{lc,y} \right) + \sum_{dc \in S^{dc}_{lc}} \alpha_{dc,y} \left(I_{dc,y} + FP^{CO_2}_{dc,y} + LS_{dc,y} \right) + \\
\sum_{zc \in S_{zc}} \alpha_{zc,y} \left(I_{zc,y} + FP^{CO_2}_{zc,y} + LS_{zc,y} \right) + \sum_{bc \in S_{bc}} \alpha_{bc,y} \left(I_{bc,y} + FP^{CO_2}_{bc,y} + LS_{bc,y} \right)
\end{array} \right] \right\} \right\}
$$

Model dimensions:

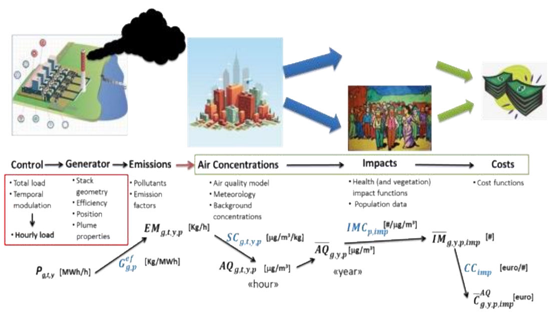
- Set of grid elements (x1000)
- Set of planning hours (8760)
- Set of planning years (2030 – 2040 - 2050)
- Set of planning scenarios

MILP problems will millions of decision variables and constraints

Model decompositions are needed!

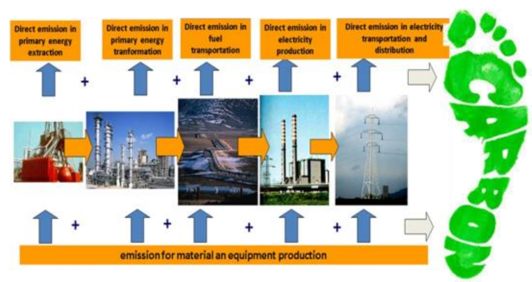
Environmental impact modelling

Air quality impact modelling



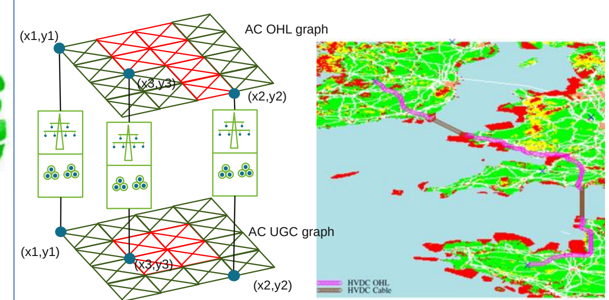
Linearized model quantifying air quality impact related costs in dependence of generation

Carbon footprint modelling



CO_2 emission cost of power generation as direct input, CO_2 impact of new grid investments using LCA

Landscape impact modelling



Using optimal routing routing algorithm quantifying landscape impact cost for OHL and cable investments

Environmental impact scenarios

Climate change avoidance costs
€/tCO_2 equivalent (€2016)

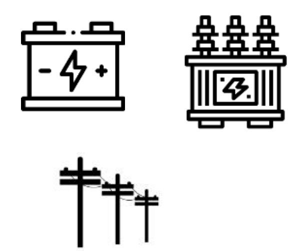
CO_2 emission	Low	Central	High
2030	60	**100**	189
2040 and 2050	156	**269**	498

Generation cost for conventional generators

- Fuel cost
- Air quality impact cost
- CO_2 emission cost

Investment cost

- Production
- Transportation
- Operation
- Dismantling
- Recycling



Flexible load modelling

upward and downward Demand Shifting

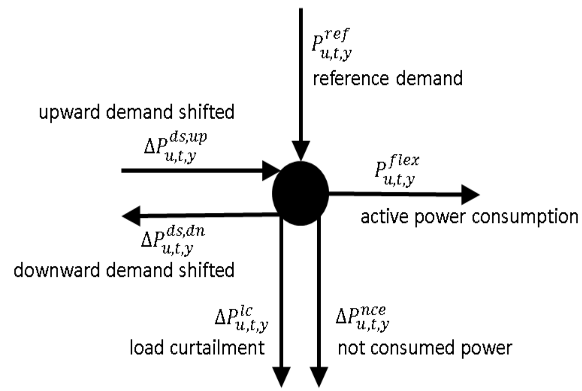
voluntary reduction (Not Consumed Energy)

involuntary reduction (Load Curtailment)

$$P^{flex}_{u,t,y} = P^{ref}_{u,t,y} + \Delta P^{ds,up}_{u,t,y} - \Delta P^{ds,dn}_{u,t,y} - \Delta P^{nce}_{u,t,y} - \Delta P^{lc}_{u,t,y}$$

$$\left.\begin{aligned} & P^{flex}_{u,t,y} \geq 0 \\ & 0 \leq \Delta P^{ds,up}_{u,t,y} \leq \Delta^{ds,up,max}_{u,t,y} \\ & 0 \leq \Delta P^{ds,dn}_{u,t,y} \leq \Delta^{ds,dn,max}_{u,t,y} \\ & 0 \leq \Delta P^{nce}_{u,t,y} \leq \Delta P^{nce,max}_{u,t,y} \\ & 0 \leq \Delta P^{lc}_{u,t,y} \leq P^{ref}_{u,t,y} \end{aligned}\right\}$$

bounds on variables



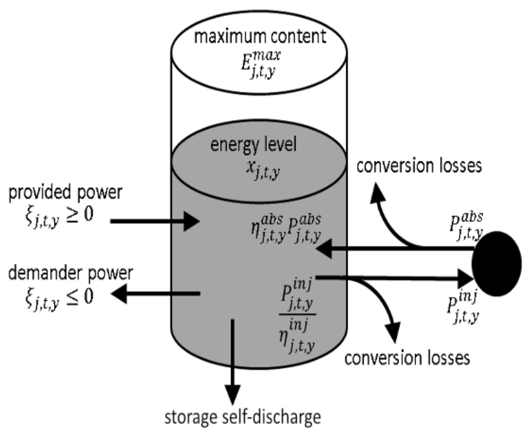
$$\sum_{t \in \{\tau - T^r + 1, \ldots, \tau\}} \left(\Delta P^{ds,up}_{u,t,y} - \Delta P^{ds,down}_{u,t,y}\right) = 0 \quad \forall \tau : \tau \bmod T^r = 0$$

upward and downward demand shifts are rebalanced every T^r periods

Storage modelling

$$E_{j,y}^{max} x_{j,t,y} = \left(1 - dr_{j,y}\right)^{\Delta t} E_{j,y}^{max} x_{j,t-1,y} + \Delta t \left(\eta_{j,y}^{abs} P_{j,t,y}^{abs} - \frac{P_{j,t,y}^{inj}}{\eta_{j,y}^{inj}} + \xi_{j,t,y} \right)$$

- energy stored at time t
- self-discharge
- energy stored at time $t-1$
- energy absorbed from network
- energy injected into network
- exogenous term

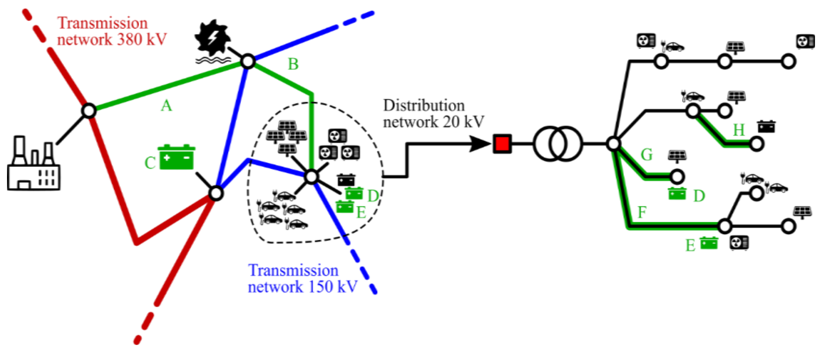


$E_{jc,y}^{min} \leq E_{jc,y}^{max} x_{jc,t,y} \leq E_{jc,y}^{max}$ bounds to energy level *x*

$0 \leq P_{jc,t,y}^{abs} \leq P_{jc,y}^{abs,max}$ bounds on power absorbed from network

$0 \leq P_{jc,t,y}^{inj} \leq P_{jc,y}^{inj,max}$ bounds on power injected into network

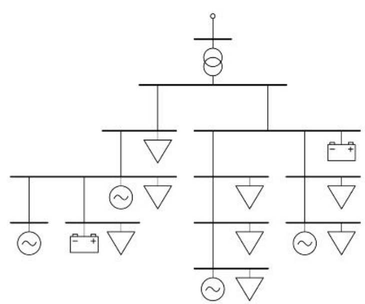
Transmission and distribution grid modelling



In order to maintain computational tractability, linearized models are adopted:

- DC approximation for AC/DC transmission grids
- linearized approach (DISTFLOW-like) simplifying but not eliminating reactive power for distribution grids
- Synthetic distribution grids are generated on the basis of few metrics/statistics of real networks

Original distribution network



Surrogate model

Components

- one generator
- one storage device
- one flexible load

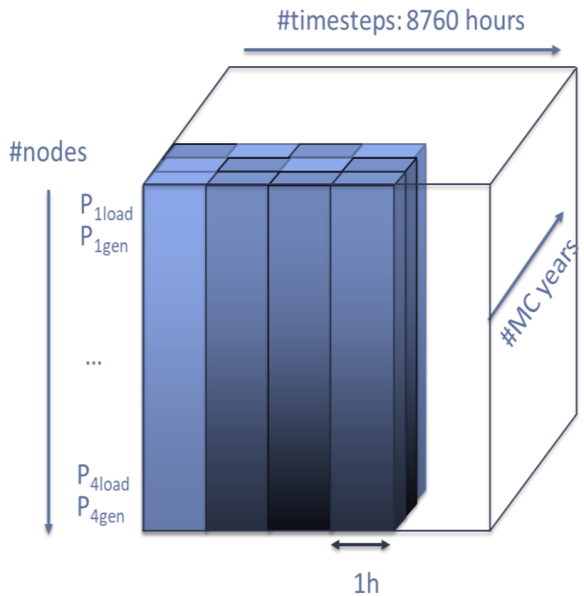
Component parameters such that:

- feasibility *implies* feasibility in original model
- cost *approximates* cost in original model

The grid model is decomposed into TNEP and DNEP.

1. Compute one surrogate model for each distribution network
2. Run TNEP problem with the surrogate distribution networks attached to calculate optimal solution for transmission network, costs related to transmission network, power exchanges between transmission and distribution networks
3. Fix power exchanges and run DNEP problem for each distribution network to calculate optimal solution for distribution networks and costs related to distribution networks

Stochastic optimisation



Climate variants of 35 years (variability of RES time series and load time series) are considered in the framework of a stochastic optimisation.

The number of combinations is reduced to two by using **clustering-based scenario reduction techniques**.

Adopting a Monte Carlo approach would present a modeling problem: if every Monte Carlo run is executed separately, then investment decisions are taken separately and there is a problem in putting together results that can be substantially diverging.

So, the dispatch costs of the different variants are weighted together in the target function, each with their own probability (**stochastic optimization**).

In order to retain numerical tractability, the dispatch calculation of the different variants is split by using the **Benders' decomposition**. Such methodology allows to decompose a master problem dealing with the investment decisions from the optimum dispatch calculation for each Monte Carlo variant and for all target years.

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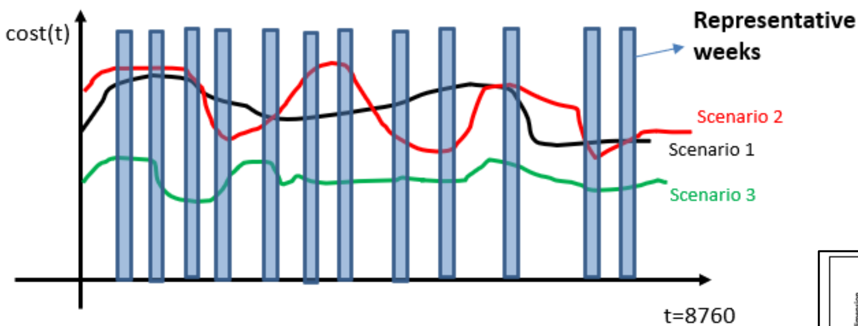
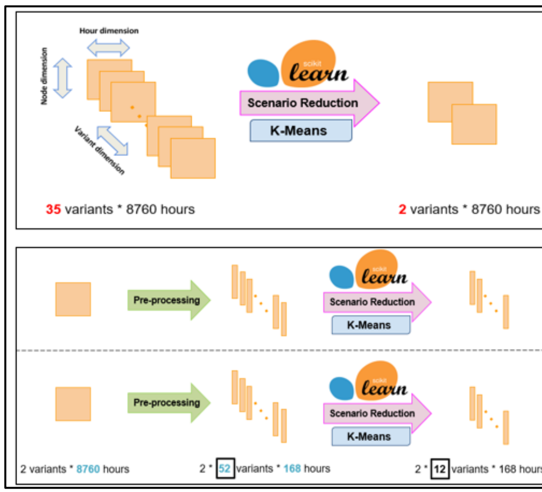
Reduction of the model size through clustering



In order to simplify the problem, only a few representative weeks are selected

A two-step approach is adopted in order to:

- select 12 representative weeks
- reduce 35 climatic variants to 2 equivalent ones:



STEP 1 *– It consists in performing a standard reduction on the number of yearly variants.*

STEP 2 *– it consists in splitting independently every remaining yearly variant in 52 weekly variants (pre-processing) and then performing a standard reduction on the number of weekly variants independently for each initial yearly variant.*

Grid expansion planning process

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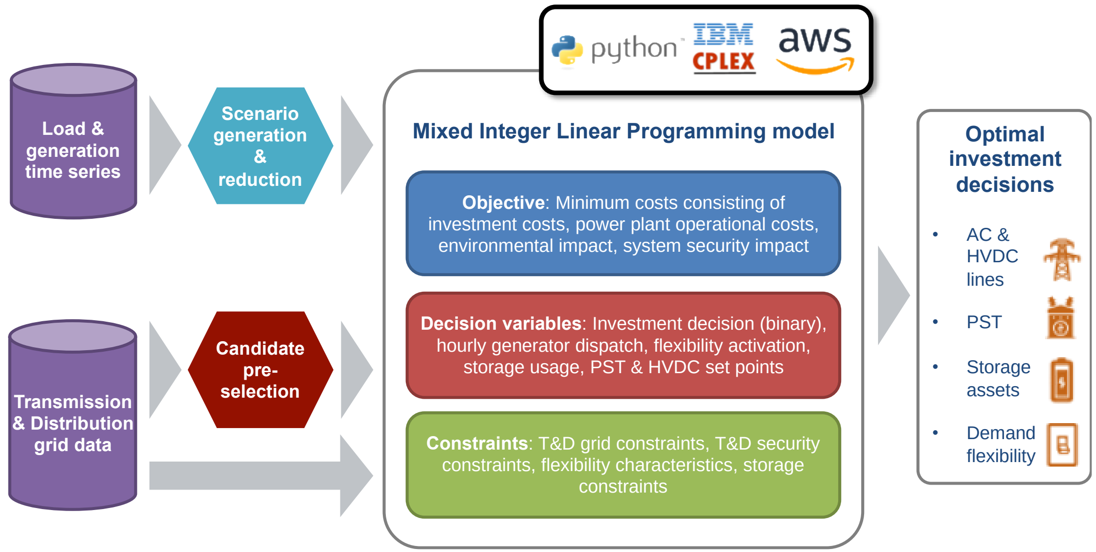
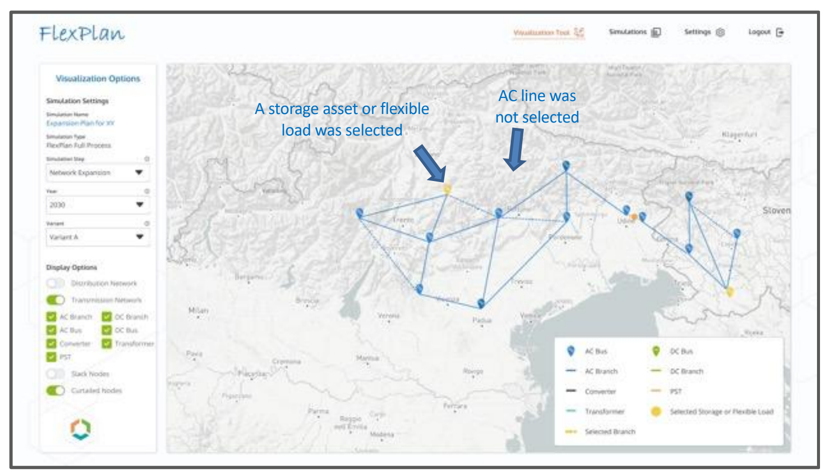
Methodology part

- Role of the **non-expanded Optimal Power Flow**
  - Simulation of the scenario and indication of the level of congestion for grid elements
- Role of **Pre-processor**
  - Identification of potential asset investments aimed at solving congestion (with priorities depending on congestion severity – Lagrange Multipliers)
  - Identification of nodes in which storage/demand flexibility can be beneficial for congestion management (using Locational Marginal Prices)
  - Proposal of storage technology based on characteristics of congestions and territory
- Role of **Planning tool**
  - Returns the list of the candidates which minimizes the total costs (CAPEX+OPEX), and details on their behavior

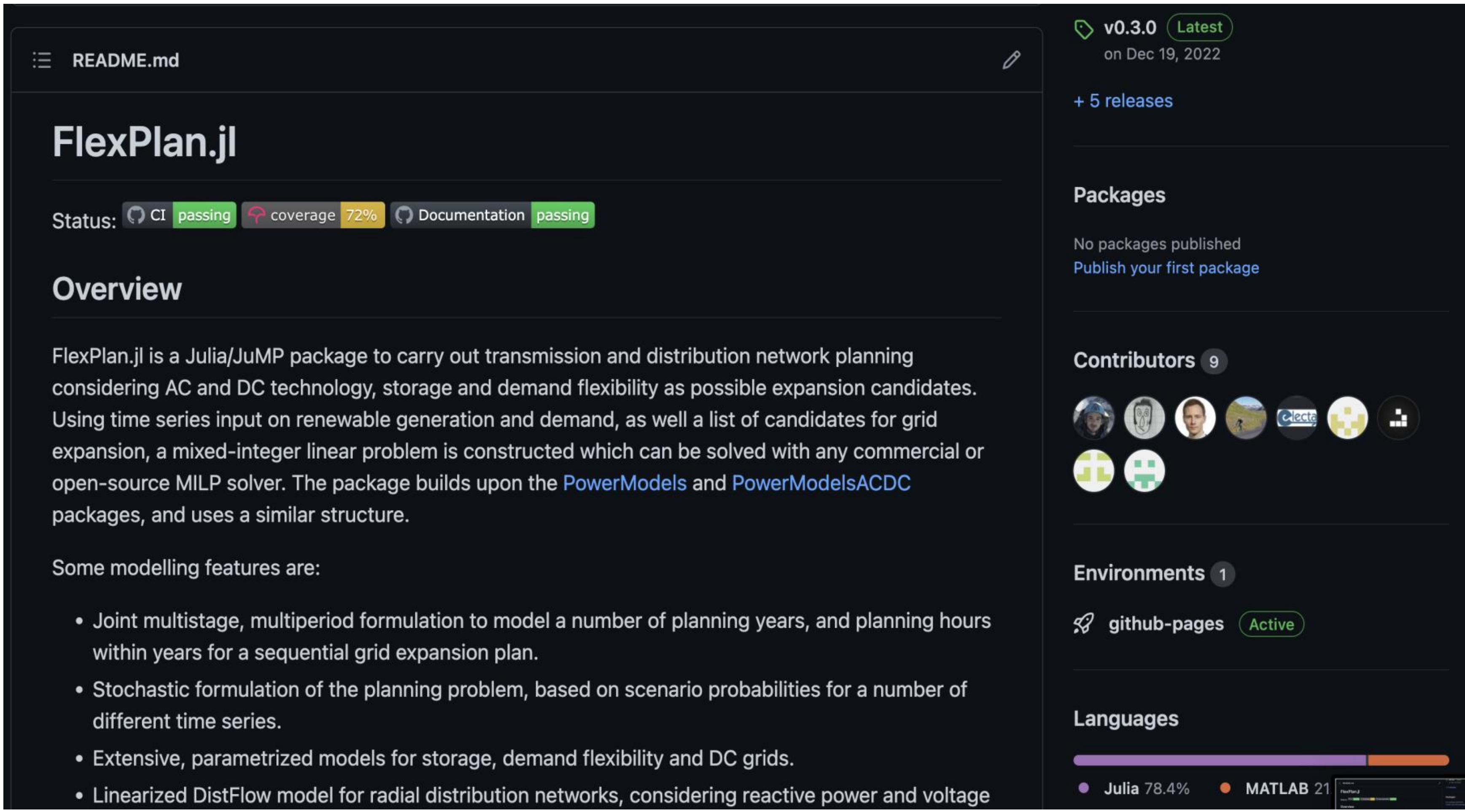
The FlexPlan planning tool





FlexPlan model – Open-source implementation

Electa-git / FlexPlan.jl



Agenda

FlexPlan

- Introduction
- Grid modelling
- Scenario data
- Results and analysis

Grid modelling

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- Data sources
- Data processing
- France & Benelux regional case
- Applied grid simplifications
- Assumptions
- Synthetic distribution networks

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Data sources

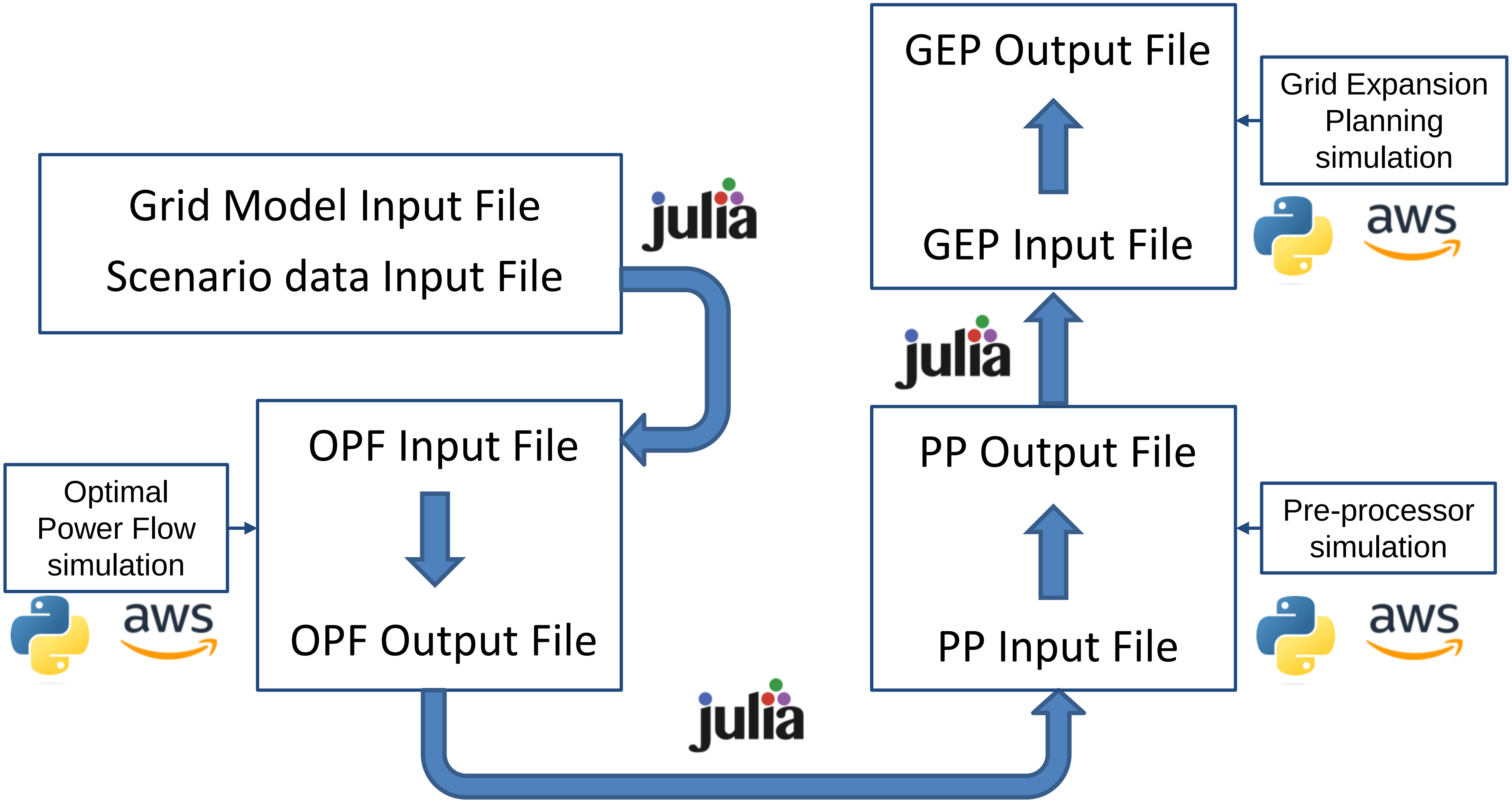
- France and Benelux grids: ENTSO-E TYNDP data

The modelling data for Benelux and French grid was provided initially in the PSS/E (.raw) format.

The data was converted to PowerModels.jl dictionaries for testing using an Optimal Power Flow (OPF) and further processing.

Data processing

For each planning year (2030,2040,2050):



France & Benelux regional case

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The RC is split in two areas because of the computation complexity of the problem.

After simplifications:

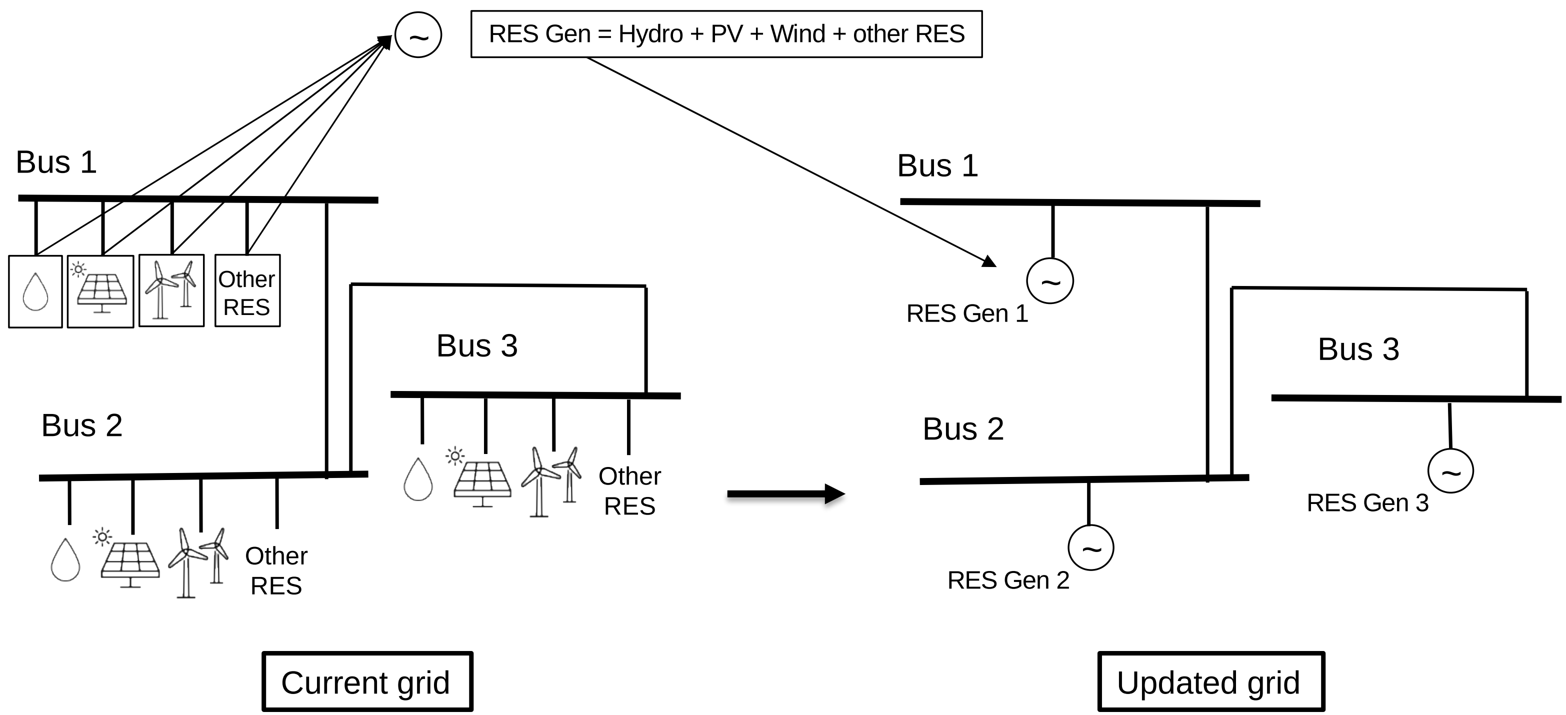
	France
Number of nodes	6649
of which in transmission network	2665
of which in distribution network	3984
Number of AC branches	6662
of which in transmission network	2922
of which in distribution network	3740
Number of transformers	868
Number of storages	6
Number of loads	3212

	BeNeLux
Number of nodes	3607
of which in transmission network	2390
of which in distribution network	1217
Number of AC branches	3181
of which in transmission network	2069
of which in distribution network	1112
Number of transformers	1128
Number of storages	2
Number of loads	1315

Applied grid simplifications

FlexPlan

- French grid reduction

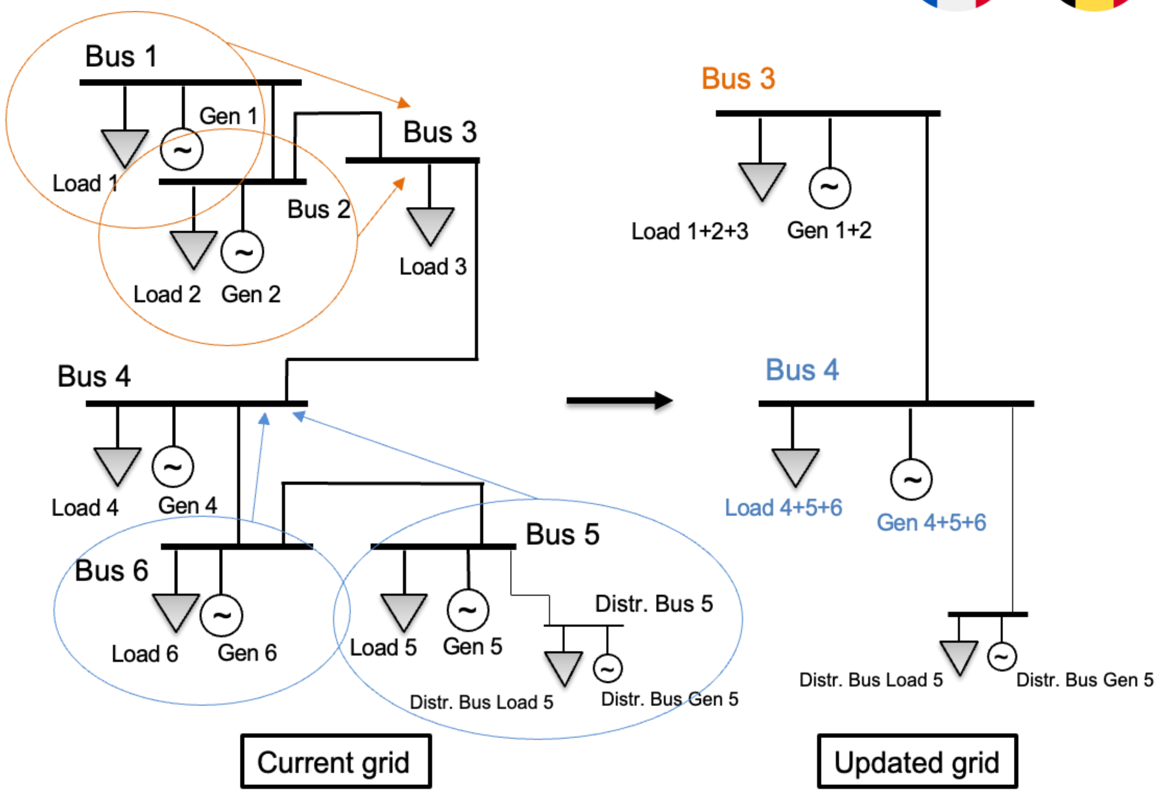


All RES sources are combined in a single RES generator for each bus without losing information

Applied grid simplifications

FlexPlan

- France & Benelux grid reduction



- The grid is reduced in sub-areas where buses, load and generators are combined
- Applied to selected buses
- The didstribution neworks are attached to the reduced bused without further reductions

Assumptions

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Grid Model input file:

- Value Of Loss Load (VOLL): 50 k€/MWh
- Generation curtailment cost: 235.6 €/MWh
  - Highest generation cost among the generators
- Generation cost: varying between 0 and 235.6 €/MWh
- Storage efficiency: 90%

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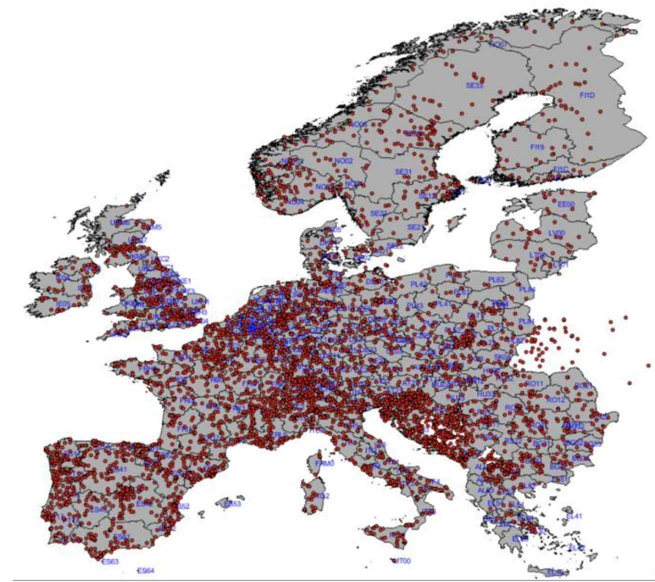
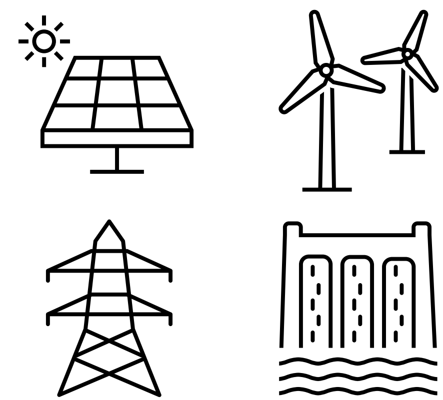
Time series from MILES

- MILES (Model of International Energy Systems) provides time series on regional level:
  - Renewable energy series:
    - Solar
    - Wind
    - Hydro reservoir
    - Hydro run of river (RoR)
    - Other renewable energy sources
  - Cross-border flows
- Time series are generated based on the TYNDP 2020 scenarios:
  - Distributed energy (DE)
  - Global ambition (GA)
  - National trend (NT)
- More details are provided in Deliverables 4.1 and 4.2





Data sources

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- France and Benelux data series: MILES data

Number of considered sub-regions per country per regional case:

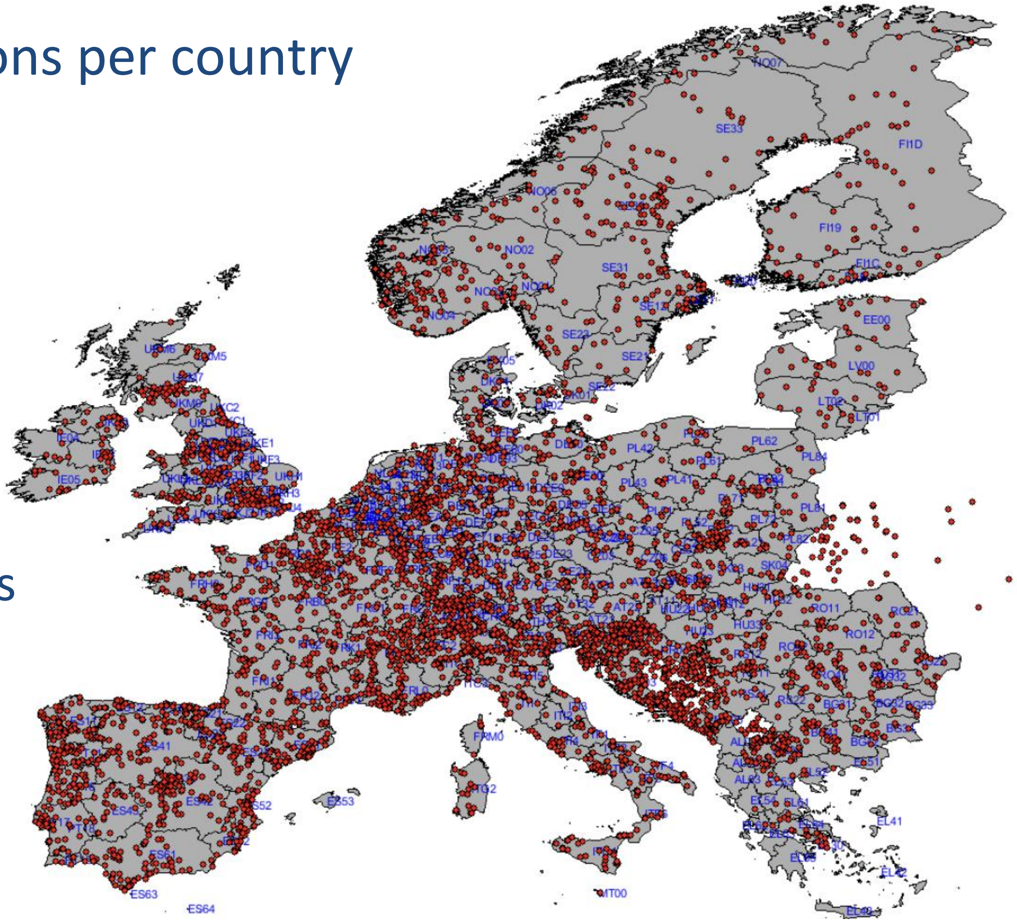
France: 766

Netherlands: 37

Luxembourg: 11

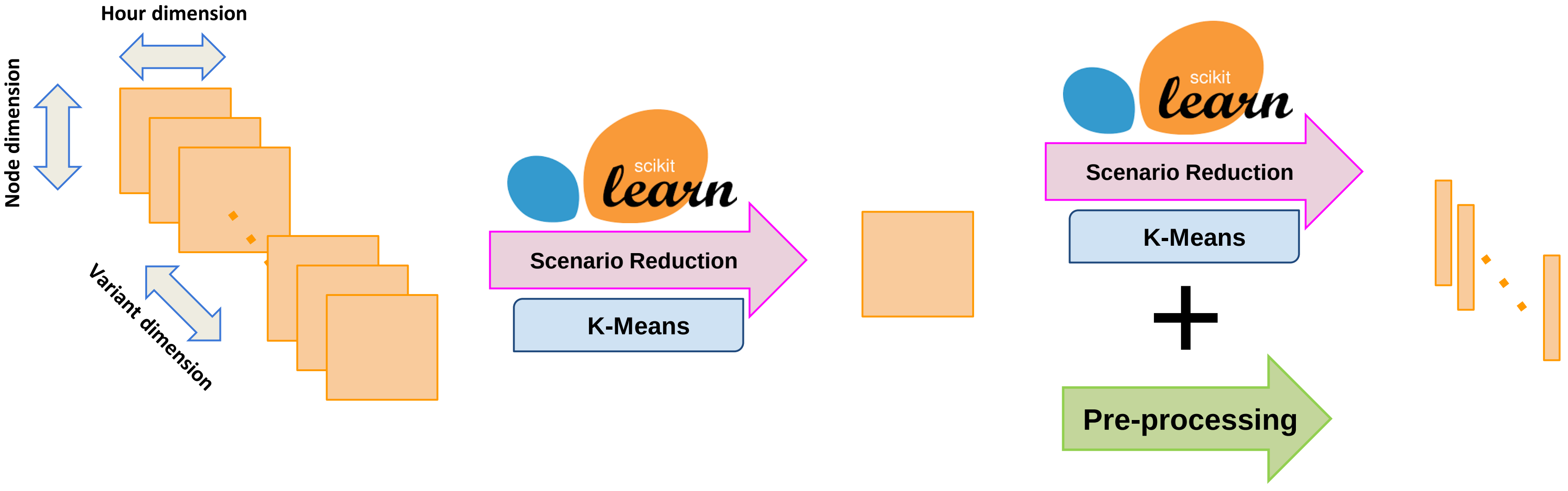
Belgium: 46

The MILES detailed output provides the installed generation capacity for each node of the transmission grid provided by ENTSO-E as an individual sub-region of the pan-EU results.



Transmission grid nodes in Europe considered as sub-region in MILES

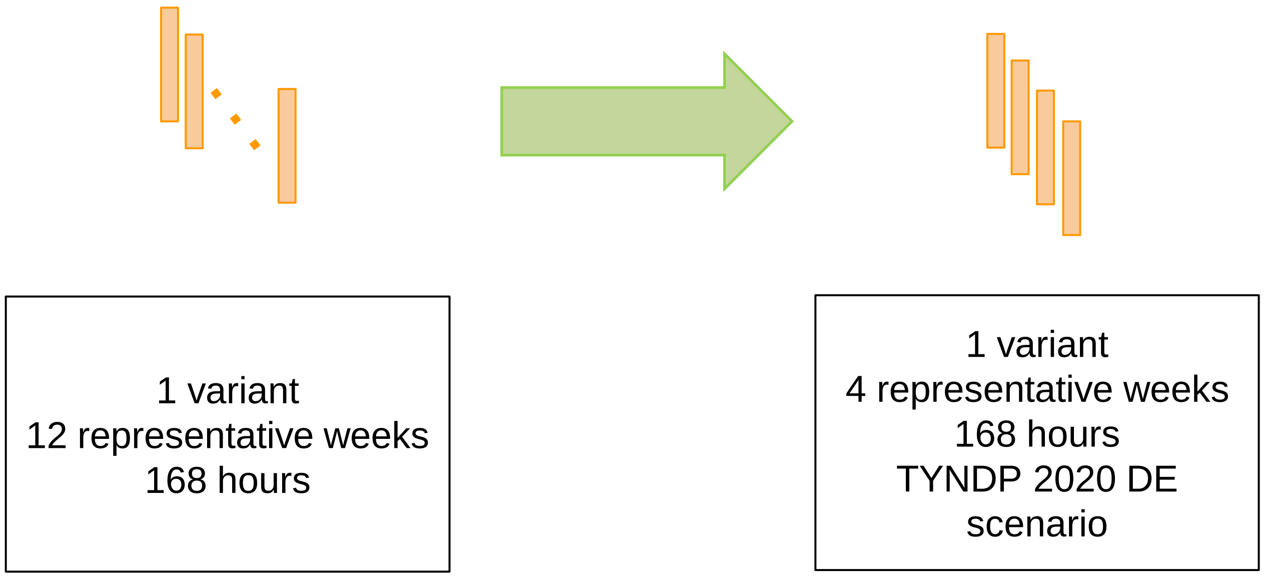
Scenario reduction



35 variants 8760 hours	1 variant 8760 hours	1 variant 12 representative weeks 168 hours

This process is conducted for all TYNDP 2020 scenarios

Scenario reduction



To reduce the size of the model further, the selected scenario is only based on the **distributed energy (DE)** scenario of TYNDP 2020

Scenario overview

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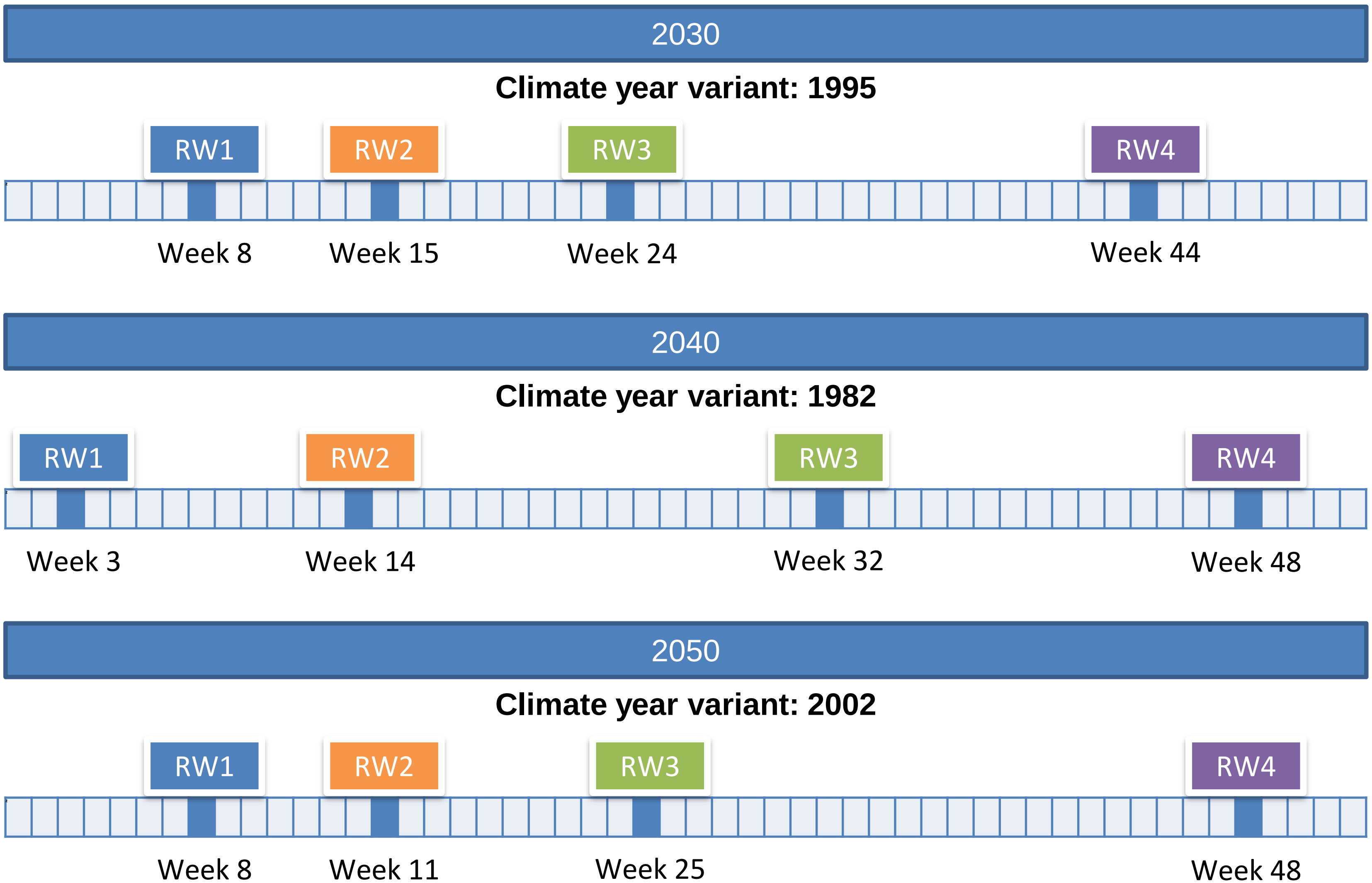

Scenario overview

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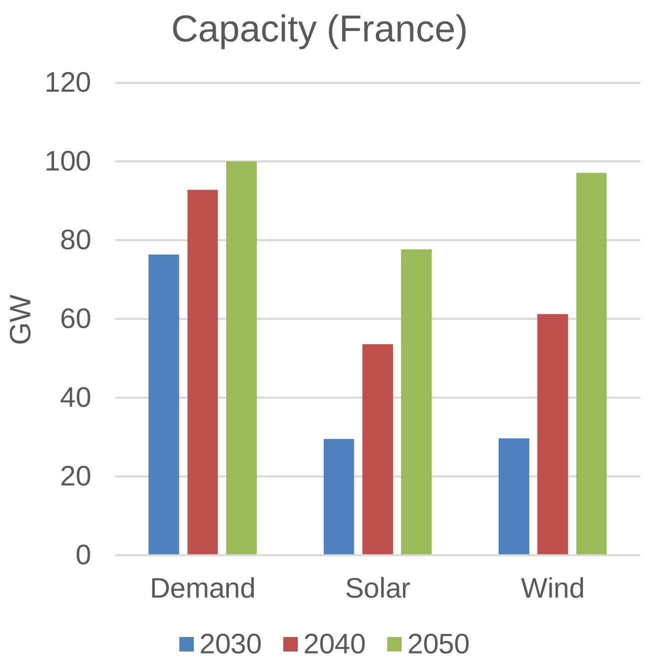
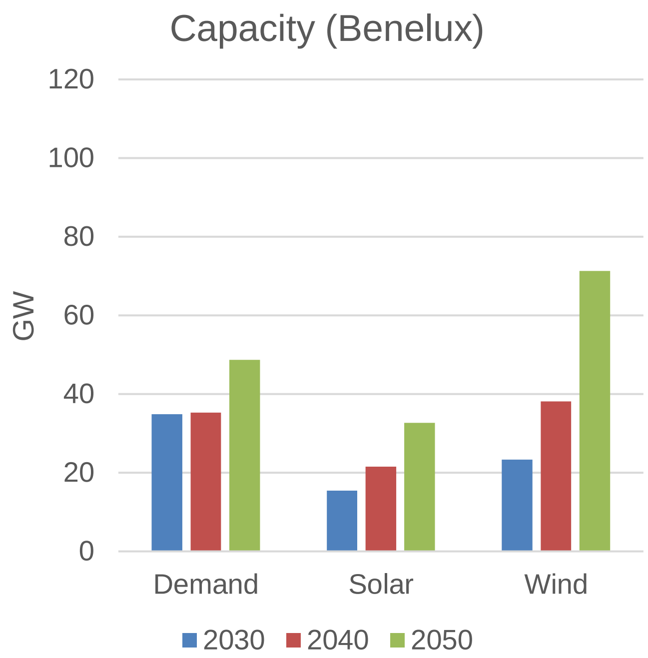
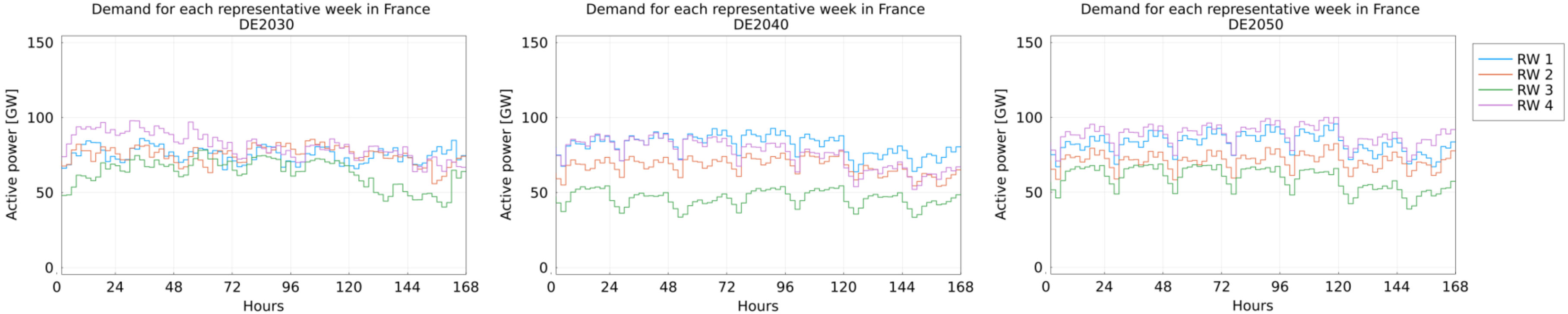
Demand and RES generation capacity in each year



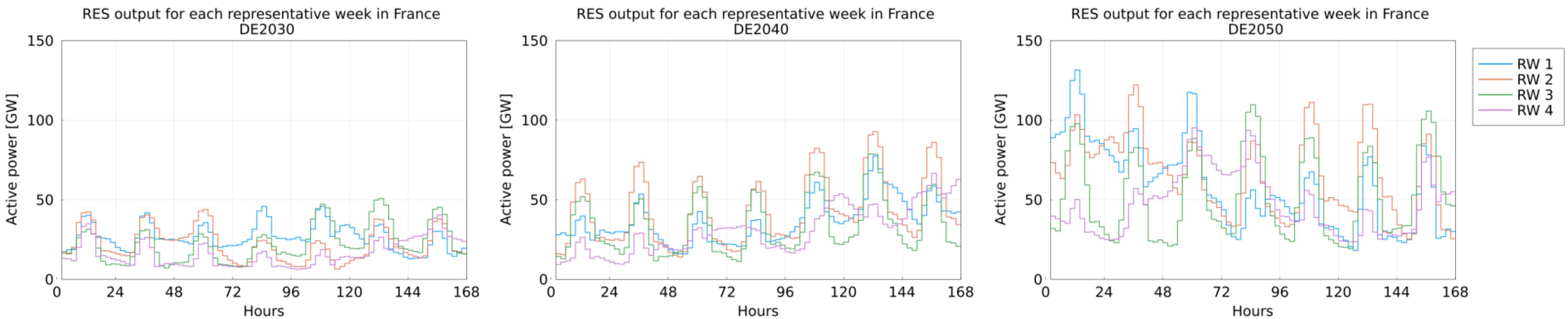


Time series - France

Demand



RES



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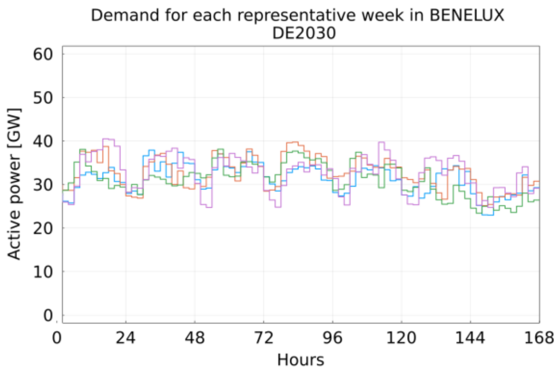
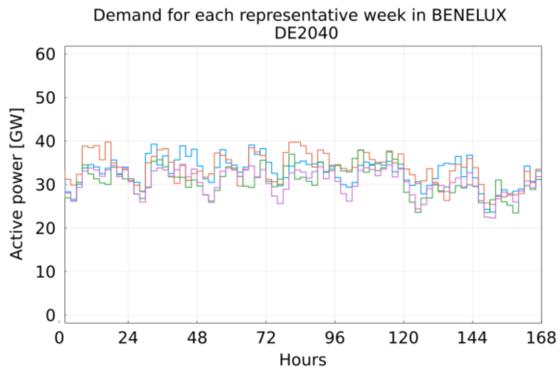
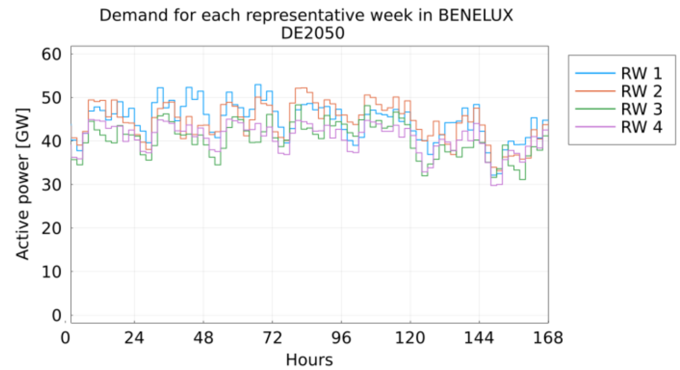
Time series - Benelux

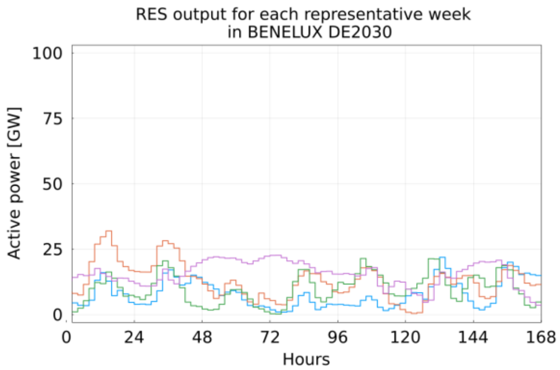
Demand

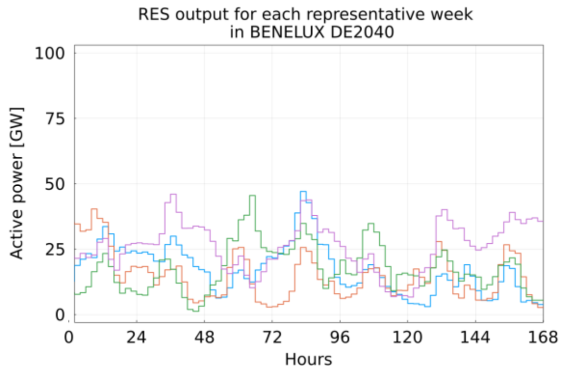


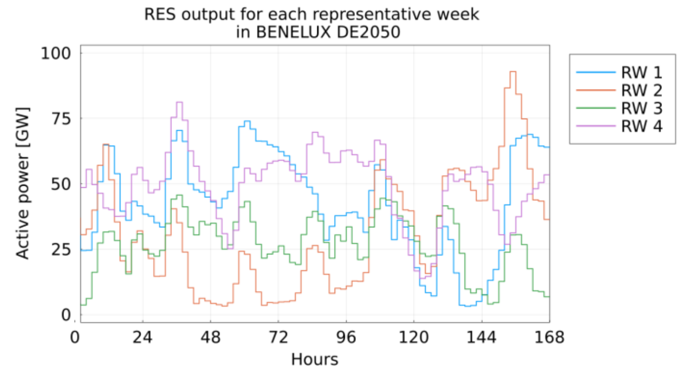




RES







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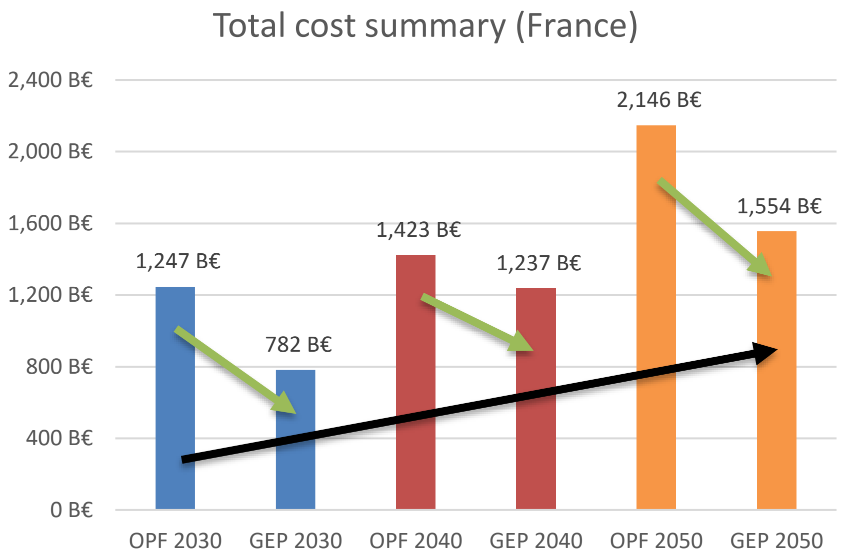
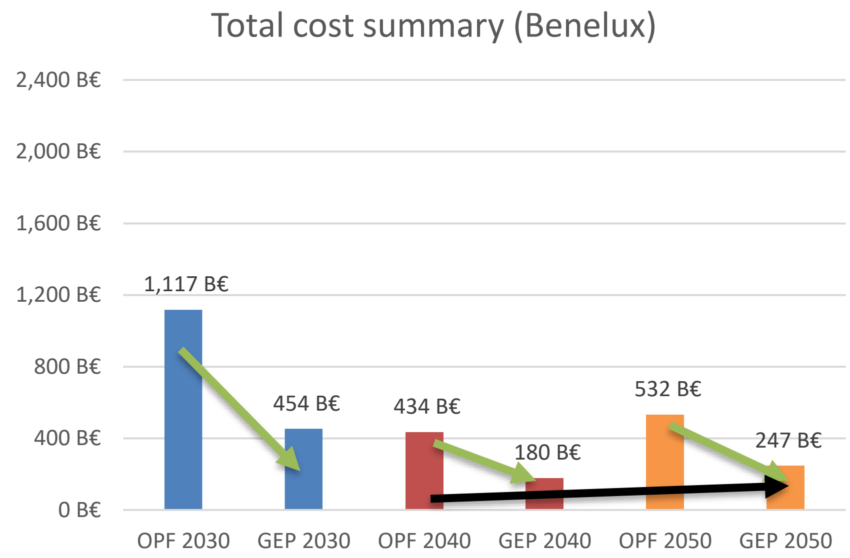
Overview of simplification

FlexPlan

Grid model	Scenario data	Simulation setup
Grid simplification by reducing the number of grid elements	1 climate year variant	MIP optimality gap of 0.01%
5% of distribution networks	1-decade time horizon instead of 3	
~100 planning candidates	4 representative weeks instead of 12	
	2-hour time resolution instead of 1 hour	

Results – Cost overview





The total costs decrease after performing grid expansion planning

In general, the total costs increase each year

Special case for Benelux from 2030 to 2040: the total cost decreases because many load curtailments are resolved in 2030 without significant increase of demand

Investment overview: candidates

FlexPlan

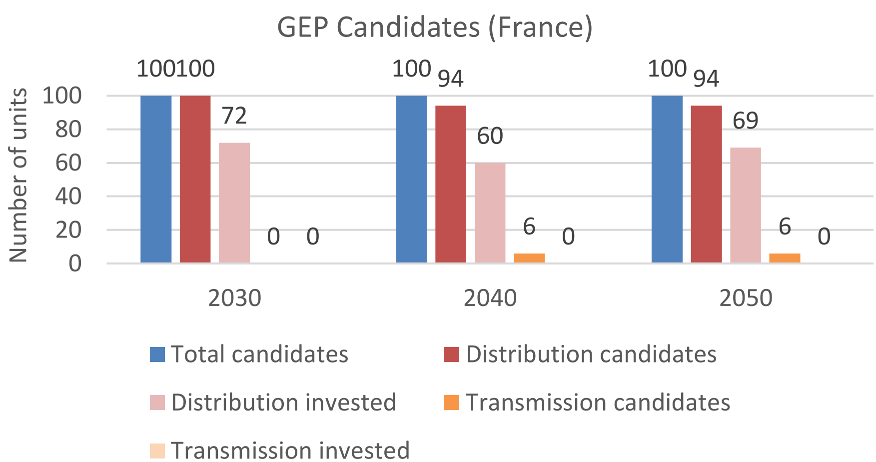
France

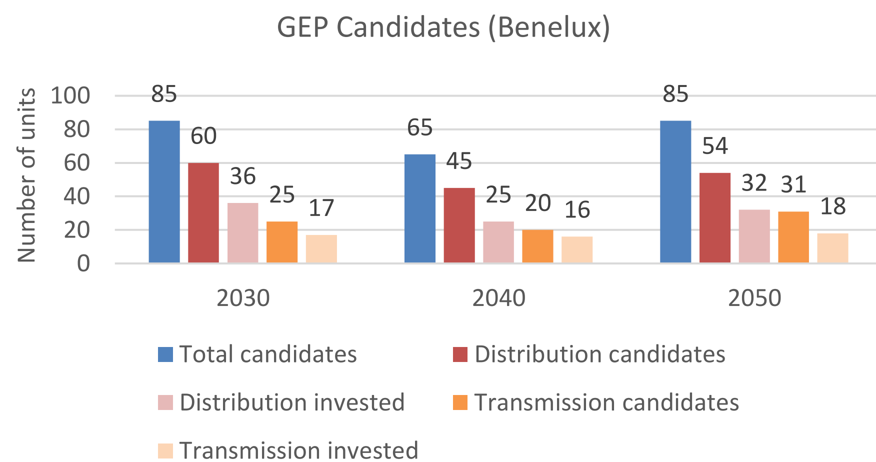
- Transmission candidates are added manually in 2040 and 2050
- No transmission candidates are built

Benelux

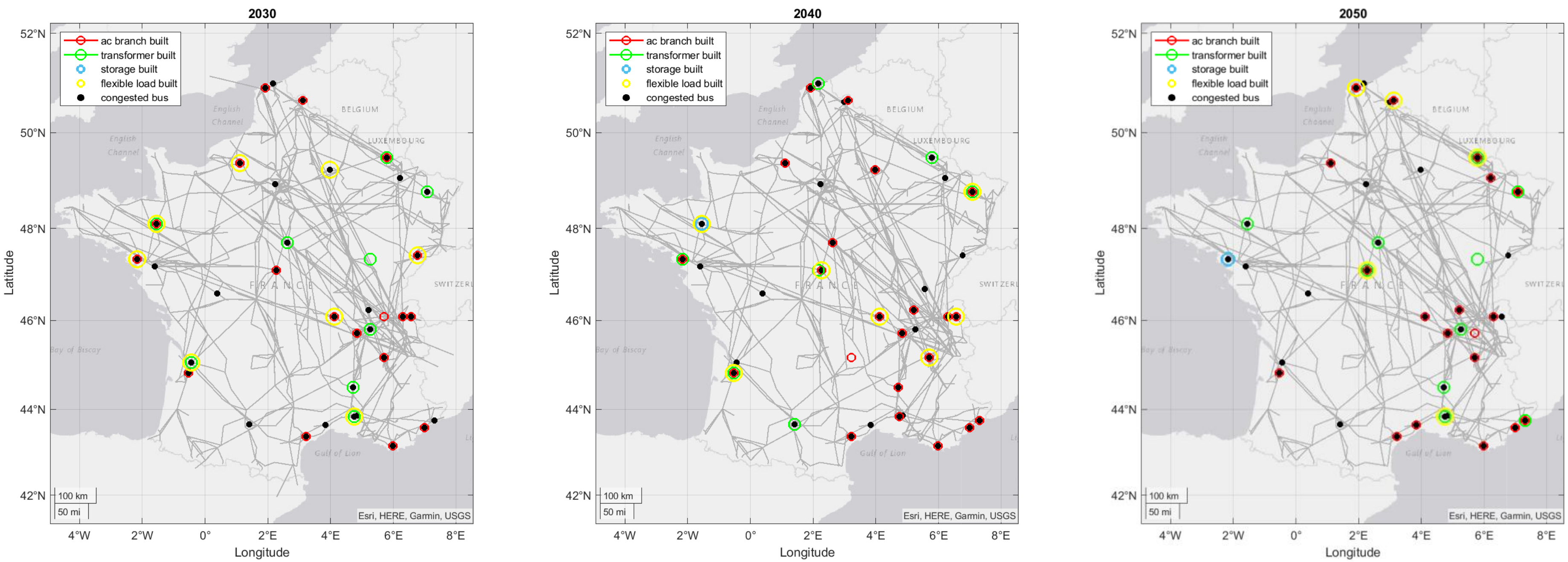
Due to some feasibility issues (some candidates are problematic):

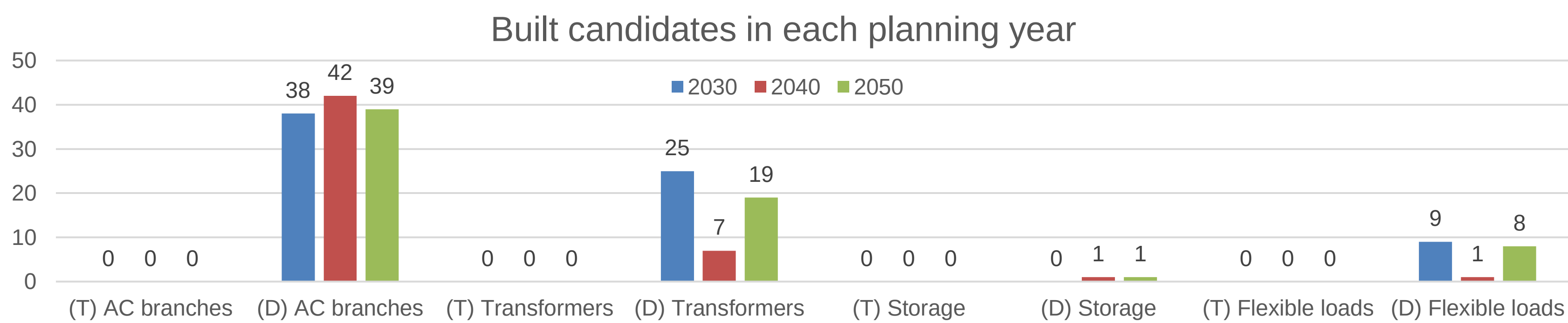
- Limited to 85 candidates in 2030 and 2050
- Limited to 65 candidates in 2040





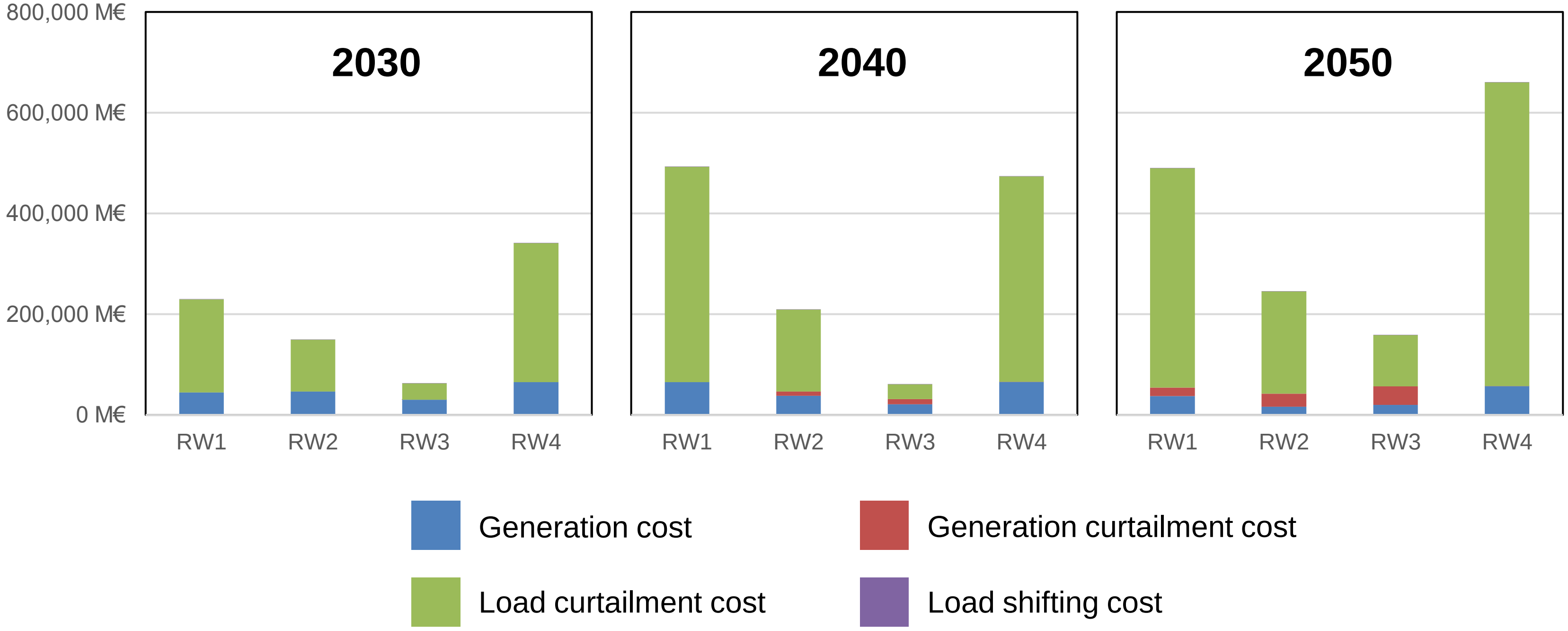
GEP France – Overview





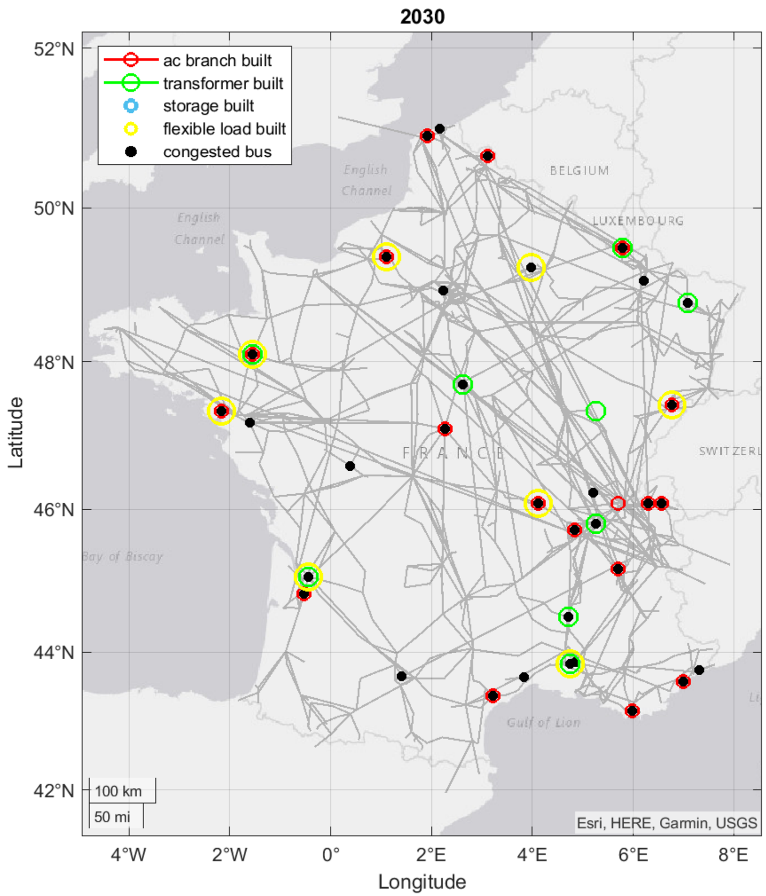
GEP France – Share of total GEP costs

FlexPlan



- In general, the total costs are higher in the autumn/winter weeks (RW1 and RW4) than in the spring/summer weeks (RW2 and RW3)
- The load curtailment cost accounts for most of the total costs
- The generation curtailment cost appear in 2040 and increase in 2050 due to the increase of renewable energy capacity

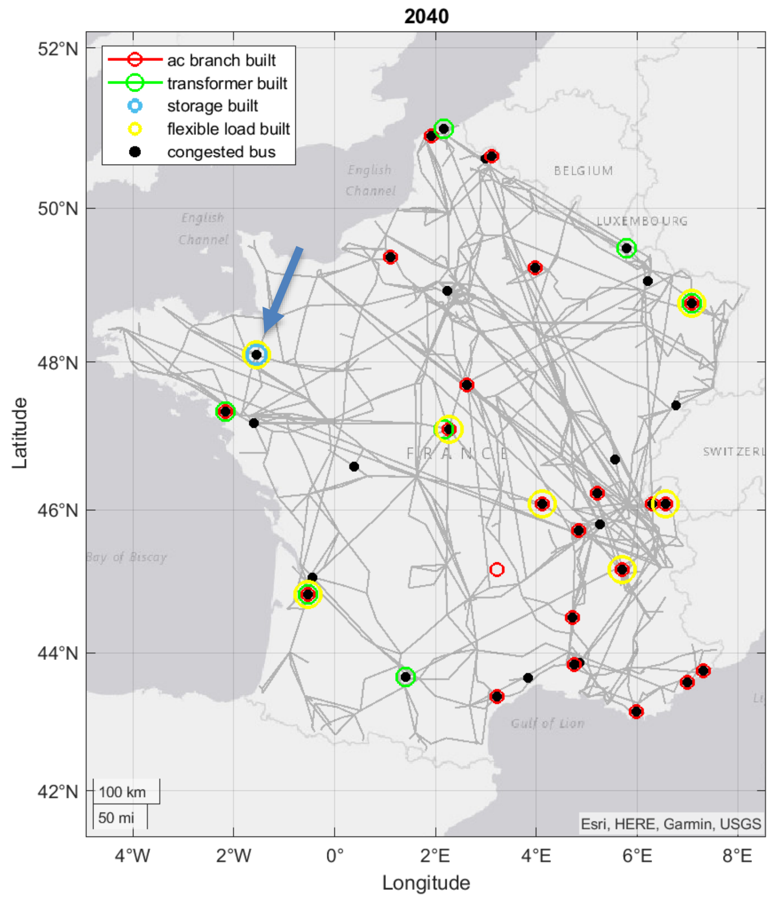
GEP France – 2030



Description of the candidates (T = transmission, D = distribution)				
Type	AC Branch	Transformer	Storage	Flexibility load
Total	60	25	0	15
Built	0 (T) 38 (D)	0 (T) 25 (D)	0	0 (T) 9 (D)
Rejected	0 (T) 22 (D)	0 (T) 0 (D)	0	0 (T) 6 (D)
Cost (€)	625445	1863393	0	9000

- Generally, we can see the candidates are in proximity to the identified congested buses
- Congestions mostly occur in the distribution networks
- No transmission candidates
- No storage candidates

GEP France – 2040

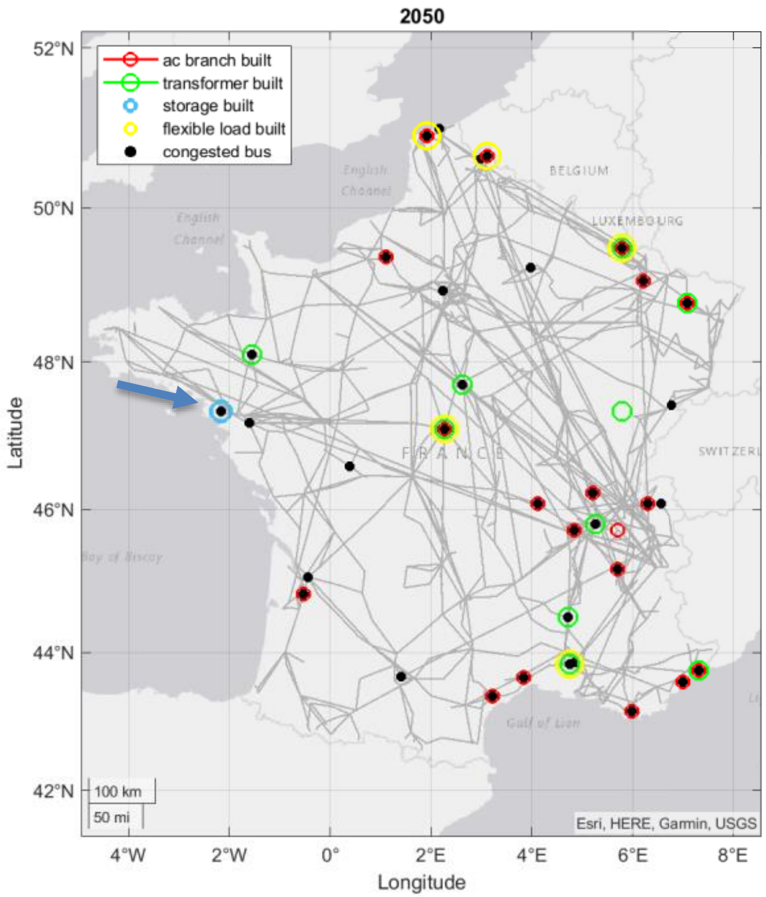


Description of the candidates (T = transmission, D = distribution)				
Type	AC Branch	Transformer	Storage	Flexibility load
Total	79	7	1	13
Built	0 (T) 42 (D)	0 (T) 7 (D)	0 (T) 1 (D)	0 (T) 8 (D)
Rejected	6 (T) 31 (D)	0 (T) 0 (D)	0 (T) 0 (D)	0 (T) 5 (D)
Cost (€)	1006757	1378346	215120	8000

- The congested buses are on similar locations as in 2030
- No transmission candidates
- 1 storage candidate on the distribution level (Rennes)

GEP France – 2050

FlexPlan

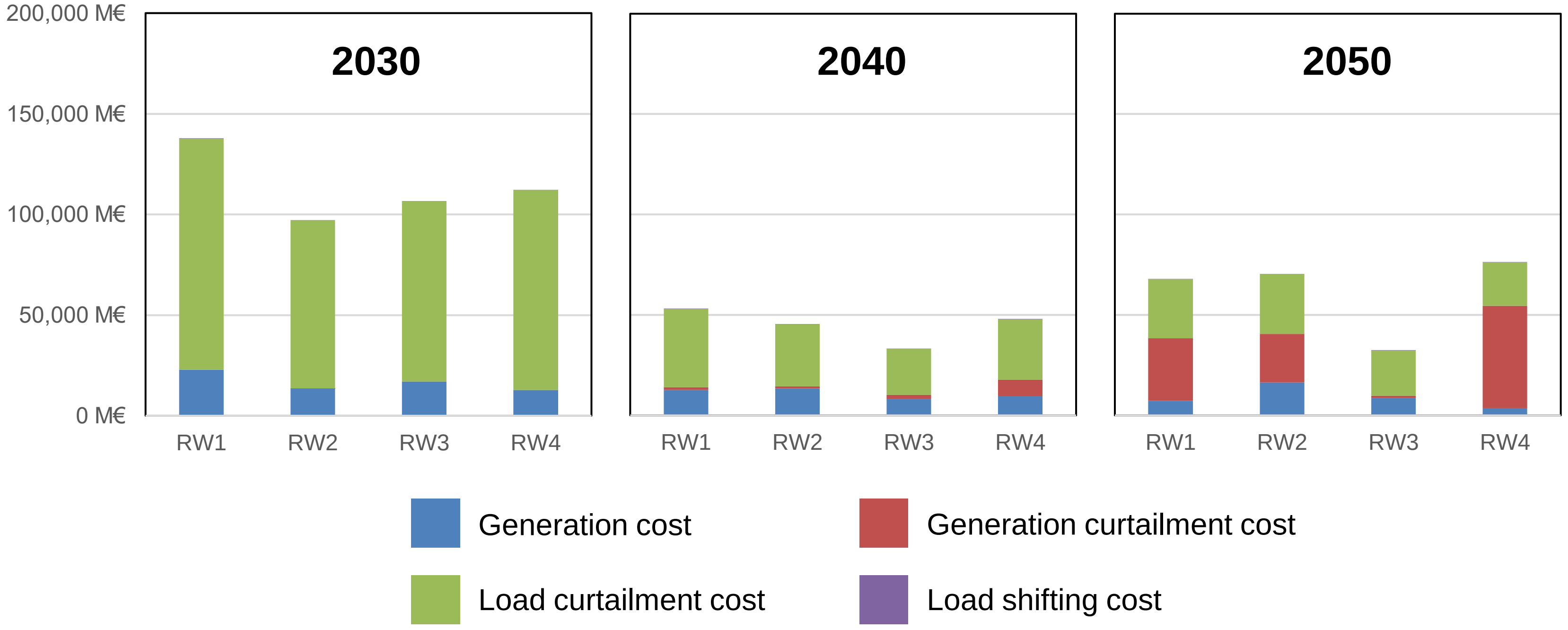


Description of the candidates (T = transmission, D = distribution)				
Type	AC Branch	Transformer	Storage	Flexibility load
Total	67	19	2	12
Built	0 (T) 39 (D)	0 (T) 19 (D)	0 (T) 1 (D)	0 (T) 8 (D)
Rejected	6 (T) 22 (D)	0 (T) 0 (D)	0 (T) 1 (D)	0 (T) 4 (D)
Cost (€)	748803	2246660	201600	8000

- The candidates are still dominated by distribution ac branches
- One built storage candidate (Nantes) and one rejected storage candidate on the distribution level

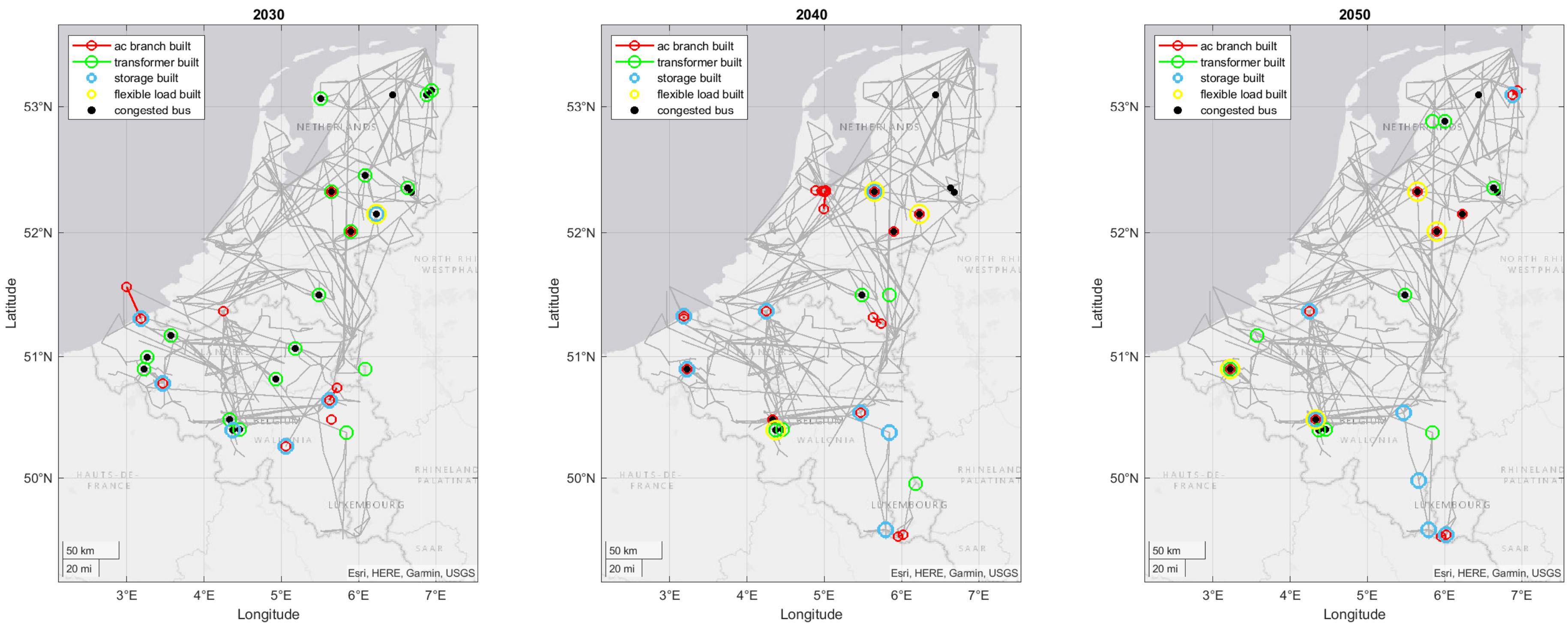
GEP Benelux – Share of total GEP costs

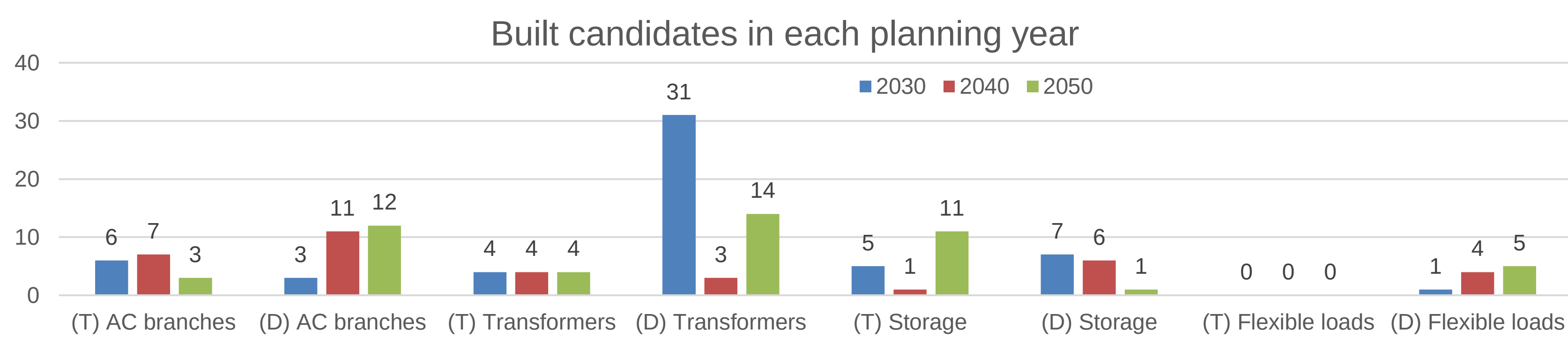
FlexPlan



- Similar to the French case, the total costs are higher in the autumn/winter weeks (RW1 and RW4) than in the spring/summer weeks (RW2 and RW3) although the differences are less significant than in the French case
- The load curtailment costs account for most of the total costs with a notable decrease in 2040
- The generation curtailment costs significantly increase in 2050. However, we can also see that the total generation cost in 2050 is overall reduced.

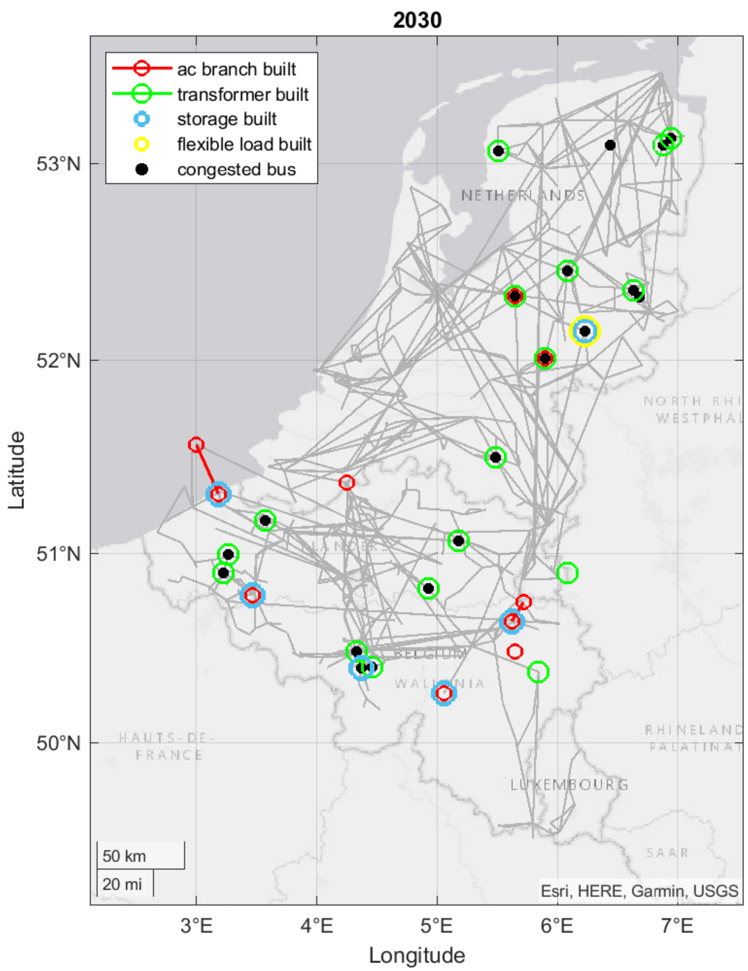
GEP Benelux – Overview





GEP Benelux – 2030

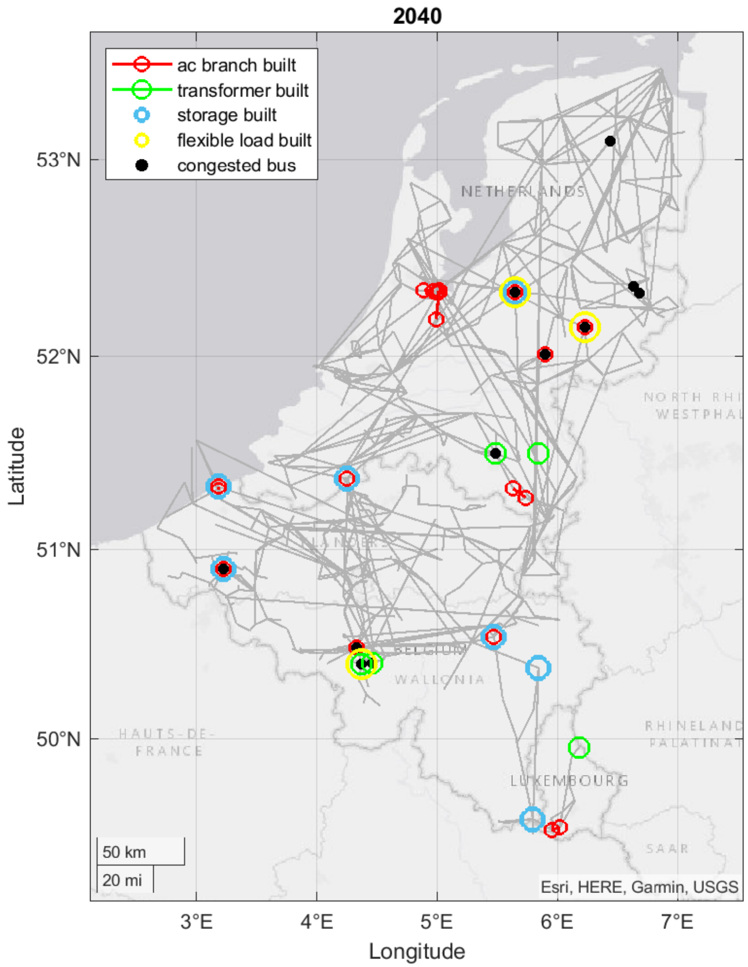
FlexPlan



Description of the candidates (T = transmission, D = distribution)				
Type	AC Branch	Transformer	Storage	Flexibility load
Total	13	35	19	18
Built	6 (T) 3 (D)	4 (T) 31 (D)	5 (T) 7 (D)	0 (T) 1 (D)
Rejected	0 (T) 4 (D)	0 (T) 0 (D)	0 (T) 7 (D)	3 (T) 14 (D)
Cost (€)	625445	1863393	0	9000

- Compared to the French case, more congestions are identified on the transmission level
- Built candidates are mostly transformers, scattered around the network, to relieve congestions both in the transmission and distribution networks

GEP Benelux – 2040

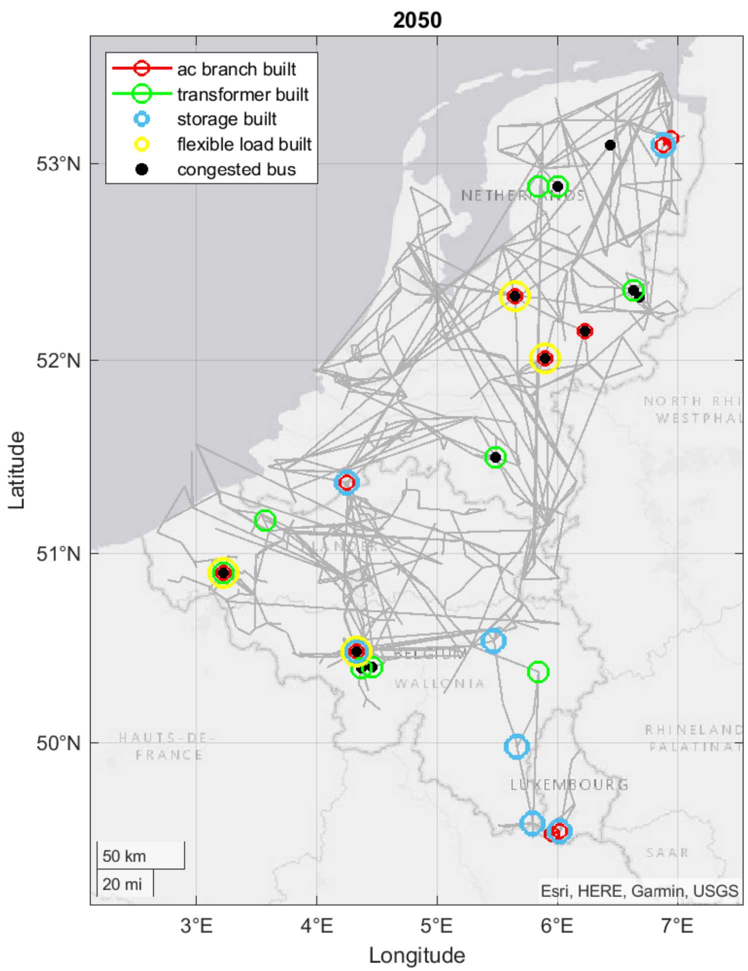


Description of the candidates (T = transmission, D = distribution)				
Type	AC Branch	Transformer	Storage	Flexibility load
Total	28	7	19	11
Built	7 (T) 11 (D)	4 (T) 3 (D)	1 (T) 6 (D)	0 (T) 4 (D)
Rejected	2 (T) 8 (D)	0 (T) 0 (D)	5 (T) 7 (D)	2 (T) 5 (D)
Cost (€)	3389394	3384234	12638730	4000

- Most congestions occur on the distribution network
- More storage candidates are built in the distribution network

GEP Benelux – 2050

FlexPlan



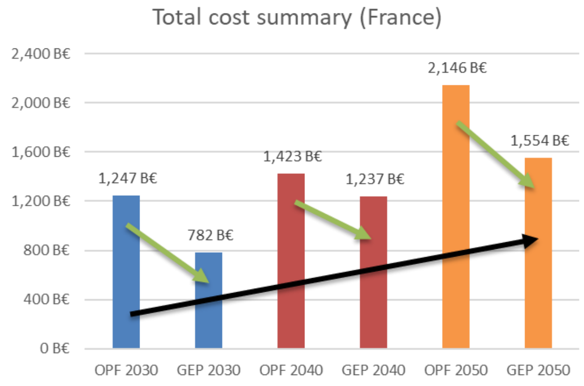
Description of the candidates (T = transmission, D = distribution)				
Type	AC Branch	Transformer	Storage	Flexibility load
Total	33	18	20	14
Built	3 (T) 12 (D)	4 (T) 14 (D)	11 (T) 1 (D)	0 (T) 5 (D)
Rejected	7 (T) 11 (D)	0 (T) 0 (D)	2 (T) 6 (D)	4 (T) 5 (D)
Cost (€)	889368	6852213	30354082	5000

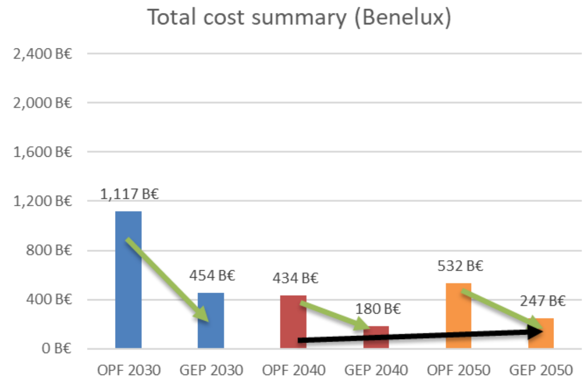
- More storage candidates are built in the transmission network
- More storage units are closer to the border with Luxembourg

Conclusion

FlexPlan

- The FlexPlan planning methodology has been demonstrated on the French and Benelux electrical networks
- Several assumptions and simplifications have been made to complement available data and feasible model outcomes
  - **Results can only be interpreted as indicative**
- The results show that the investments in the form of **AC branches, transformers, storage units, and flexible loads** from the pre-processor tool reduce the total operation costs in each planning year
- There are limitations to demonstrate results close to reality due to the accuracy of the data. This, however, can be improved through more collaborations with the stakeholders in the future as a follow-up on the project





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