Contenu CO_2 du mix électrique suisse et implications sur le développement des pompes à chaleur et du photovoltaïque

E.Romano

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UNIGE – Energy Seminar

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Questions to be answered:

- What is the real value of the carbon intensity from grid electricity ?
  - [1] Romano E., Hollmuller P., Patel M. «Assessing hourly-carbon emission due to electricity consumption - an incremental approach for an open economy The case of Switzerland», submitted paper : Université de Genève, Switzerland; 2018.

- What is the carbon savings of heat-pump in multi-family buildings with different heat demand?
  - [2] Romano E., Bertholet J.L, Fraga C., Hollmuller P., Patel M. «**Carbon savings with heat-pumps and PVs in multi-familes building ”,** Université de Genève, Switzerland; 2019.

CO_2 emissions : Swiss electricity generation

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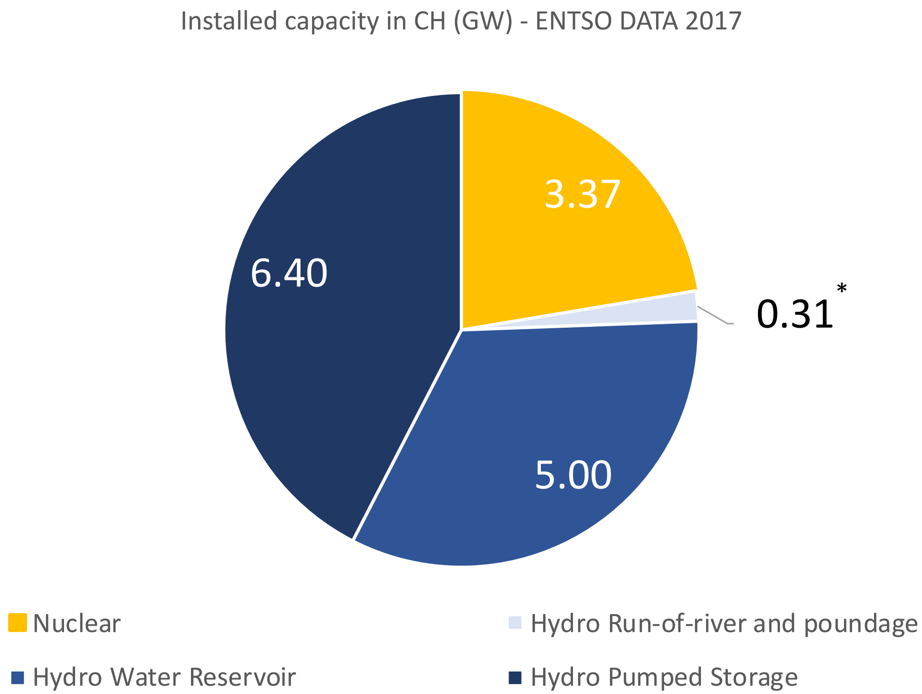


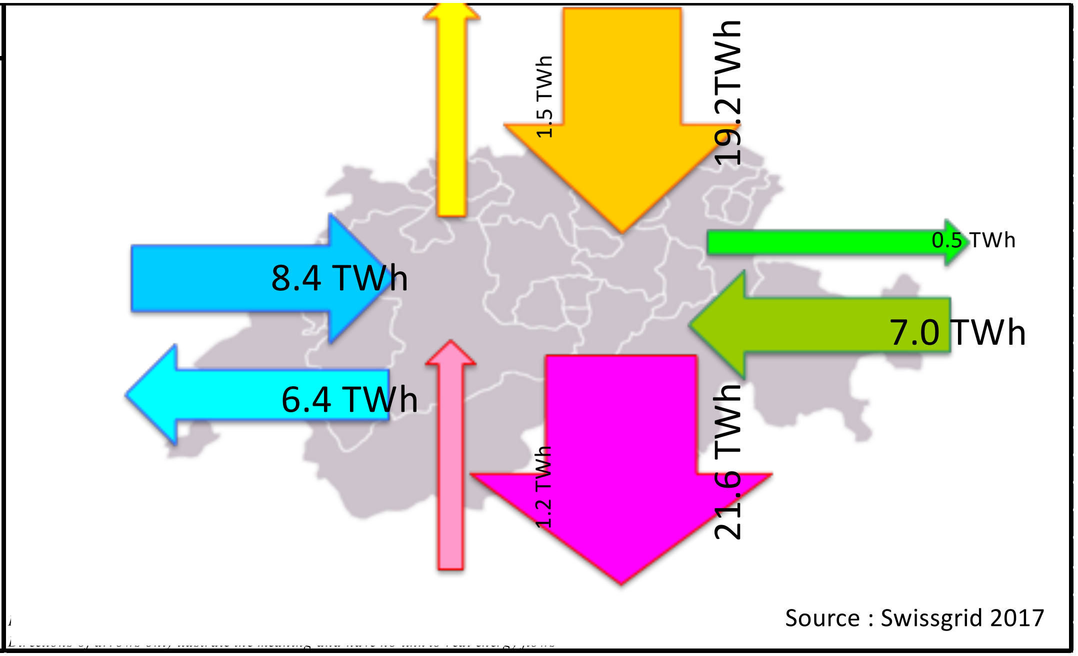
- Total installed capacity: 15.4 GW
- The generated electricity mix (TWh) is based on non-emitting technologies

(*) Plants with a generation capacity under 100MW are not required to transmit data under REMIT

Switzerland : a country at the heart of the grid

Verbundaustausch
Cross Border Exchange

CH→AT	E	457 774	MWh
	Pmax	1 092	MW
AT→CH	E	7 053 956	MWh
	Pmax	2 233	MW
CH→DE	E	1 558 591	MWh
	Pmax	2 845	MW
DE→CH	E	19 284 034	MWh
	Pmax	5 440	MW
CH→FR	E	6 363 545	MWh
	Pmax	2 987	MW
FR→CH	E	8 438 037	MWh
	Pmax	2 845	MW
CH→IT	E	21 615 970	MWh
	Pmax	5 360	MW
IT→CH	E	1 262 485	MWh
	Pmax	2 344	MW



Source : Swissgrid 2017

- Electricity consumption (2017) : 58.5 TWh
- Electricity generation (2017) : 61. 5TWh
- Total of exchanges (Imports 36.5 TWh / Exports : 30.9 TWh)

Neibourghing countries : Installed capacity

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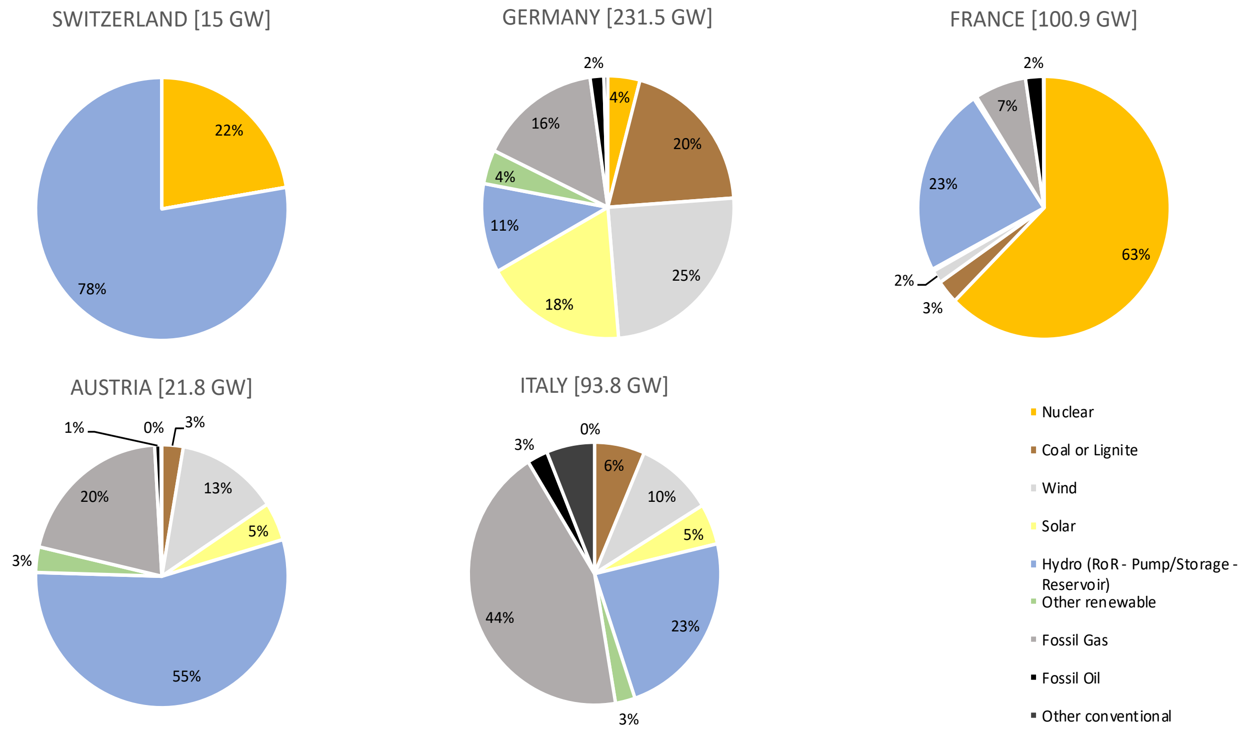

- Some neighbouring countries rely on a high-share of fossils fuels technologies.
- In DE, a small share of the installed capacity (2%) represents other conventional plants, which used blast furnace gases and coke gases for electricity generation.

Data : ENTSO 2017 / UNIGE

CO_2 emissions from electricity generation & consumption

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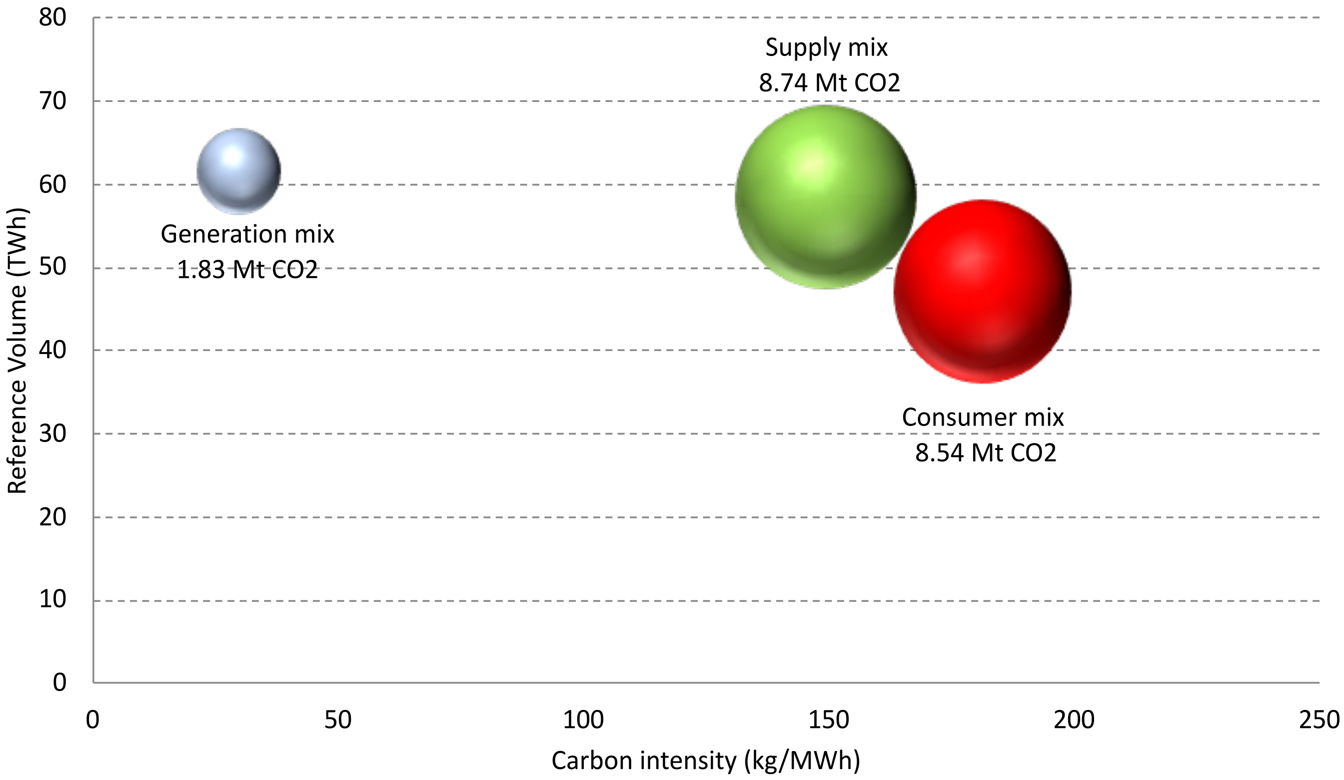
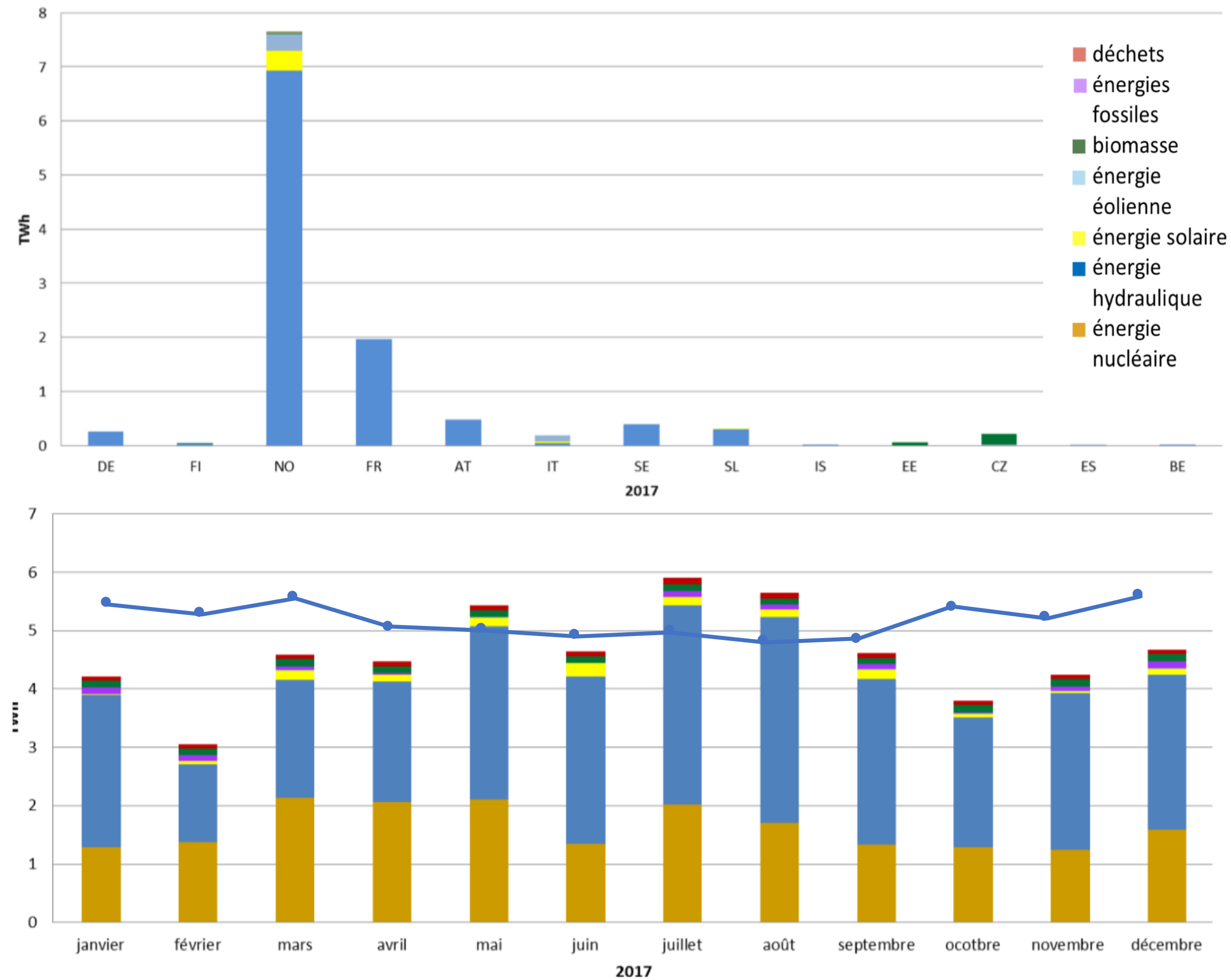
- In Switzerland, current methodologies to account for the consumption footprint are based guarantee of origins (Domestic and Europeans)



- **Generation mix :**
  The value is computed for the electricity generated in Switzerland
  Generation : 70 TWh
  CO_2 emissions 2014 : 1.6Mt CO_2
- **Supplier mix :**
  Certified electricity (Certifications) by supplier through the GO system
  Consumption : 57.46 TWh
  CO_2 emissions 2014 : 7.9Mt CO_2
- **Consumer mix :**
  Carbon footprint for non-certified consumption
  Consumption : 46.10 TWh
  CO_2 emissions 2014 : 7.8 Mt CO_2

Source : OFEV 2016, based on 2014 data

Limits of the labelling system



Source : Pronovo 2017

- Some certificates are imported from Norway, or ENTSO-E countries which have no interconnections with CH.

- Guarantees of origin in CH are generated over the summer when consumption (blue line) profile is at the lowest.

Limits of the labelling

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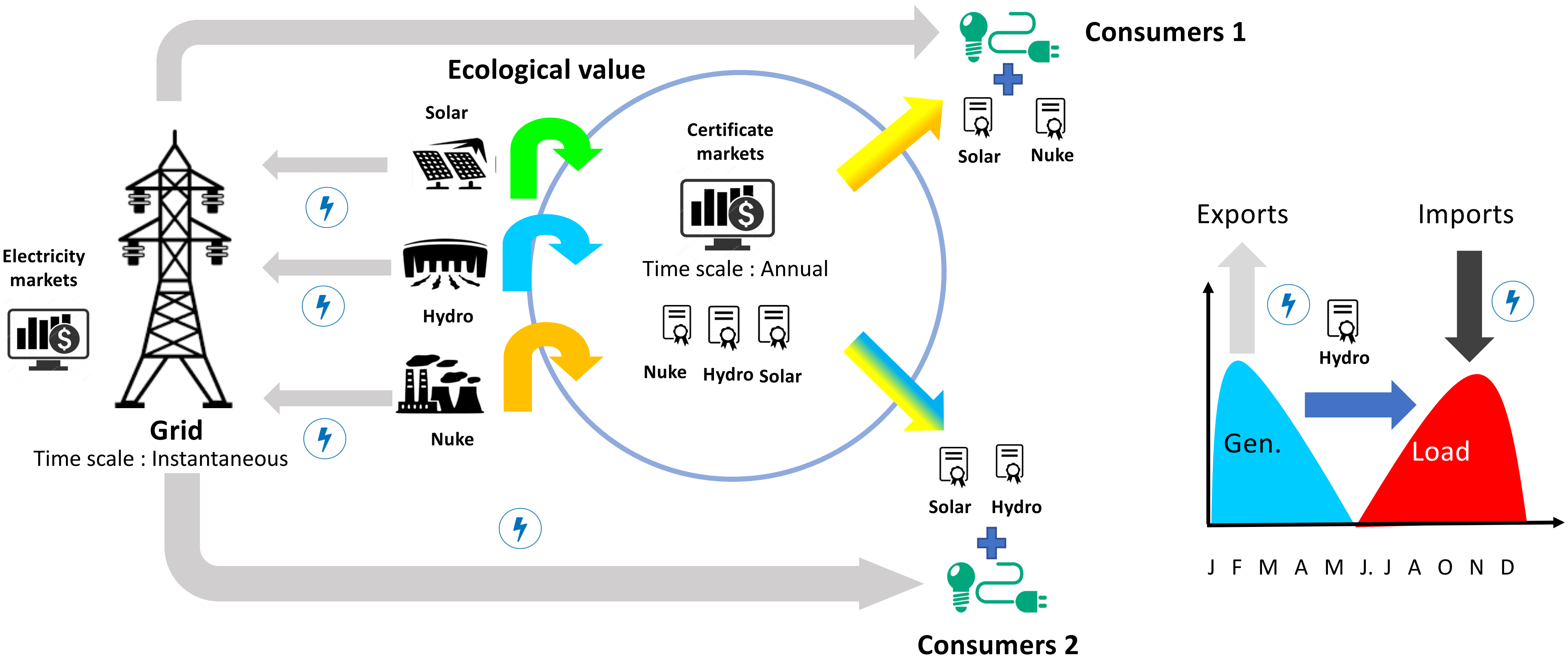

- Certificates are delivered to a producer on the basis of the annual electricity generation of their plant
- The certificates do no provide a guarantee of the simultaneity between generation injections and consumption withdrawals

Existing approaches in the scientific literature

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	Emissions responsibility	Domestic generation mix	Imports generation mix	Computational period
Approach A	Production	Average Mix	-	Yearly
Approach B	Consumer	Certified Mix	Certified or European Residual mix	Yearly
Approach C	Consumer	Average Mix	Average Mix for Direct or Indirect flows	Yearly – daily - hourly
Approach D	Consumer	Marginal	Assumptions on imports mix	Hourly
Our approach :	Consumer	Marginal	Marginal	Hourly

Marginal impact of imports on CO_2 emissions

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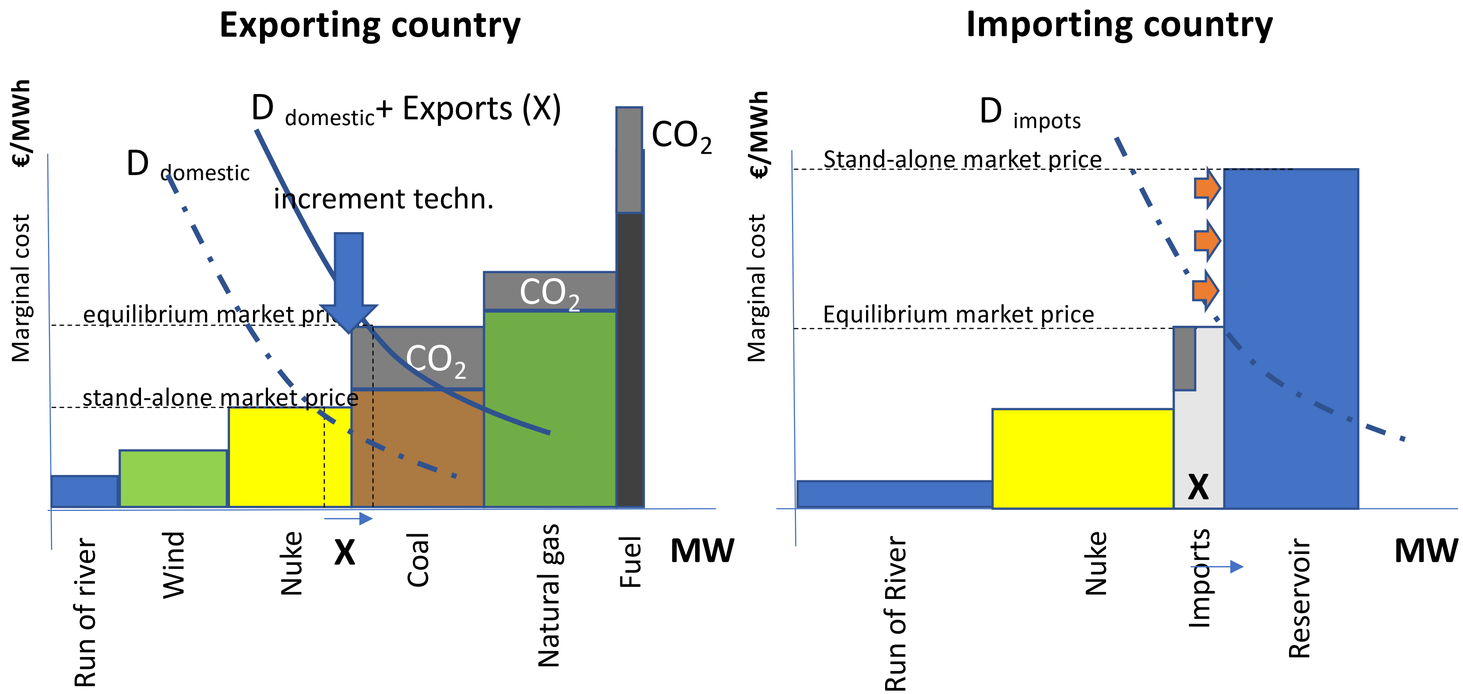

- Electricity is dispatched according to merit order based on the marginal cost of each technology (including CO_2 price)
- Prices and exchanges between countries are defined according to supply and demand for each hour.
- Generation costs in a country are minimized, to satisfy demand, thanks to the optimisation of the power plant program (vs. market prices) and through power exchanges over transmission capacities.
- When imports occurs, the **marginal impact of imports** on the merit order of neighbouring countries could be estimated.

- EU Regulation EU N° 1227/2011 & EU N°2013/543, the following data are made available by market participants :
  - **Load data**
  - **Network and congestion management data**
  - **Transmission data**
  - **Installed aggregated capacity**
  - **Generation data (dispatch data)**
  - **Market price**
- The data granularity is the hour or quarter of hour (8760 h/year or 35040/year).
- Data are provided through different platforms (EEX, ENTSO-E, Swissgrid...).

Marginal cost by technologies

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- Values are issued from Comaty F, Ulbig A, Andersson (2014)
- Electricity markets are energy only markets based on the merit order

#	Technology*	Marg. Cost (€/MWh)	#	Technology	Marg. Cost (€/MWh)
1	Wind-on-Shore	0	10	Waste	26.1
2	Wind-off-Shore	0	12	Coke	35.1
3	Solar	0	12	Coal-Gas	n.a.
4	Run-of-River	3.9	13	Gas	53.3-67.8
5	Geothermal	4.2	14	Other conventional**	50-70
6	Biomass	6.9 - 56.6	15	Storage hydroelectricity	70-120
7	Other renew.	n.a.	16	Pumped-storage hydroelectricity	n.a.
8	Nuclear	16.3	17	Oil	117.7
9	Lignite	23.9			

GHG emissions by technologies

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- Values are issued from *ecoivent* database per country
- Life-cycle assesment (kg CO2-eq/kWh) for each technology (including dismantling)

Technology	Life cycle emissions kg CO_2-eq/kWh	Technology	Life cycle emissions kg CO_2-eq/kWh
Wind-on-Shore	0.02-0.04	Municipal waste	0.347-0.568
Wind-off-Shore	0.02-0.03	Coke	0.94-0.96
Solar	0.09-0.12	Combined coal and gas	0.90
Run-of-River	0.005	Gas	0.368-0.701
Geothermal	0.08-0.09	Other conventional	0 (1) -2.9 (2)
Biomass	0.06	Storage hydroelectricity	0.01
Other renew.	0.04	Pumped-storage hydro.	0.42
Nuclear	0.01	Oil	0.864-0.932
Lignite	1.21		

Source : ECOINVENT

- To deal with the issue from blast furnaces gases, two scenarios are considered.
  - **Scenario 1** : Emissions from the blast furnace gases are considered as waste thus zero emissions level
  - **Scenario 2** : Emissions from the blast furnace gases s are accounted on behalf of the electricity sector.

The specific case of german furnace blast gases

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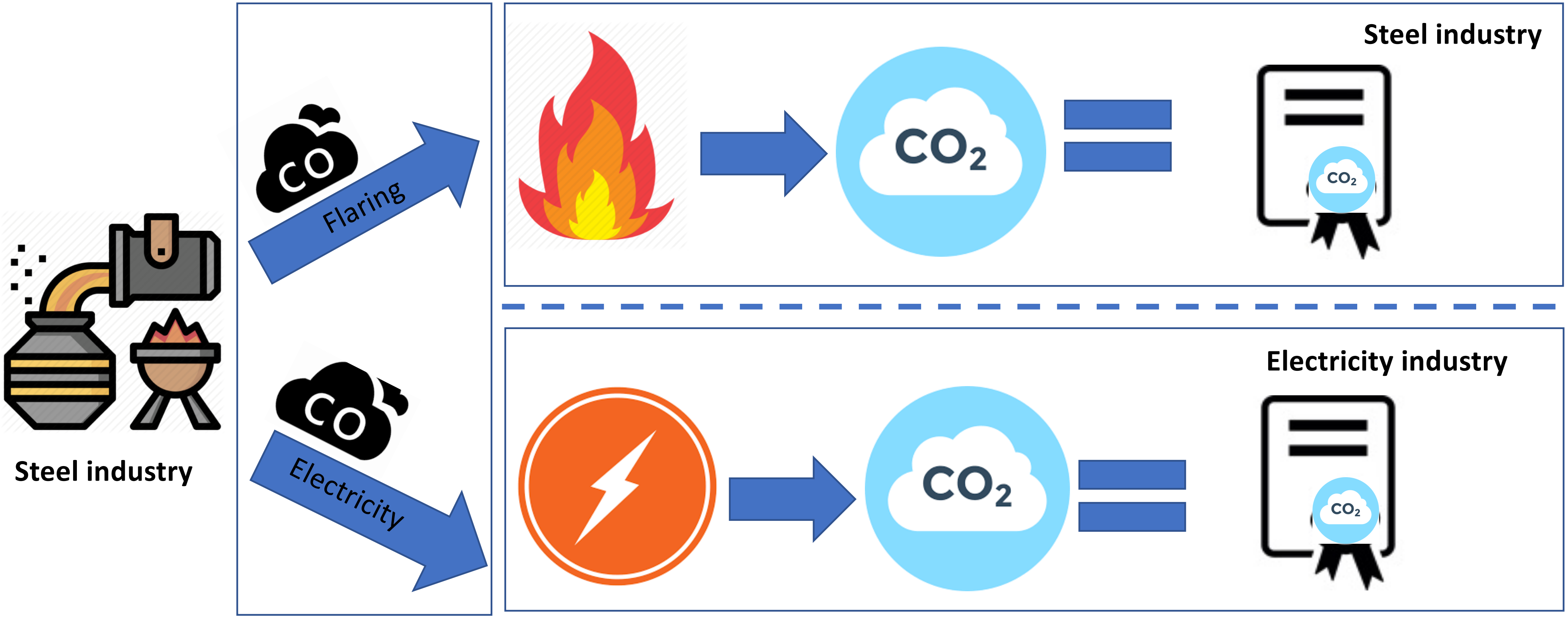
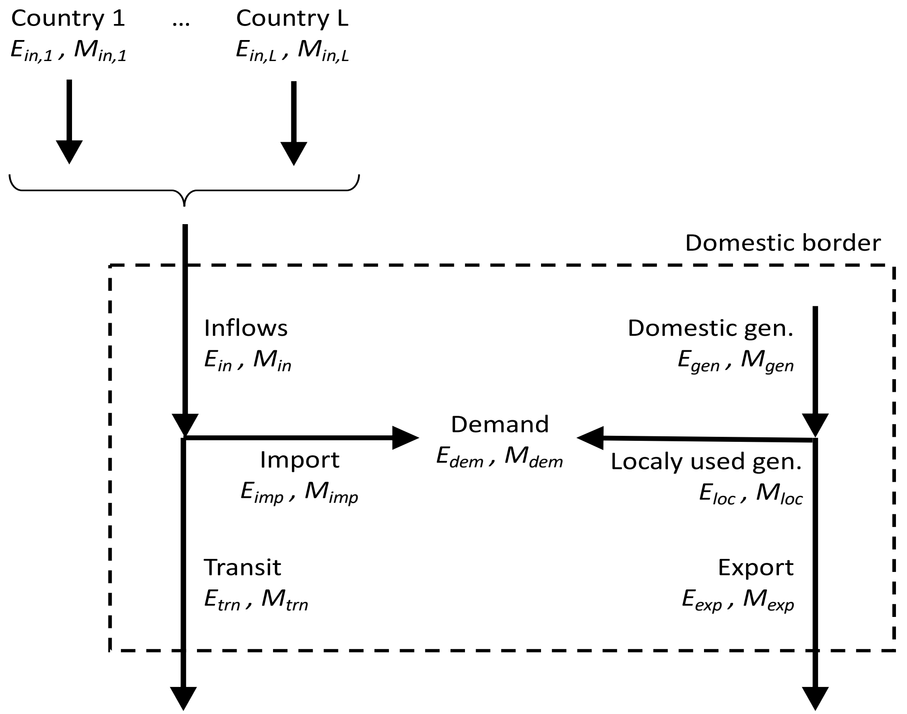
- **CO** is a waste gas from the steel industry. Not direct emissions is allowed (flaring or electricity generation is required)
- Flaring or generation decisions depend on the comparison of the electricity spot prices and the opportunity cost of the CO2 certificates (i.e resell on market).
- Carbon emission are accounted on behalf of the sector who surrender the certificate



The model



The model differentiates between :

- Inflows to CH (from neighbouring countries)
- Transits through CH
- Imports to CH (for Swiss demand)

- Domestic generation
- Domestic generation used locally
- Export

Inflows (imports & transits) by border

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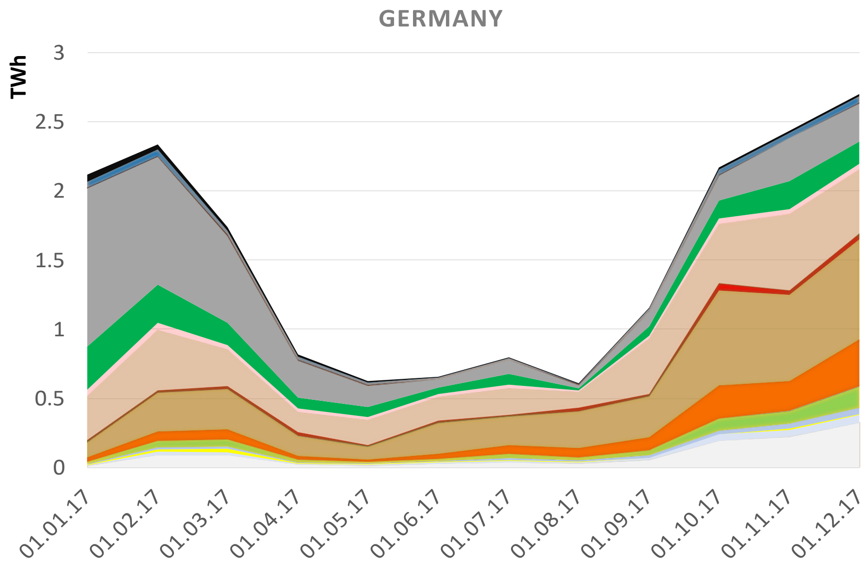
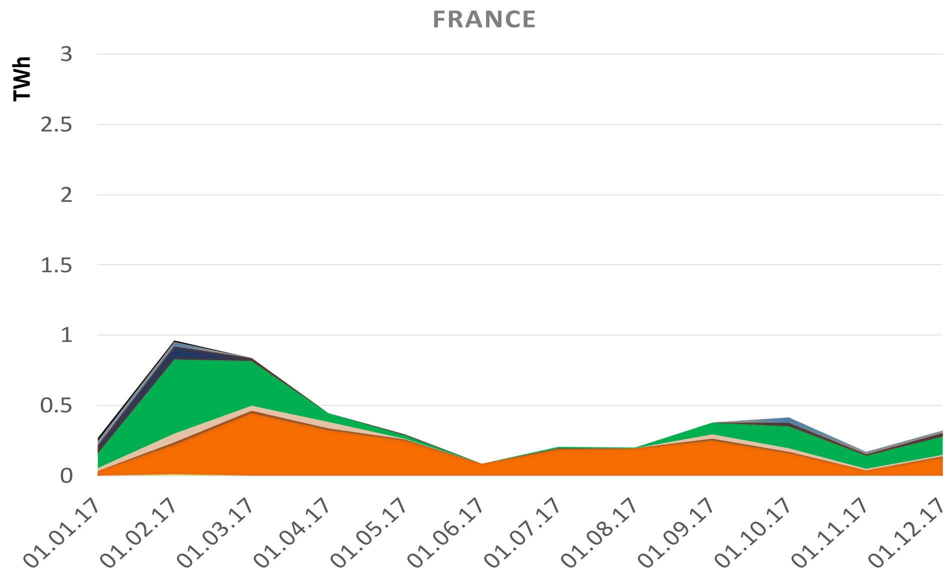




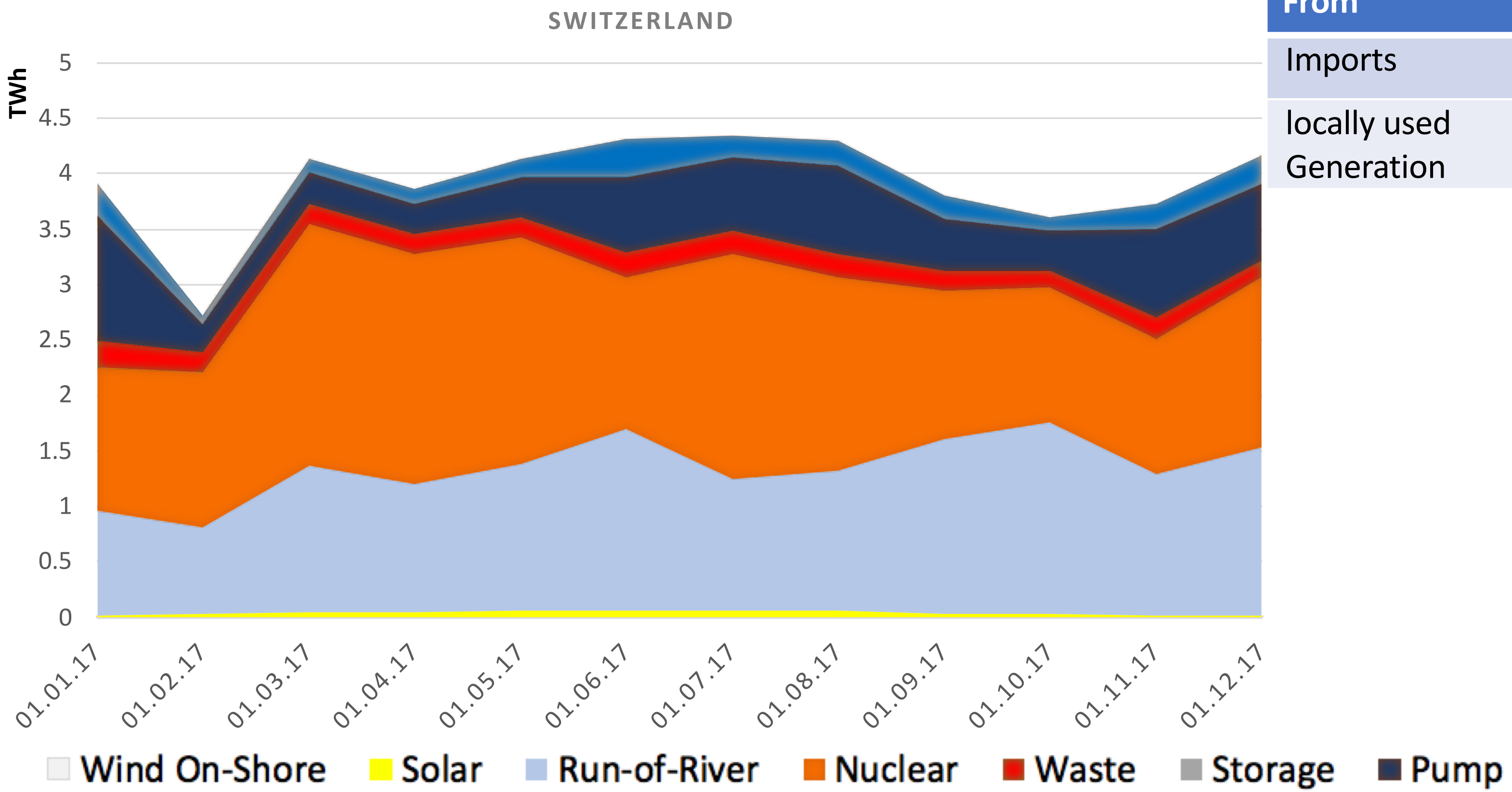
Hourly values aggregated by months

Wind On-Shore, Wind Off-Shore, Solar, Run-of-River, Geothermal, Biomass
Légende enew., Nuclear, Lignite, Waste, Coke, Coal-Gas
Gaz, Other convent., Storage, Pump, Oil

From	Inflows (TWh)
Austria	6.6
France	4.6
Germany	18.2
Italy	0.6

Generation in Switzerland

Locally used generation



Locally used generation + imports

From	Consumption (TWh)
Imports	11.0
locally used Generation	47.5

GHG emissions of inflows by technologies

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- Emissions tied to the inflows are computed at each border, at an hourly granularity.

Border	Net inflows $E_{in,L}$ TWh	Life cycle emissions (Scenario 1) $M_{in,L}$ M tCO_2-eq	Emissions factor (Scenario 1) $w_{in,L}$ kg CO_2-eq / kWh	Life cycle emissions (Scenario 2) $M_{in,L}$ M tCO_2-eq	Emissions factor, (Scenario 2) $w_{in,L}$ kg CO_2-eq / kWh
Austria	6.6	1.1	0.17	1.3	0.19
France	4.6	1.2	0.26	1.4	0.30
Germany	18.2	9.9	0.54	20.4	1.12
Italy	0.6	0.1	1.20	0.3	1.21
Total / Average	30	12.3	0.41*	23.4	0.78*

(*)annual average values

Table 5: GHG emissions from surrounding countries in inflows - Year 2017

GHG emissions : imported and domestic

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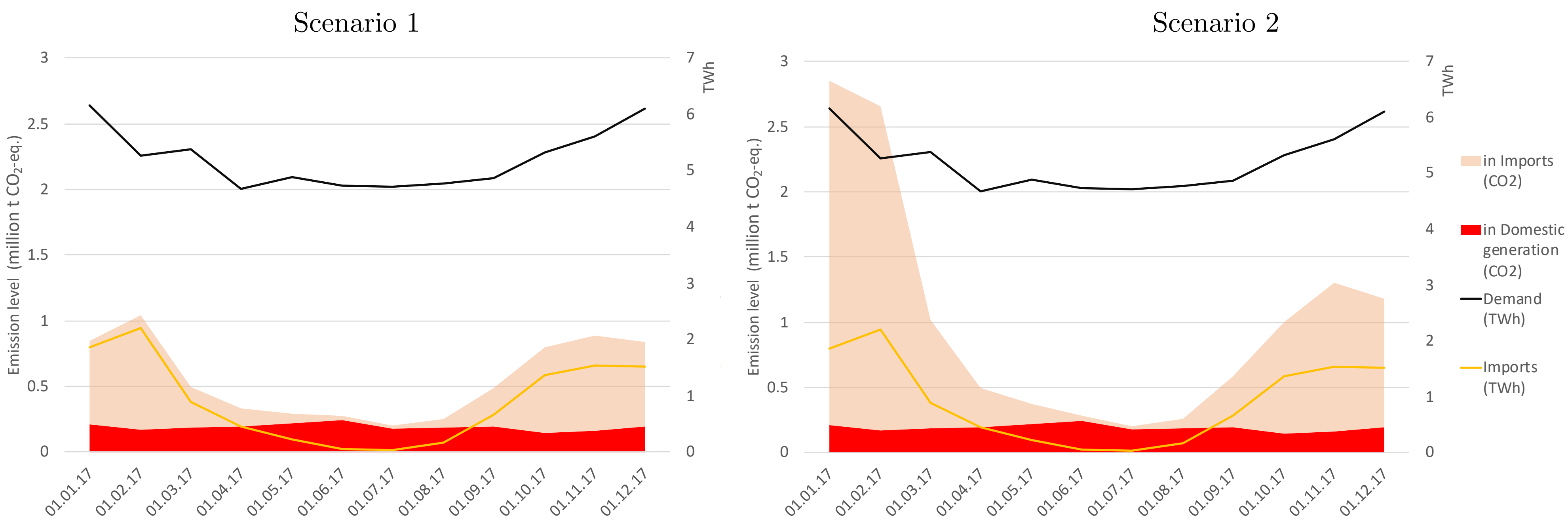

Figure 8: Electricity & CO_2 emissions in Switzerland from netted imports and locally used domestic generation - Year 2017

The GHG emissions differs for both scenarios as furnaces gases played a major role during winter (2016-2017) when European generation capacity suffered from outages (French nuclear) , demand was high due to a cold snap, and spikes prices were observed on electricity markets.

GHG emissions : imported and domestic

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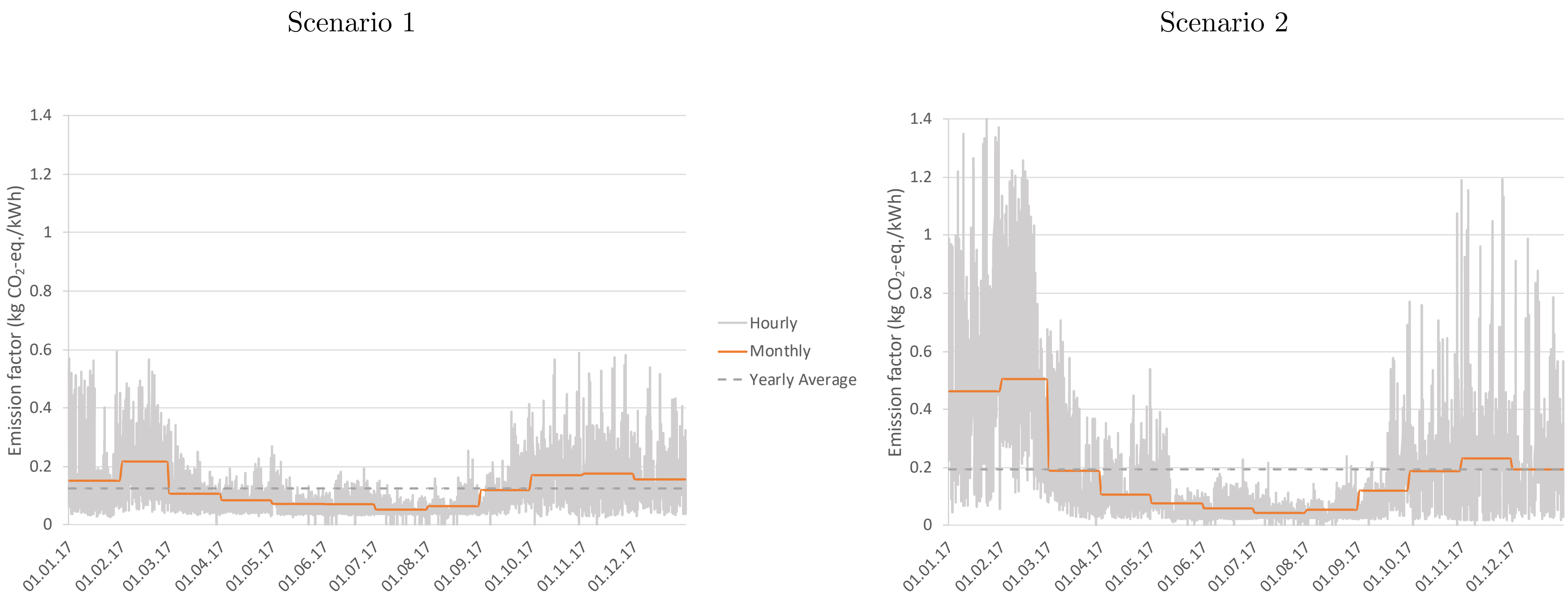
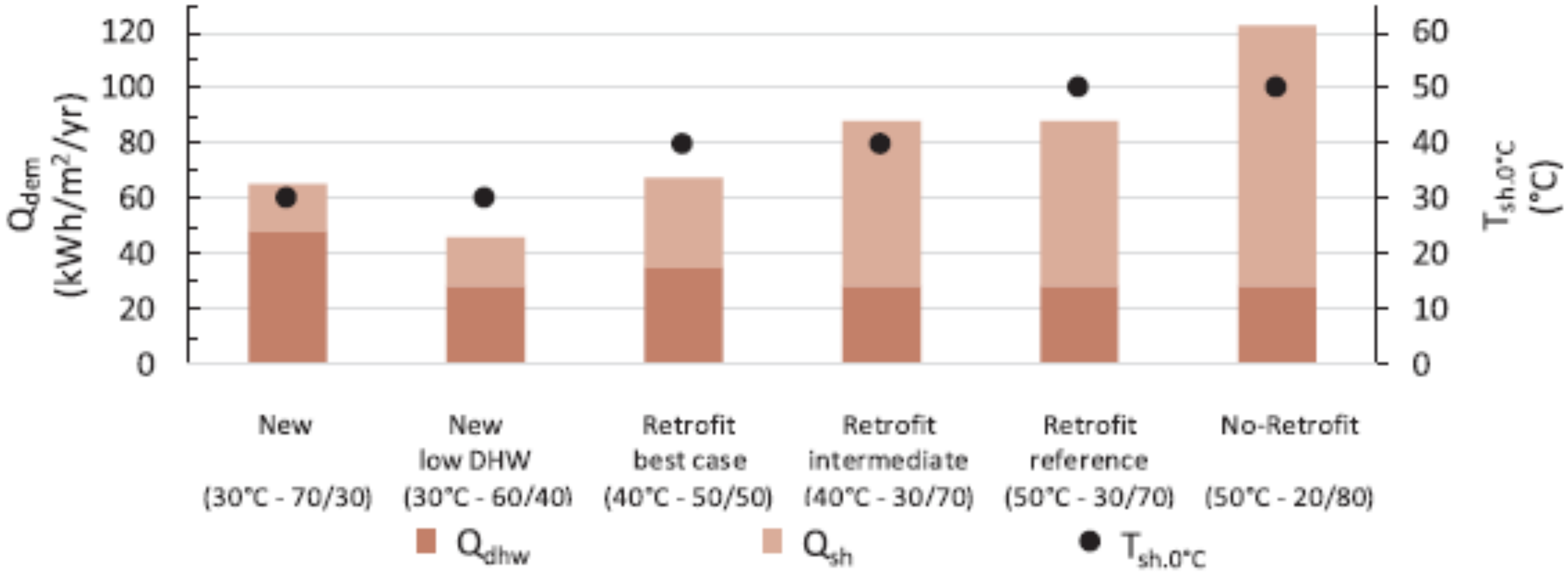


Figure 9: Hourly, monthly and yearly CO_2 emission factors - Year 2017

Emission factor : 108 g $CO_{2\text{-eq}}$ /kWh
Total emissions : 6.6 Mt $CO_{2\text{-eq}}$

Emission factor : 197 g $CO_{2\text{-eq}}$/kWh
Total emissions : 12.1 Mt eq CO_2

Building sample : SH and DHW demand



Source: Fraga et al., 2018 (https://archive-ouverte.unige.ch/unige:104908)

Qdhw: domestic hot water

Qsh: space heating demand

Tsh,0°C: température chauffage à 0°C

Temperature and heat demand

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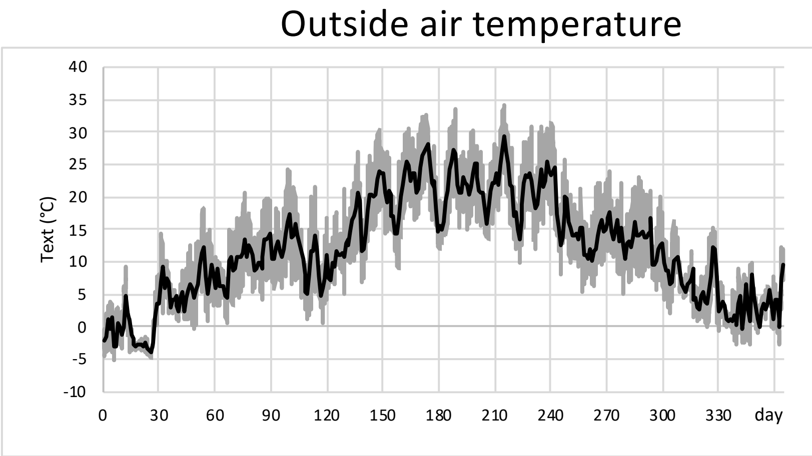

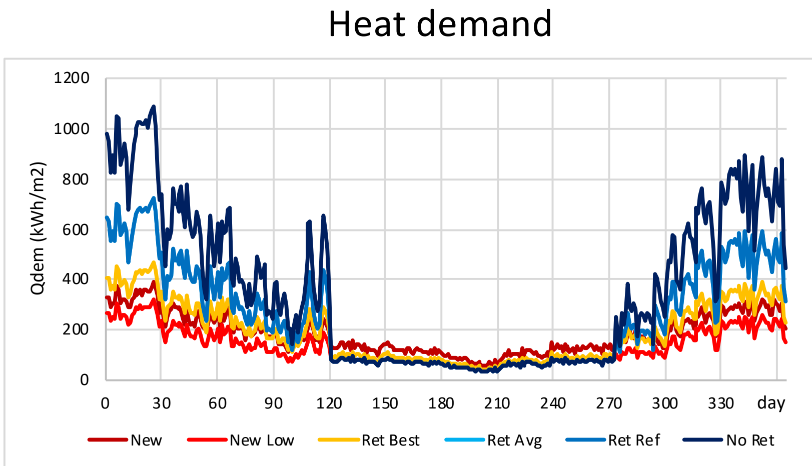

- The daily heat demand is highly correlated to the outside air temperature, and dependent of the building type.
- Reference year: 2017

Which ressources for which heat demand ?

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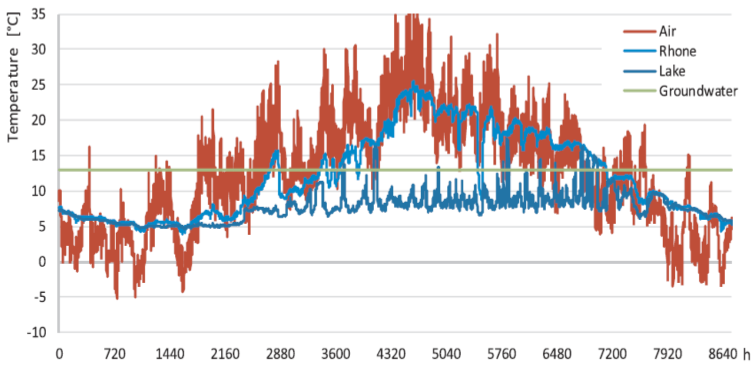
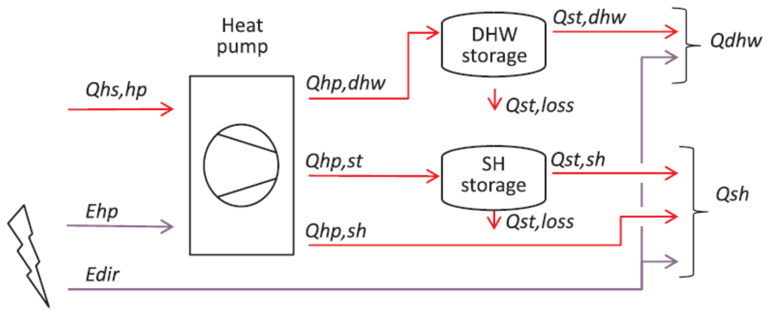
Comparative analysis (numerical simulation)
COP are issued from manufacturer's datasheet

Ressource temperature

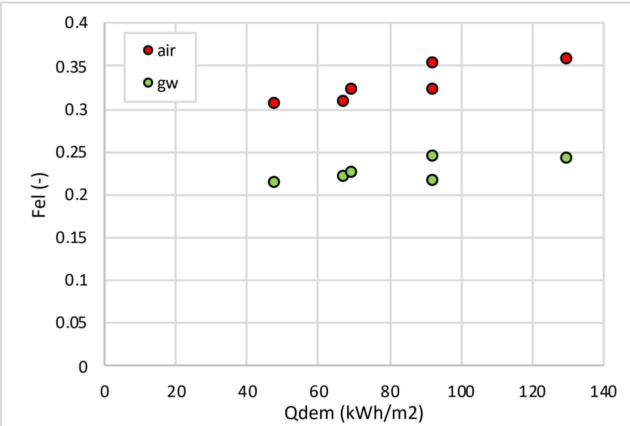


Source: Fraga et al., 2018 (https://archive-ouverte.unige.ch/unige:104908)

System



Heat pump : electricity factor



- 2 heat sources are under focus : air source and ground water

- The hourly electricity consumption of the HP results from an input/output table based on the working temperatures for the heat pumps, which depends on evaporator inlet and the condenser outlet temperatures.

Electricity load of heat pumps (dynamic)

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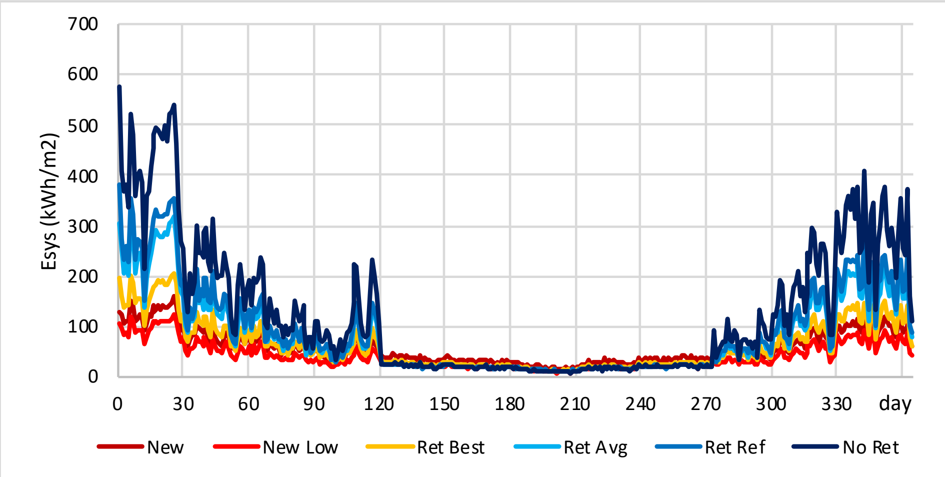
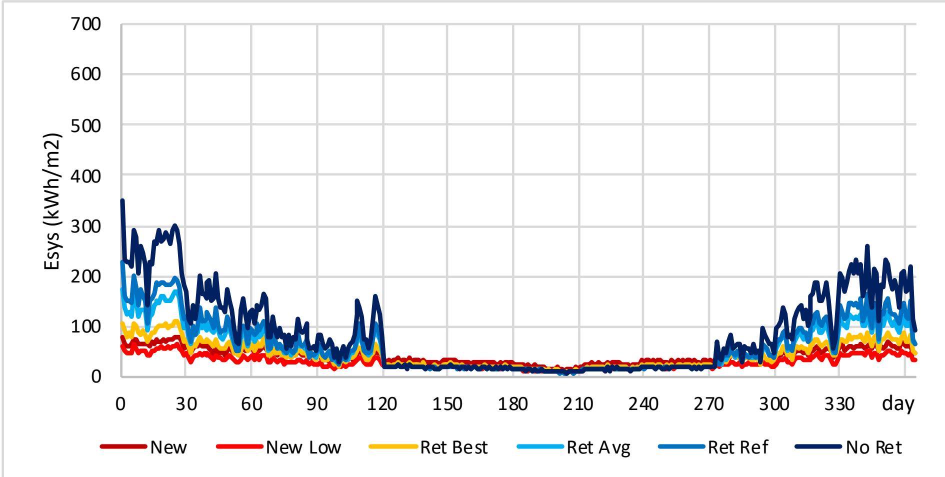
Air



Ground water



- The electricity load has seasonal pattern with the highest shared observed during the winter season when SH is high.
- The electricity demand is about 30% lower for ground water HP than air source HP

Carbon emissions (dynamic)

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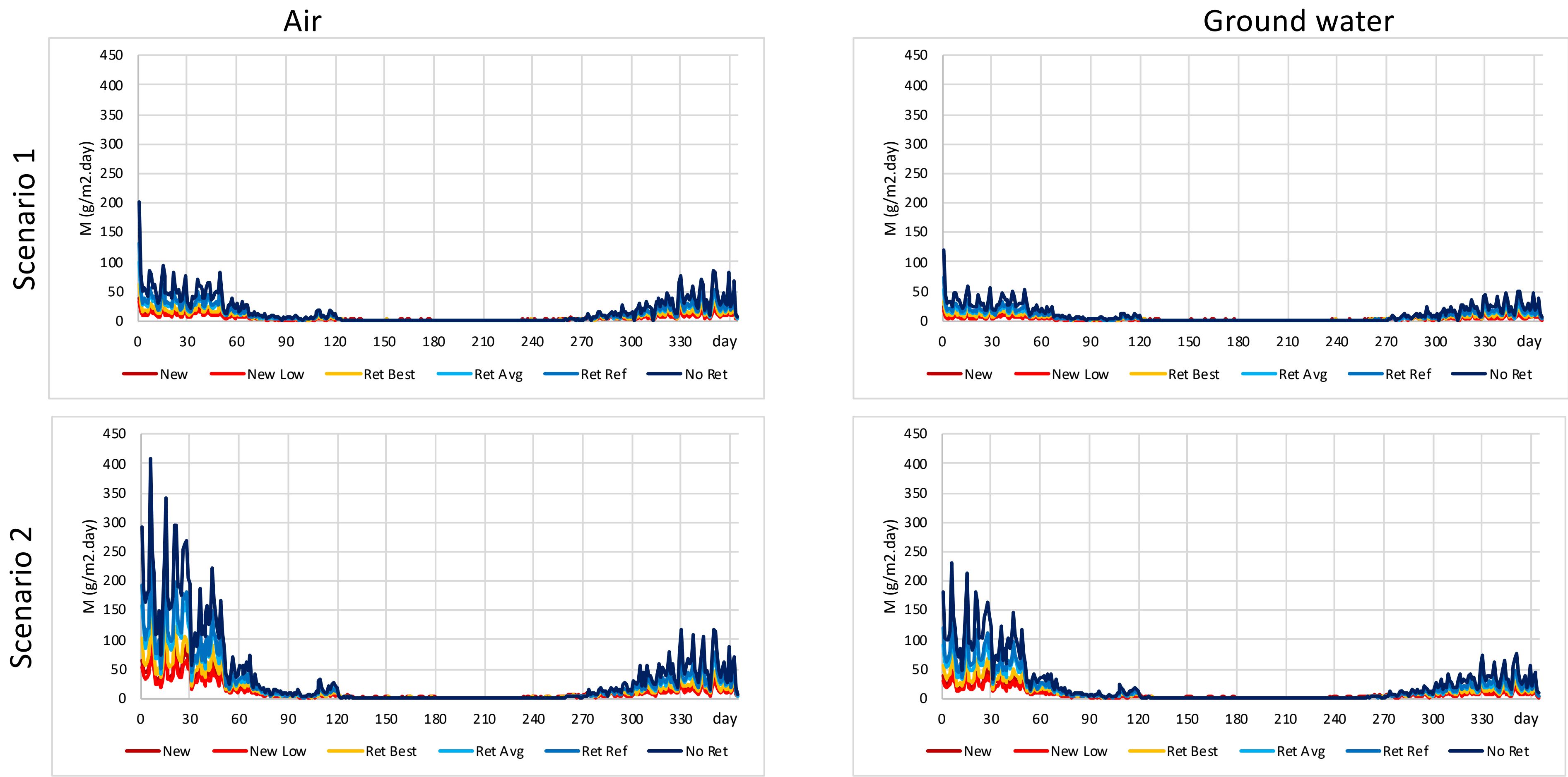

Recall : Scenario are dependent on the accounting method for CO_2 emissions by the blast furnace units.

Carbon emissions and emission factor of heat pump (Scenario 1)

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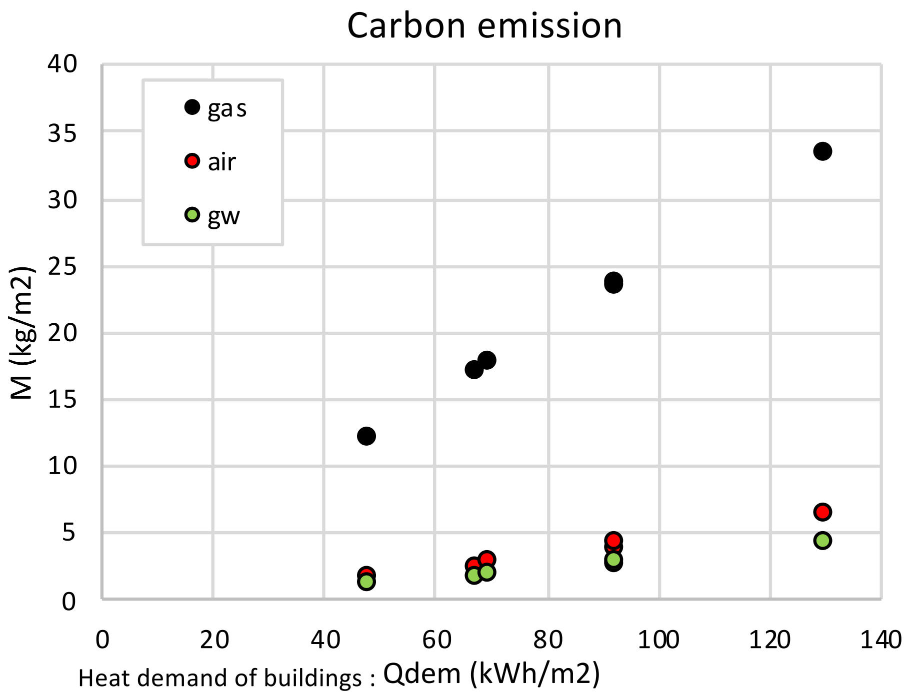
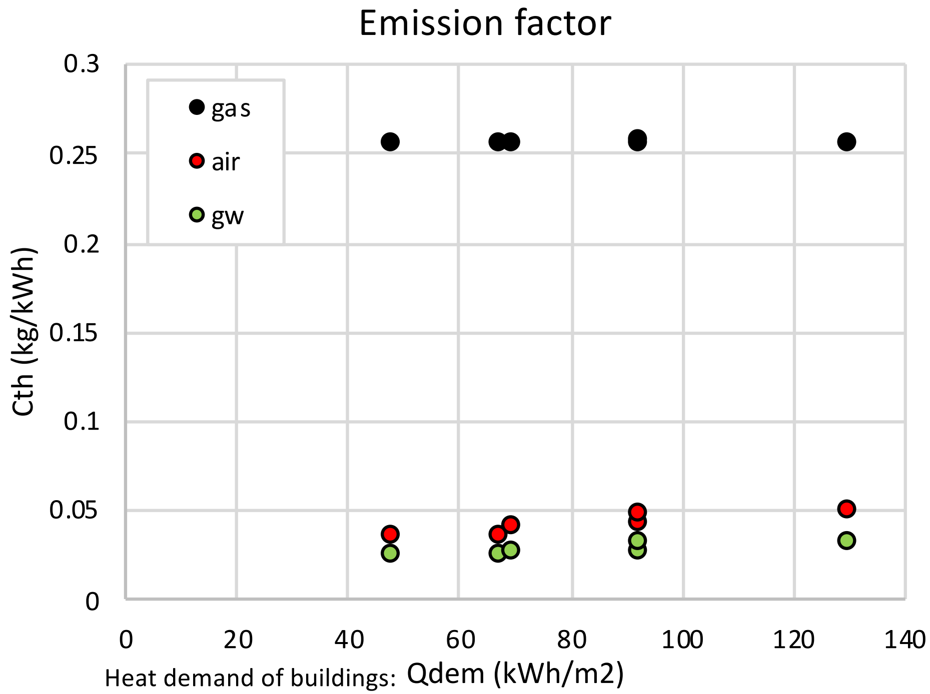
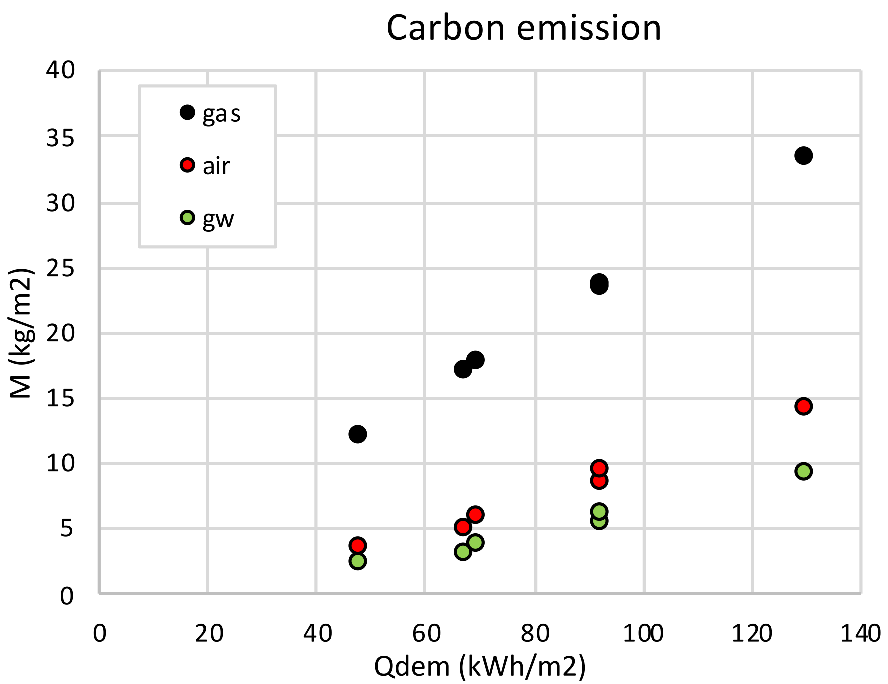
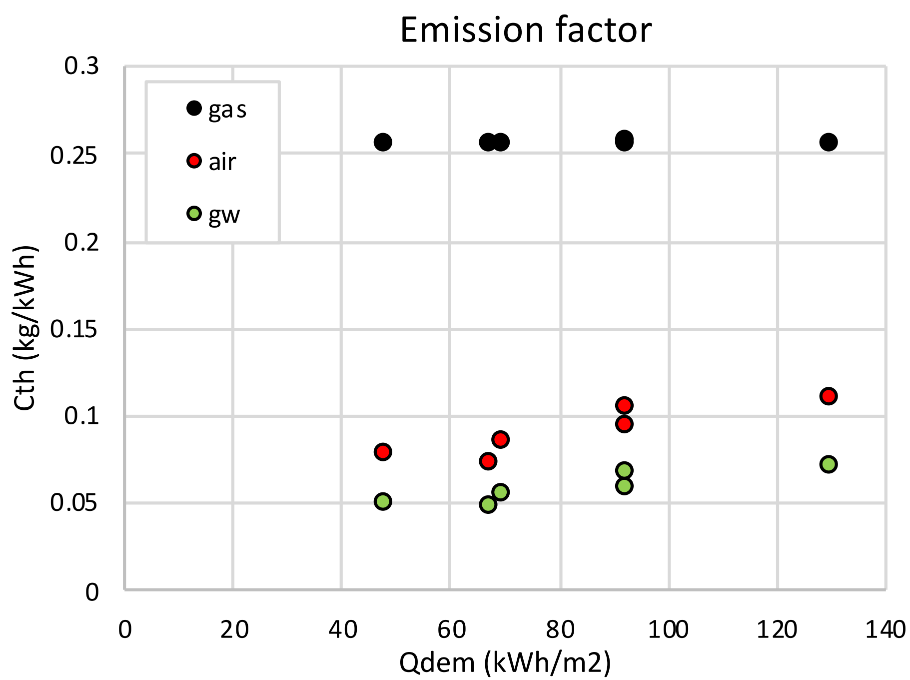




Carbon emissions and emission factor of heat pump (Scenario 2)

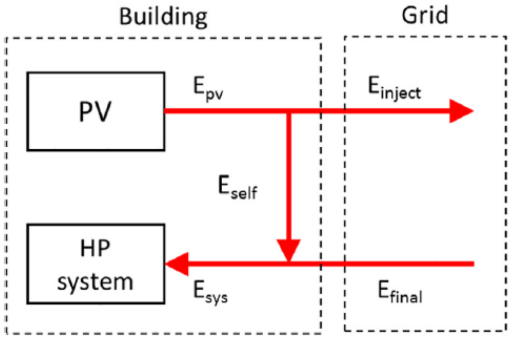




- Geothermal heat pump emits up to 36% emissions than air source HP, due to
  i. a lower electricity consumption,
  ii. a weaker seasonality of the load profile.

- Benchmarked vs gas heaters, carbon savings from heat pumps range from **60% and 81%.**

HP + PV for MF buildings (numerical simulation)



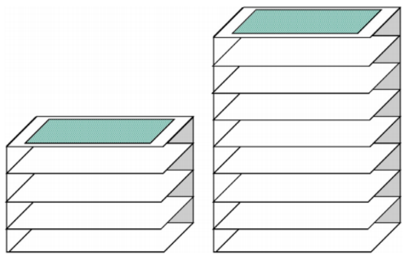
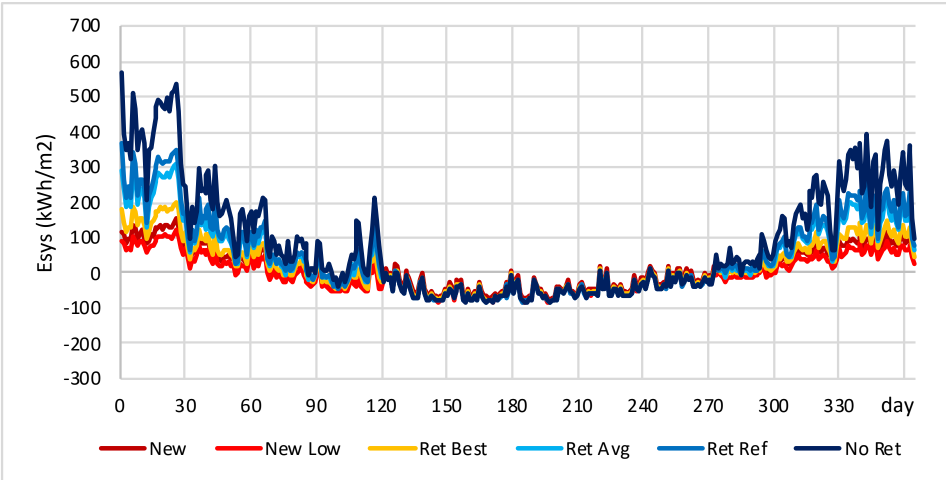


Fig. 4. Left – Low-rise Building (0.2 m^2_{roof}/m^2_{SRE}, 4 storeys*); Right – high-rise Building (0.1 m^2_{roof}/m^2_{SRE}, 8 storeys*) * – Hypothesis of an available roof area (shaded area) equal to 80% of the heated area of a floor.

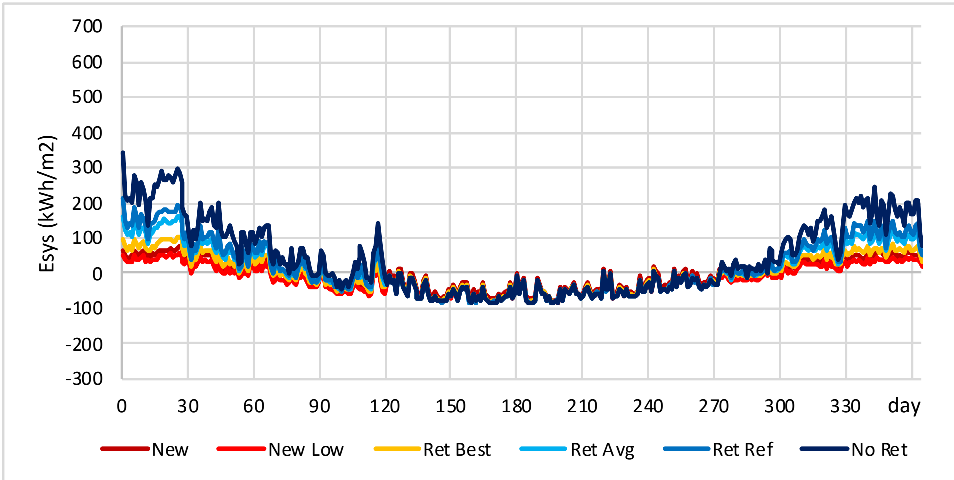
- Annual balance: possibilty to cover(a high share) of the HP demand through the generation of the PV unit.
- Hourly/ Daily: temporal decorrationbetween PV & PAC ⇔ imports/exports

Source: Fraga et al., 2018 (https://archive-ouverte.unige.ch/usnige:104908)

Air source



Ground Water



HP + PV Emissions generation (dynamics)

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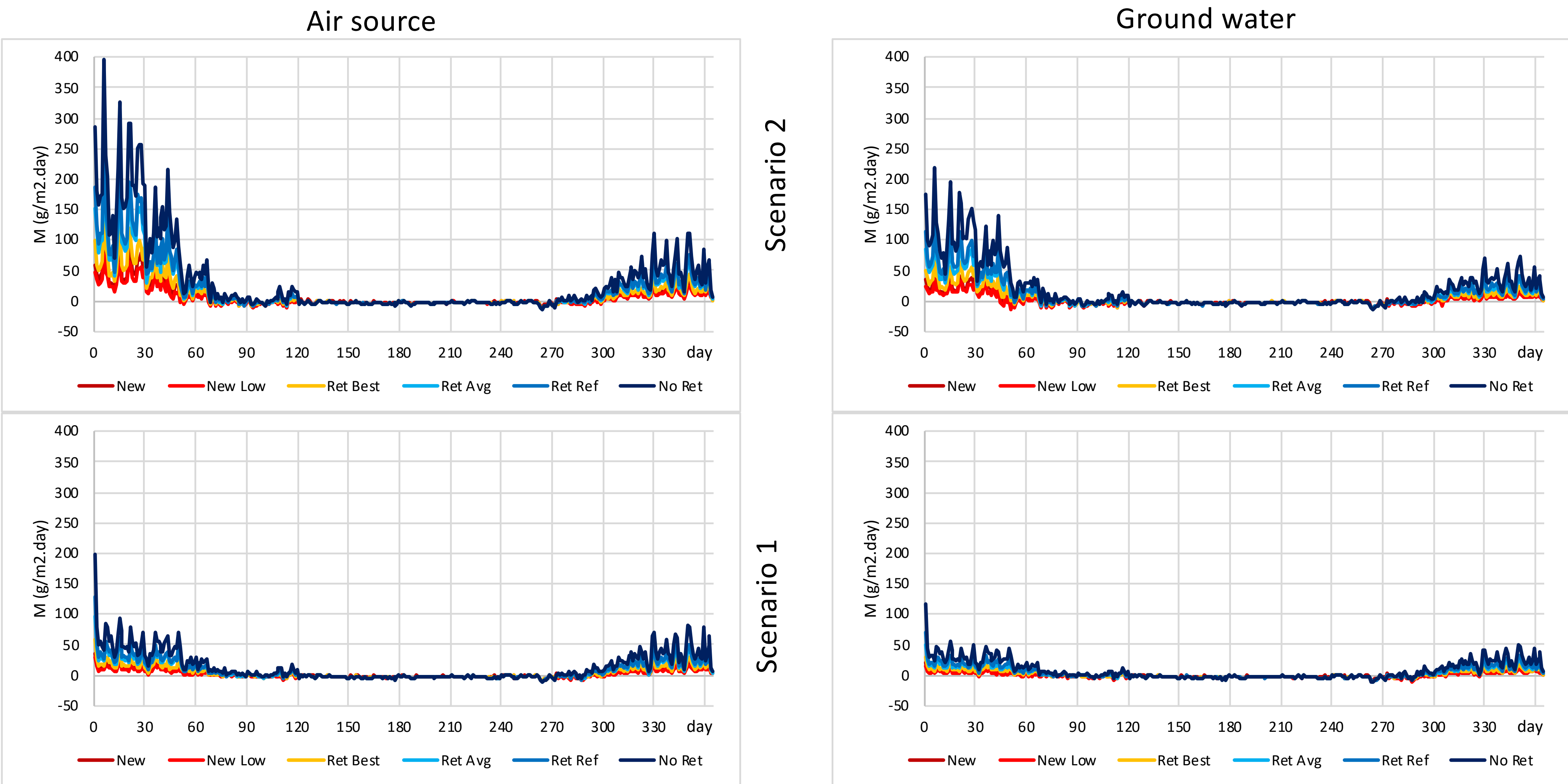

HP + PV Emissions generation (annual)

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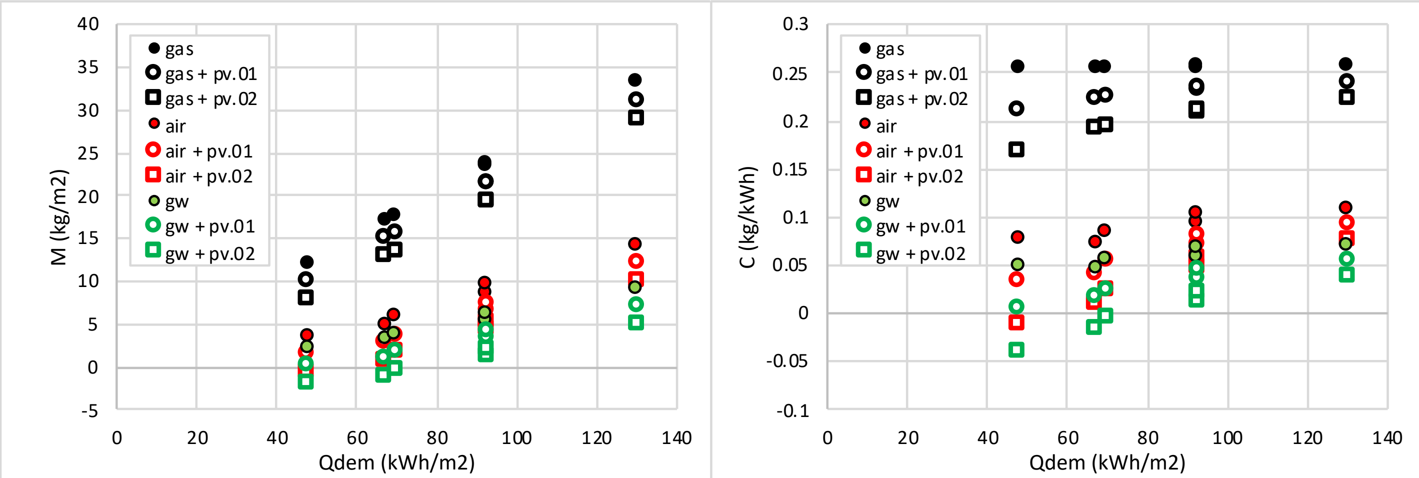
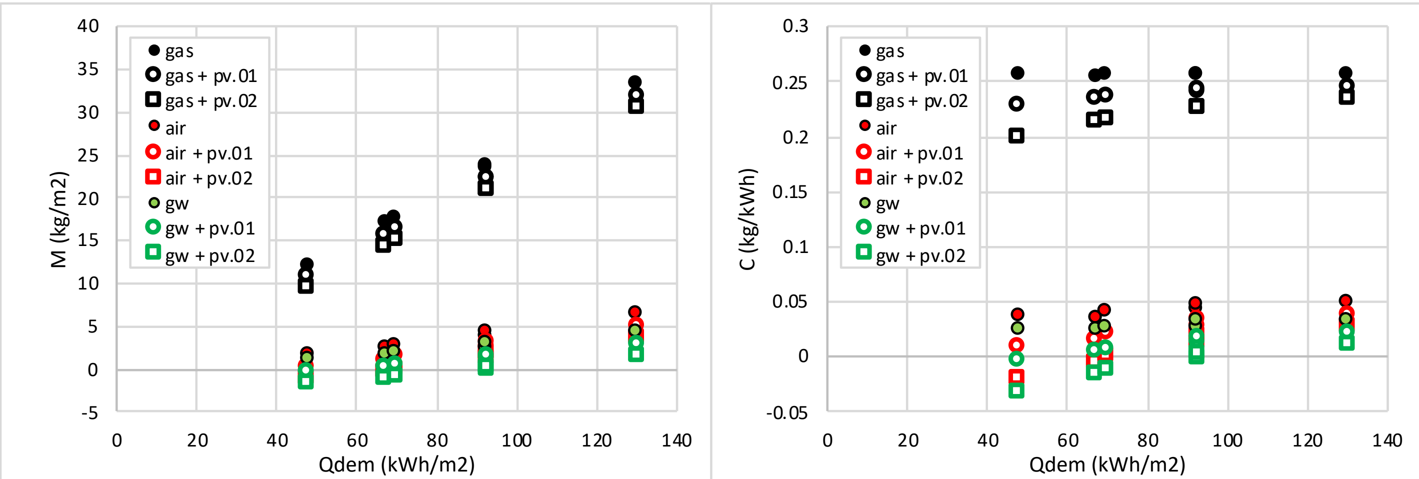
Scenario 2



Scenario 1



- Combining PV and HP has a limited impact on CO_2 savings as the generation of PV occurs in summer when heat demand is low, and carbon content from the electricity grid is lower.

Impact analysis

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Variables	Coef.	Std. Err.	z	P>z	[95% Conf.	Interval]
CO2 equation						
trend	-0.045	0.011	-4.030	0.000	-0.067	-0.023
$Q_{dem,a}$	1.029	0.018	57.430	0.000	0.994	1.064
Fgrid	1.240	0.007	186.220	0.000	1.227	1.253
COP	-1.086	0.030	-36.050	0.000	-1.145	-1.027
T_a	-0.342	0.008	-44.530	0.000	-0.357	-0.327
k_1	-4.784	0.092	-51.810	0.000	-4.965	-4.603
COP equation						
Heat						
Ground Water	1.218	0.010	123.950	0.000	1.199	1.237
Build						
New Low	0.114	0.017	6.760	0.000	0.081	0.147
No Ret	-0.171	0.017	-10.080	0.000	-0.204	-0.138
Ret Avg	0.122	0.017	7.190	0.000	0.088	0.155
Ret Best	-0.027	0.017	-1.570	0.117	-0.060	0.007
Ret Ref	-0.214	0.017	-12.620	0.000	-0.247	-0.180
Ta	0.037	0.001	31.250	0.000	0.035	0.040
k_2	3.047	0.016	189.640	0.000	3.015	3.078

Model to Explain CO_2 emissions with respect to

- COP
- Grid electricity factor
- Temperature
- Building demand

The COP is explained with respect to

- Heat source
- Building type
- Temperature

Carbon savings though optimal production management

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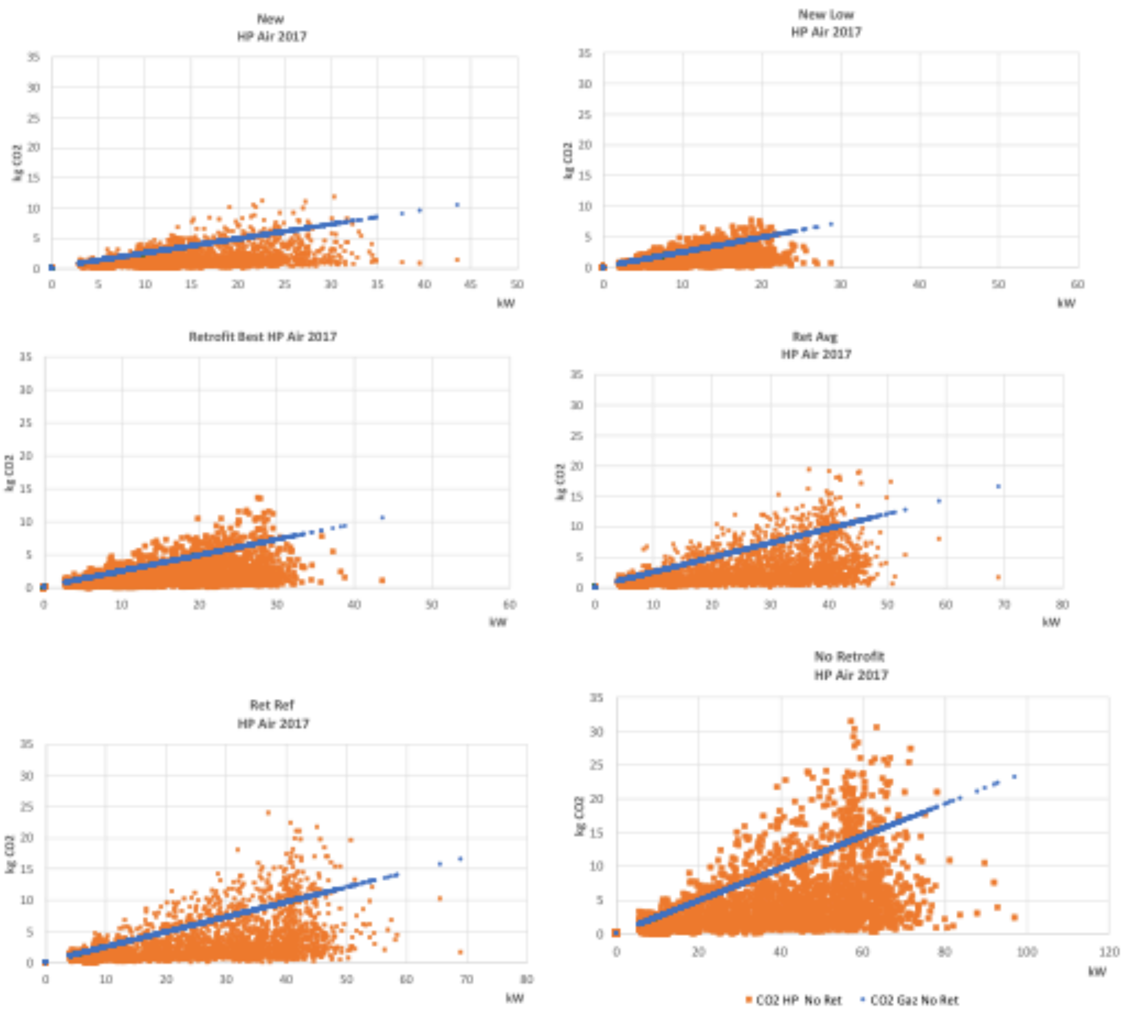

- Combining HP and gas heaters, and optimise their running given the carbon signal.

- Operate the gas heaters whenever emissions from heat pumps exceed the emissions from HP

- Objective function is compted at an hourly granularity:

$$\min_{\tau} \sum_{t=1}^{8760} \tau_t \, (E_{sys,t} \, E_{grid,t}) + (1\text{-}\tau_t)(Q_{dem,t} . E_{grid,t})$$

- Which gains can be accomplished on
  - installed heat pump capacity ?
  - carbon savings ?

Carbon savings through optimization

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Building	hours of gas operability	CO2 Emissions (kg)		CO2 savings	Capactiy required (HP only)	Capactiy required (with gas)		Heat pumps capacity gains
		HP	Mix		kWelec/day	HP (kWelec/day)	Gas (kW/day)	
New	237	4587	4359	-5%	17.70	15.85	43.56	-10%
New Low	251	3458	3289	-5%	12.98	10.94	28.90	-16%
Ret Best	335	5543	5173	-7%	19.80	19.80	43.68	0%
Ret Avg	328	8059	7520	-7%	21.71	21.07	69.09	-3%
Ret Ref	423	8954	8107	-9%	23.39	23.31	69.09	0%
No Ret	426	13215	11921	-10%	34.34	34.27	97.15	0%

- With interoperability : CO_2 savings range form 5 to 10%
- Heat-pumps capacity gains range from 0 to 16%.

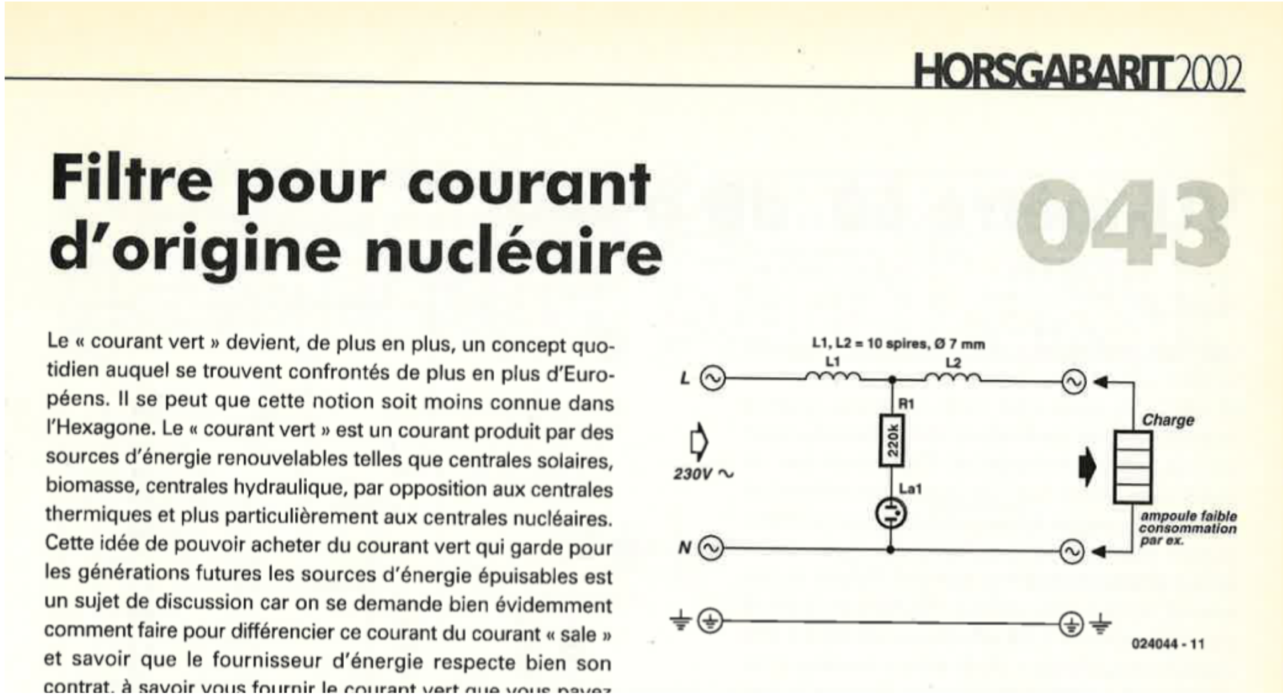
Conclusions

- Methodology offers a profile of CO_2 emissions over the year.
  - Useful for climate policy and energy policy.

- Methodology is based on the hourly data and incremental impact of the imports on the generation mix from neighbouring countries

Finally, don't be fooled…

- Efficiency for this kind of filter still needs to be prooved ….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Filtre pour courant d'origine nucléaire

043

Le « courant vert » devient, de plus en plus, un concept quotidien auquel se trouvent confrontés de plus en plus d'Européens. Il se peut que cette notion soit moins connue dans l'Hexagone. Le « courant vert » est un courant produit par des sources d'énergie renouvelables telles que centrales solaires, biomasse, centrales hydraulique, par opposition aux centrales thermiques et plus particulièrement aux centrales nucléaires. Cette idée de pouvoir acheter du courant vert qui garde pour les générations futures les sources d'énergie épuisables est un sujet de discussion car on se demande bien évidemment comment faire pour différencier ce courant du courant « sale » et savoir que le fournisseur d'énergie respecte bien son contrat, à savoir vous fournir le courant vert que vous payez

Source : *Revue Elektor*, **1er Avril 2002**

Thank you for your attention