Dimensioning of multi-clouds with follow-the-renewable approaches for environmental impact minimization

Fanny Dufossé
LIG, INRIA Grenoble, UGA
Joint work with Miguel Vasconcelos(UGA,USP) & Daniel Cordeiro(USP), Sao Paulo

April 14, 2022

Energy efficiency of servers

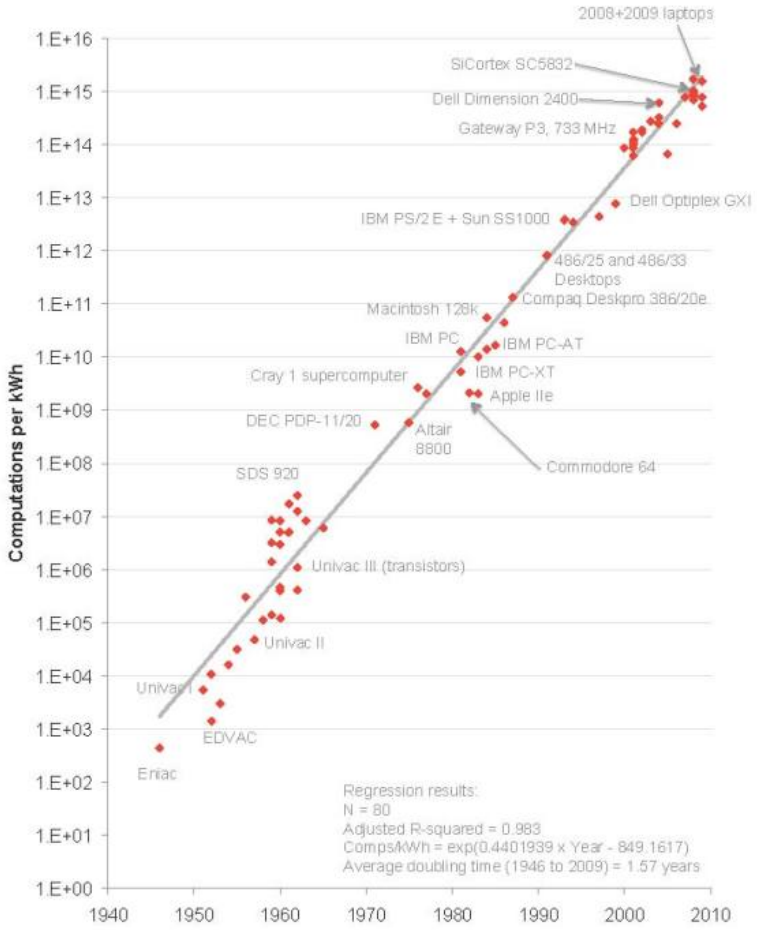
Koomey's law

Efficiency doubled every 1.57 years from 1946 to 2009.

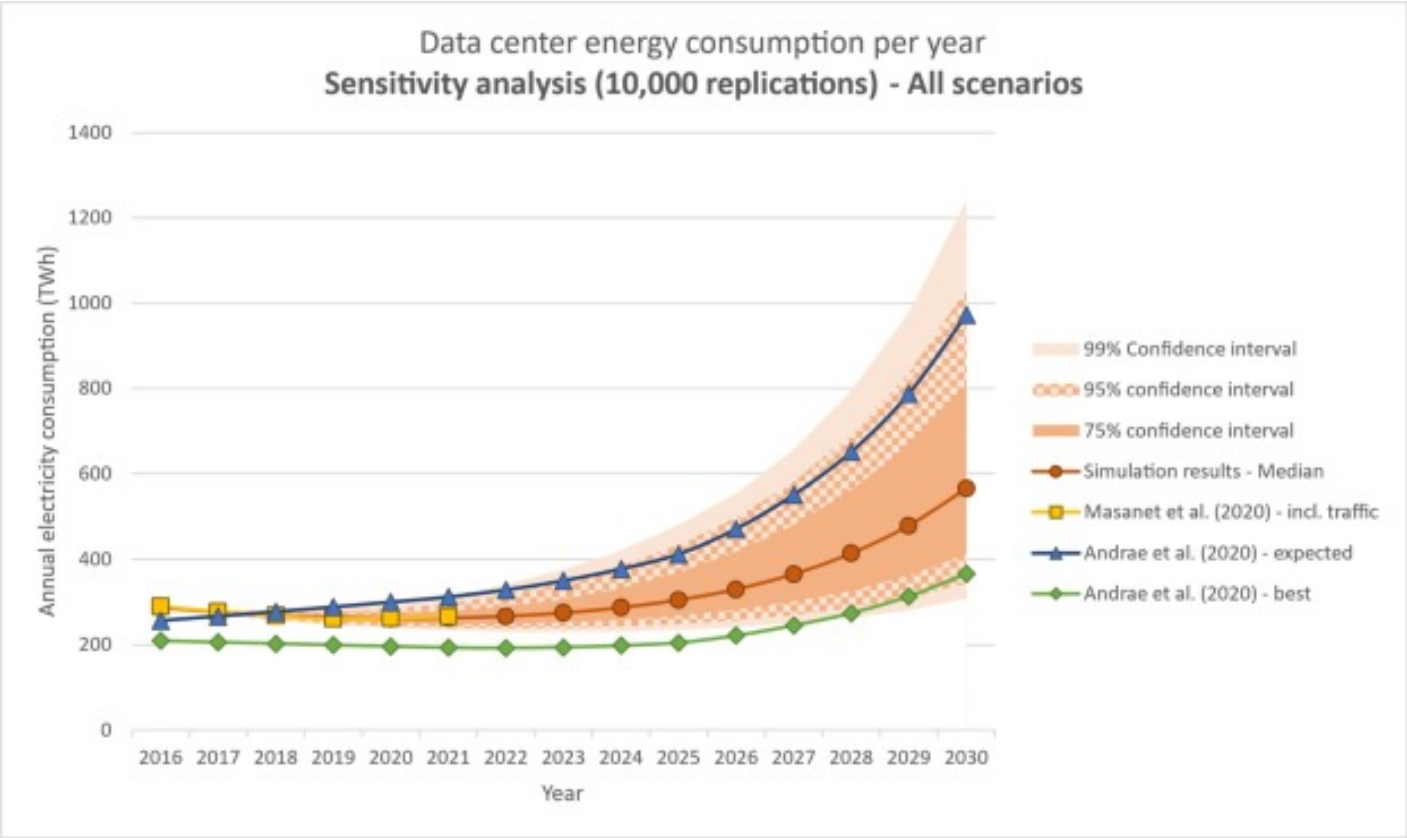
Koomey, J., Berard, S., Sanchez, M., & Wong, H. (2010).

Implications of historical trends in the electrical efficiency of computing.

IEEE Annals of the History of Computing, 33(3), 46–54



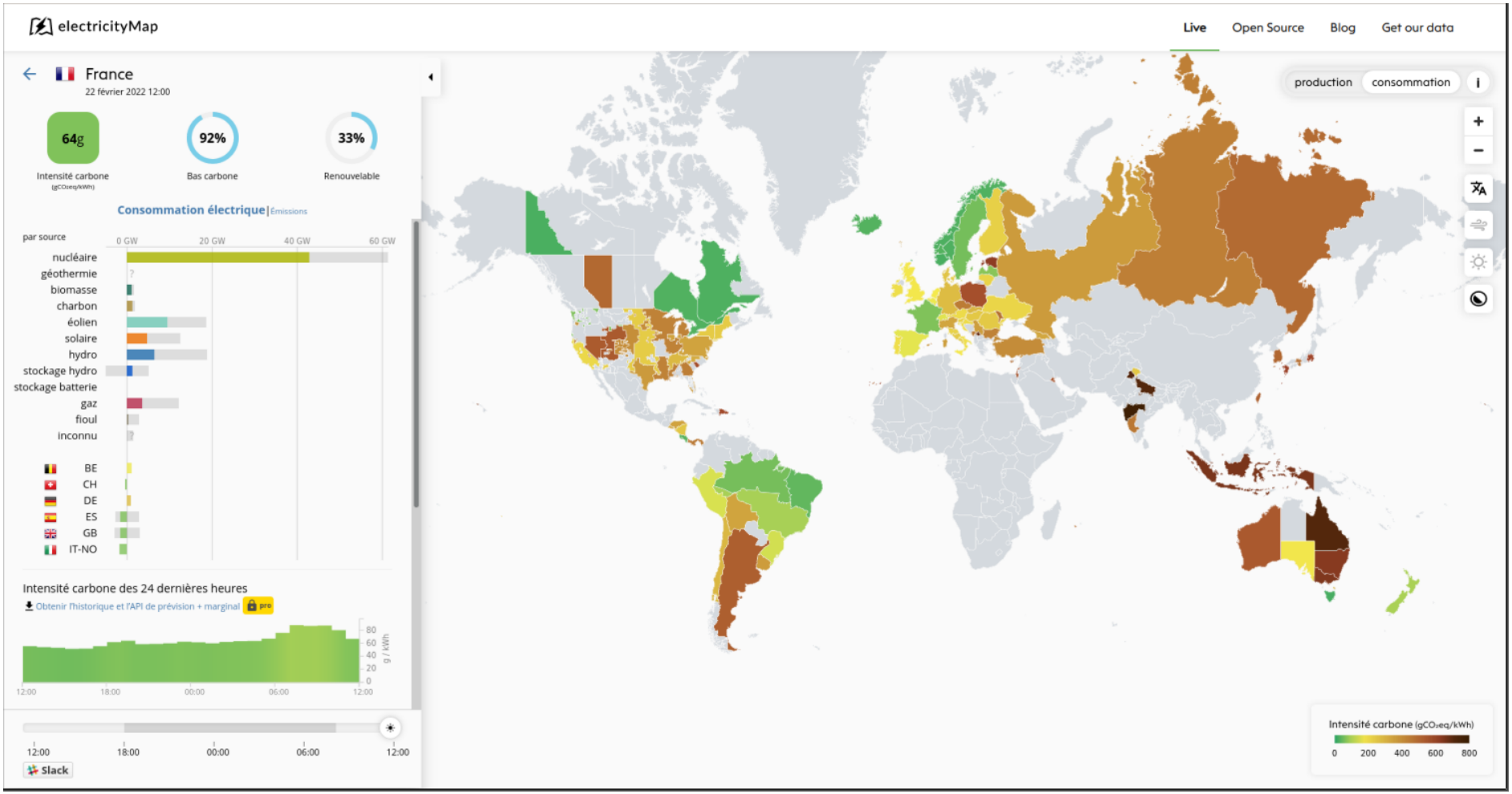
Energy consumption of clouds



Koot, M. & Wijnhoven, F. (2021). Usage impact on data center electricity needs: A system dynamic forecasting model.

Applied Energy, 291, 116798

Energy sources



https://app.electricitymap.org/map

Energy sources

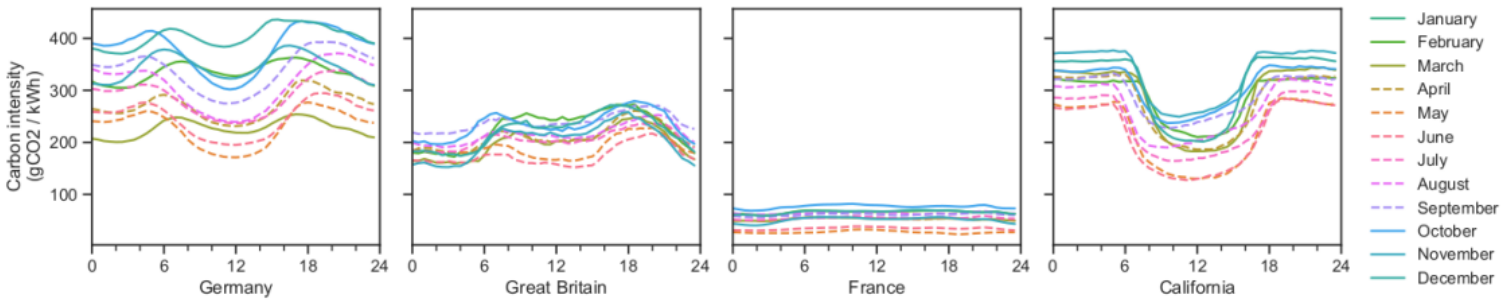


Figure 5: Daily mean carbon intensity of Germany, Great Britain, France and California by month. Since all regions are located in the northern hemisphere and therefore exhibit similar seasonal patterns, we use the same cyclic colormap to illustrate the differences between winter (solid lines) and summer months (dashed lines).

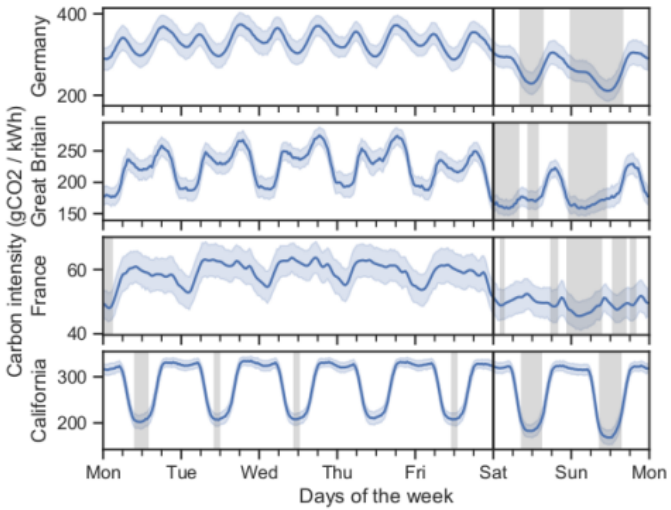


Figure 6: Mean carbon intensity during a week. The confidence interval describes the 95th percentile. Highlighted in gray are the 24 hours with lowest carbon intensity, which predominantly fall on the weekend across all regions.

Wiesner, P., Behnke, I., Scheinert, D., Gontarska, K., & Thamsen, L. (2021). Let's wait awhile: how temporal workload shifting can reduce carbon emissions in the cloud.

In *Proceedings of the 22nd International Middleware Conference* (pp. 260–272)

Why combining data centers and renewable power plant

Impact of DC on local electric network:

- electric consumption: biggest DC at 150MW (between $\simeq$ .5 and 1kW per capita in China and Europe)
- New DC imply deep changes in production/consumption equilibrium
- Requires new power plant
- Commitment of GAFAM to 100% renewable energy

How to become green:

- On-site investment
- Power Purchase Agreement
- Virtual PPA
- Renewable Energy Credit
- Utility choice/Utility green energy tariff

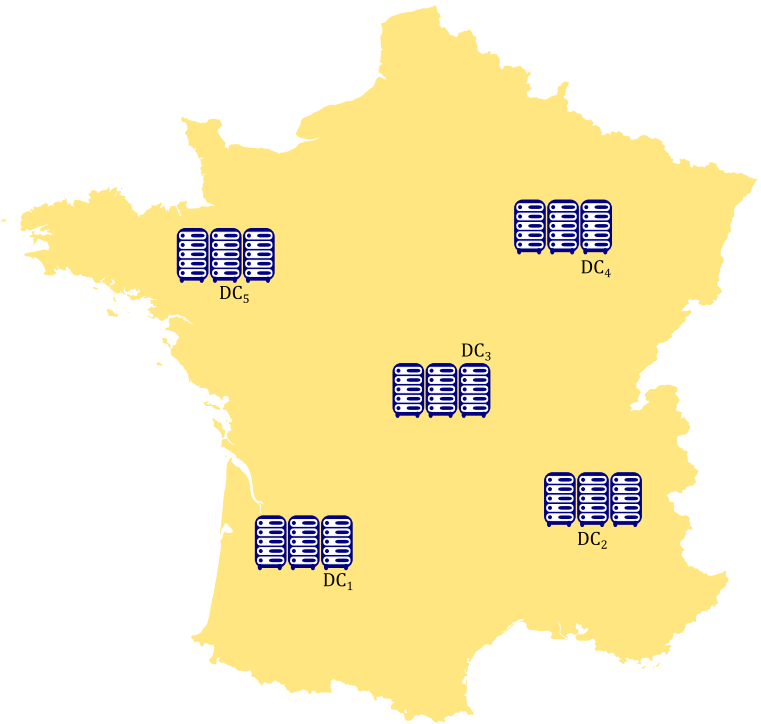
Problem formulation

Cloud:

- M data centers (DC) spread across a country
- DC equipped with photovoltaic panels (PV) and brown power plant
- Incoming workload = VMs

Challenges:

- Minimize brown energy consumption
- Predict each local green power production
- Determine VM migration



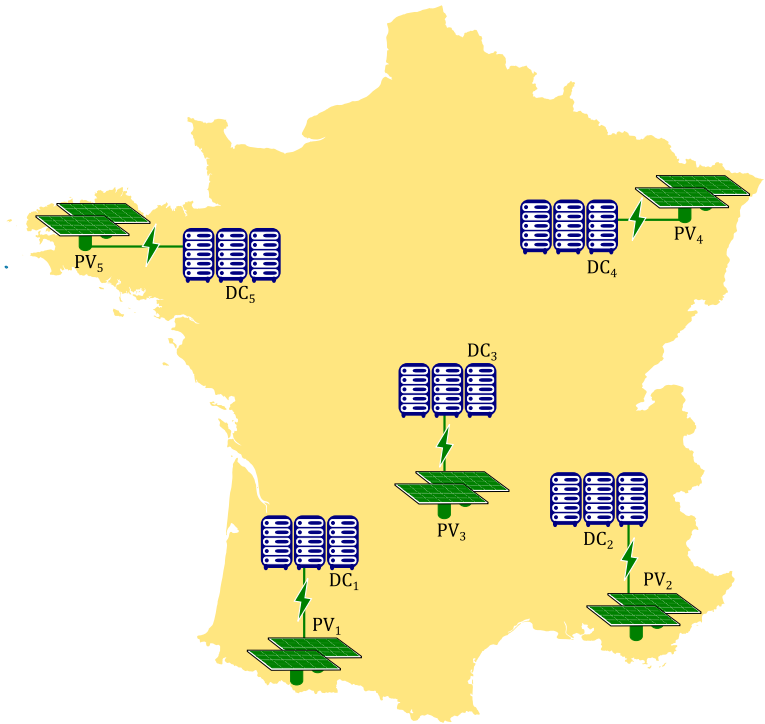
Problem formulation

Cloud:

- M data centers (DC) spread across a country
- DC equipped with photovoltaic panels (PV) and brown power plant
- Incoming workload = VMs

Challenges:

- Minimize brown energy consumption
- Predict each local green power production
- Determine VM migration



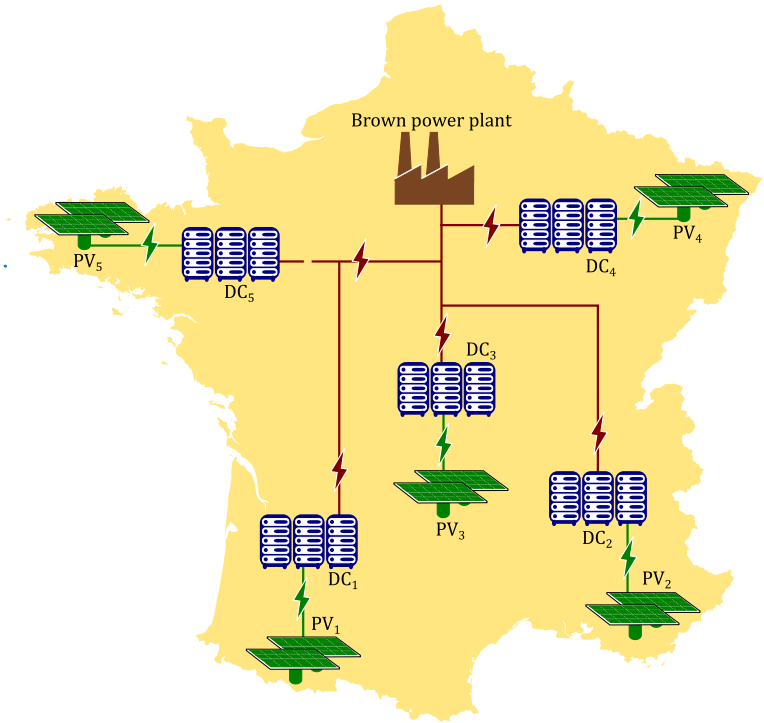
Problem formulation

Cloud:

- M data centers (DC) spread across a country
- DC equipped with photovoltaic panels (PV) and brown power plant
- Incoming workload = VMs

Challenges:

- Minimize brown energy consumption
- Predict each local green power production
- Determine VM migration



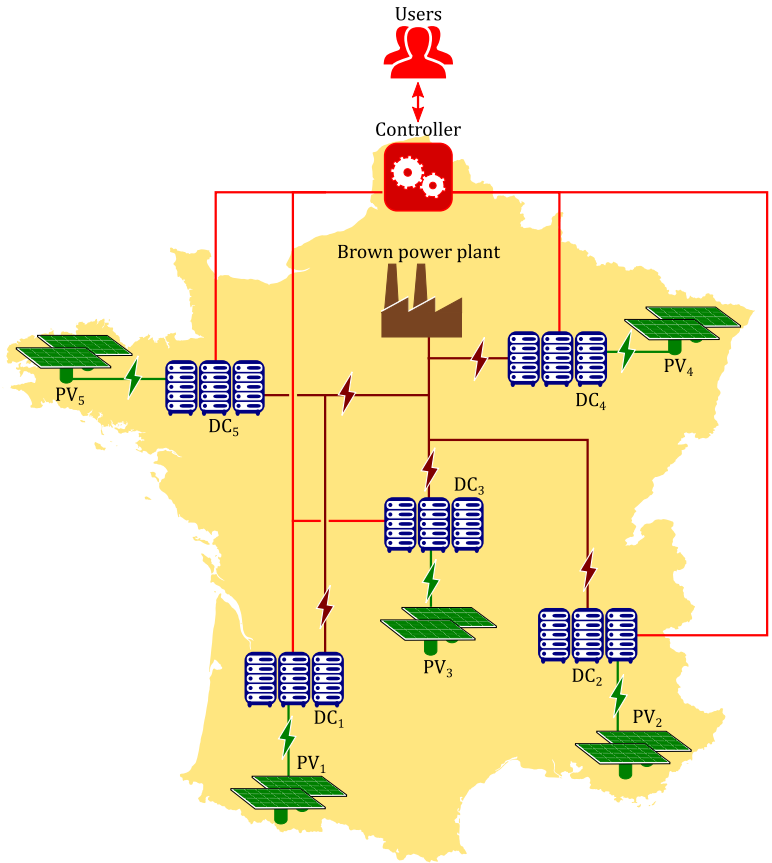
Problem formulation

Cloud:

- M data centers (DC) spread across a country
- DC equipped with photovoltaic panels (PV) and brown power plant
- Incoming workload = VMs

Challenges:

- Minimize brown energy consumption
- Predict each local green power production
- Determine VM migration



Hypotheses

- Servers are homogeneous
  - Computing speed
  - Energy consumption
- Heterogeneous VMs
  - Submitted by time-slots
  - At unpredictible rate
  - Various duration and CPU and memory requirement
- Migration intra and inter DC
- Energy consumption of the network neglected

Platform model

Based on Grid5000:

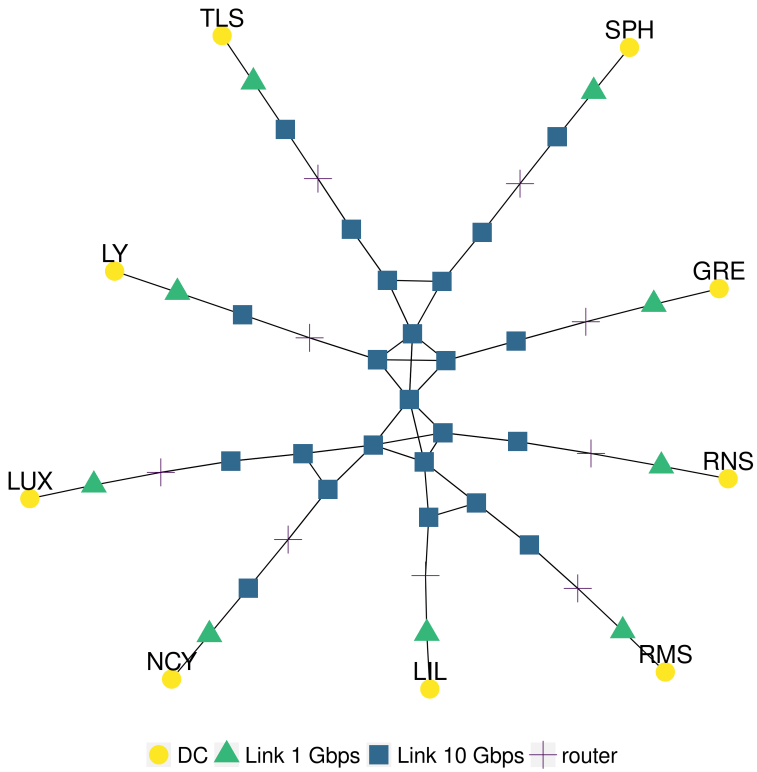
- 9DC
- 1035 servers

Basis PV sizing:

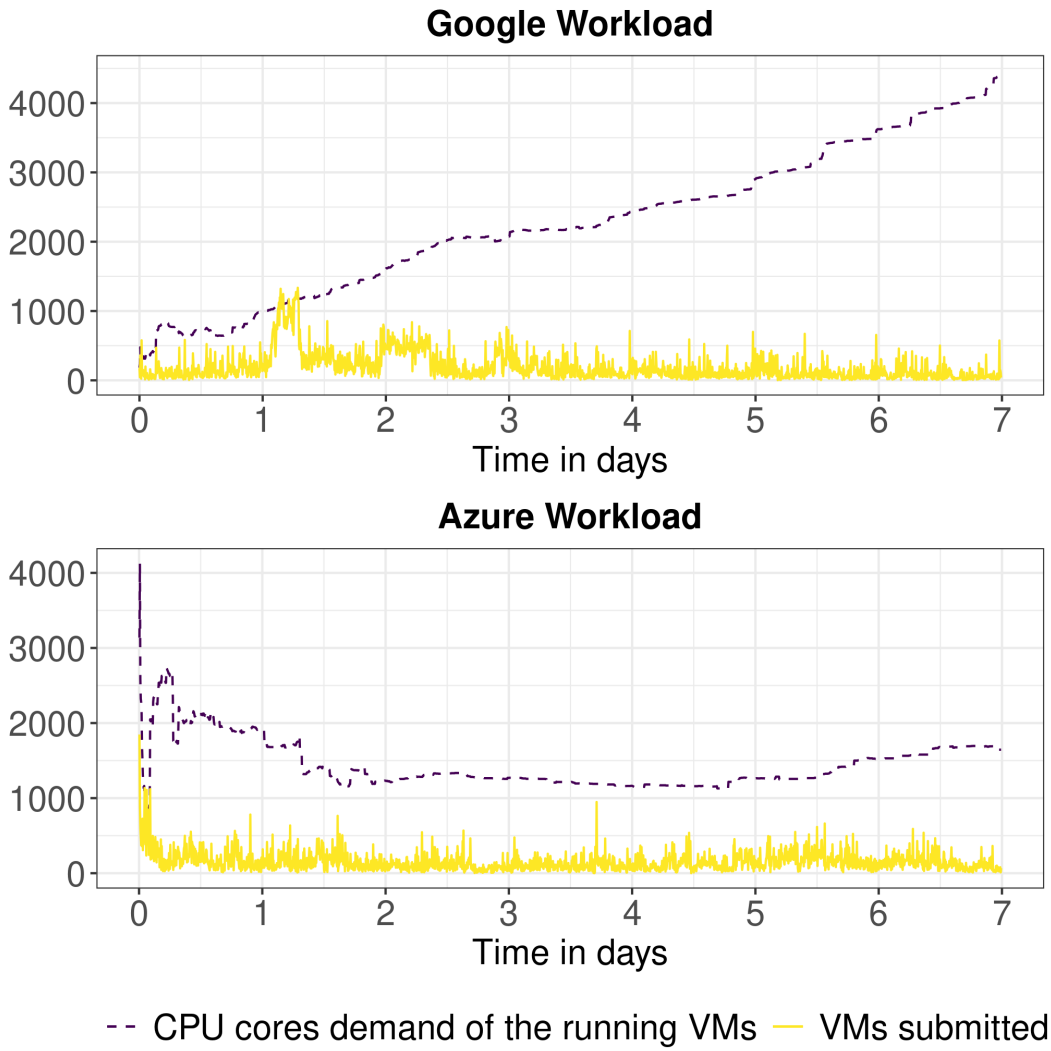
- 3 PV panel per Server
- 3105 PV panels

Modeling of one week

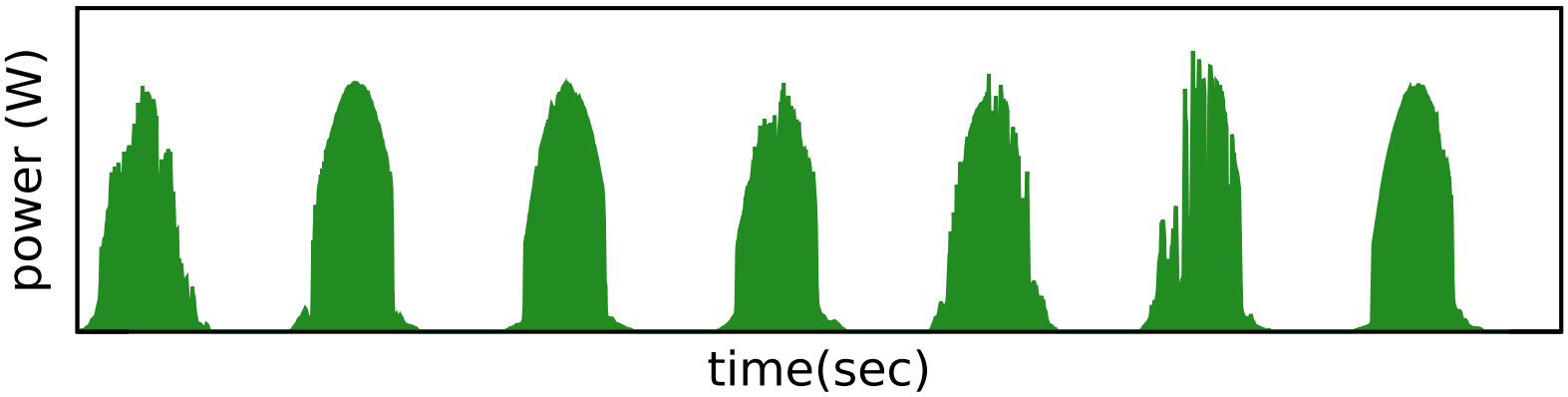
Time slots of 5min



Simulation input: Workload



Simulation input: Photovoltaic Panel



Photovolta project (Nantes)

4 panel Sanyo HIT-240-HDE4

Total power $4 * 240Wc = 960Wc$

Total area $4 * 1,38m^2 = 5,52m^2$

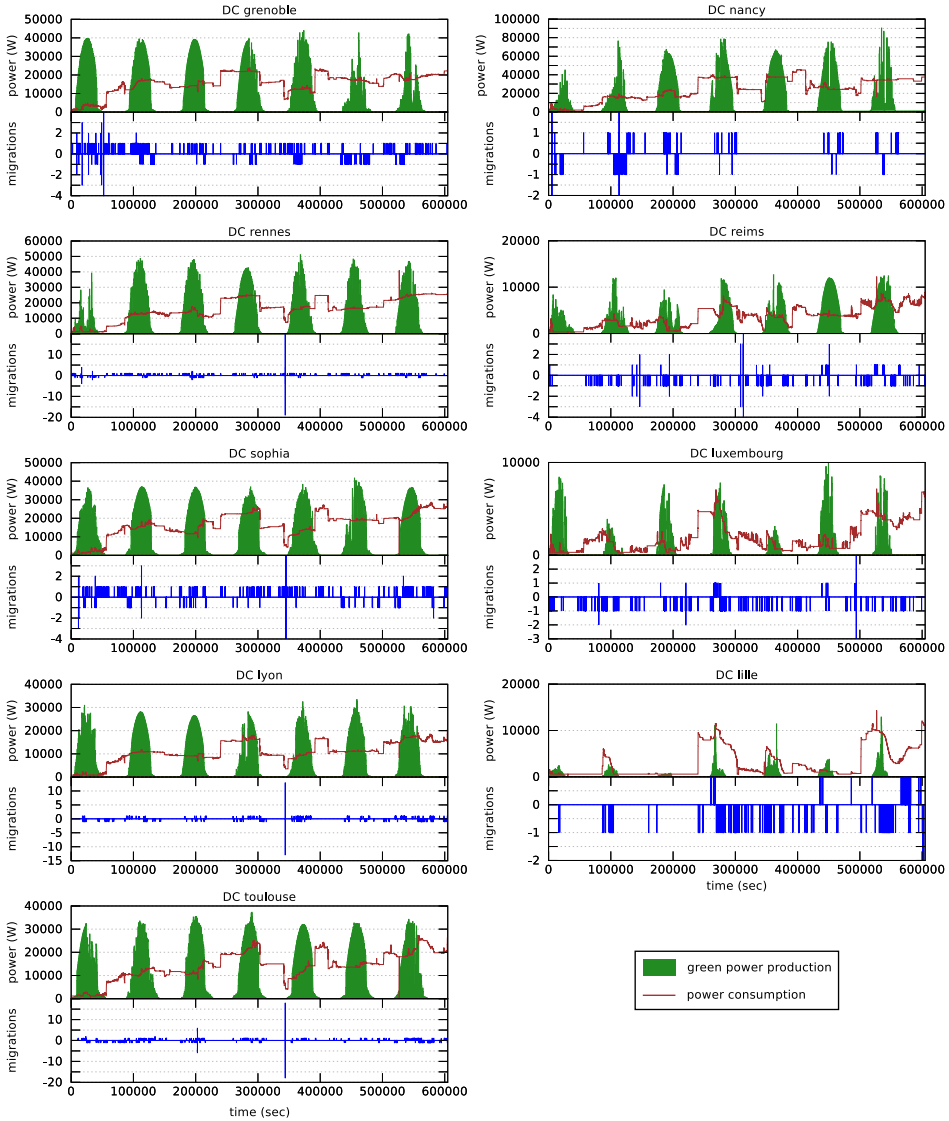
First papers

Camus, B., Dufossé, F., & Orgerie, A. (2017). A stochastic approach for optimizing green energy consumption in distributed clouds.
In *SMARTGREENS 2017 - International Conference on Smart Cities and Green ICT Systems* Porto, Portugal: SMARTGREENS

Camus, B., Blavette, A., Dufossé, F., & Orgerie, A. (2018a). Self-Consumption Optimization of Renewable Energy Production in Distributed Clouds.
In *2018 IEEE International Conference on Cluster Computing (CLUSTER)* (pp. 370–380). Belfast, UK: IEEE

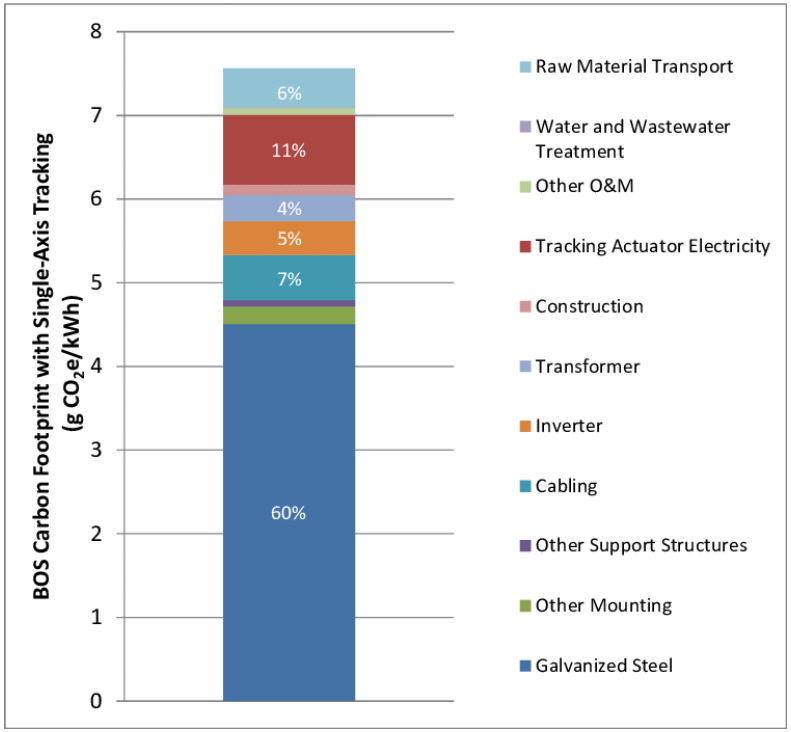
Camus, B., Dufossé, F., Blavette, A., Quinson, M., & Orgerie, A. (2018b). Network-Aware Energy-Efficient Virtual Machine Management in Distributed Cloud Infrastructures with On-Site Photovoltaic Production.

In *2018 30th International Symposium on Computer Architecture and High Performance Computing (SBAC-PAD)* (pp. 86–92). Lyon, France: IEEE



Dimensioning of solar panels

- Compromise between
  - Brown energy reduction
  - Footprint of PV manufacturing
- The footprint per panel
  - Estimated at $250 kg\ CO^2 eq$
- Depend on PV lifetime (15y? 25y? 40y?)



Sinha, P., Schneider, M., Dailey, S., Jepson, C., & de Wild-Scholten, M. (2013). Eco-efficiency of cdte photovoltaics with tracking systems.

In *2013 IEEE 39th Photovoltaic Specialists Conference (PVSC)* (pp. 3374–3378).: IEEE

Footprint of the PV farms

Footprint:

- Estimated at $250 kg\ CO^2 eq$
- 3105 panels
- $776,25 T\ CO^2 eq$

Lifetime:

- Degradation rate estimated between 1% and 2%
- According to IPCC, 20y for concentrated solar power, 25y for solar PV

Footprint per week

	15y	25y	40y
3105 panels	$1.00 T\ CO^2 eq$	$0.60 T\ CO^2 eq$	$0.37 T\ CO^2 eq$

Consumption with PV dimensioning

	W	Green P.	Total C.	Brown C.
0 PV	G	0MWh	25.26MWh	25.26MWh
Basis	G	10.47MWh	25.56MWh	17.23MWh
$\times$2 PV	G	20.94MWh	25.63MWh	15.50MWh
$\times$3 PV	G	31.41MWh	25.63MWh	14.81MWh
0 PV	A	0MWh	30.32MWh	30.32MWh
Basis	A	10.47MWh	30.57MWh	21.22MWh
$\times$2 PV	A	20.94MWh	30.59MWh	18.80MWh
$\times$3 PV	A	31.41MWh	30.60MWh	17.88MWh

Dimensioning vs Lifetime

	W	$55 gCO^2eq/kWh$	$250 gCO^2eq/kWh$	$750 gCO^2eq/kWh$
0PV	G	$1.39 TCO^2eq$	$6.31 TCO^2eq$	$18.94 TCO^2eq$
Basis	G	$.95 TCO^2eq$	$4.31 TCO^2eq$	$12.92 TCO^2eq$
$\times$2 PV	G	$.85 TCO^2eq$	$3.87 TCO^2eq$	$11.62 TCO^2eq$
$\times$3 PV	G	$.81 TCO^2eq$	$3.70 TCO^2eq$	$11.11 TCO^2eq$
0PV	A	$1.67 TCO^2eq$	$7.58 TCO^2eq$	$22.74 TCO^2eq$
Basis	A	$1.17 TCO^2eq$	$5.30 TCO^2eq$	$15.91 TCO^2eq$
$\times$2 PV	A	$1.03 TCO^2eq$	$4.70 TCO^2eq$	$14.10 TCO^2eq$
$\times$3 PV	A	$0.98 TCO^2eq$	$4.47 TCO^2eq$	$13.41 TCO^2eq$

Bias and future work

Bias:

- Correlation between footprint of electricity and PV generation
- Same amount of PV per location
- Seasonal weather impact
- Degradation and failure of PV

Future work:

- Energy storage: battery and hydrogen
- Dimensioning of energy storage
- Dimensioning of servers vs QoS