Au cœur de l'efficacité énergétique

Long-term investments in electrical distribution grids: a real options approach

UMR CNRS 5269 - Grenoble-INP – Université Grenoble Alpes

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Problem statement

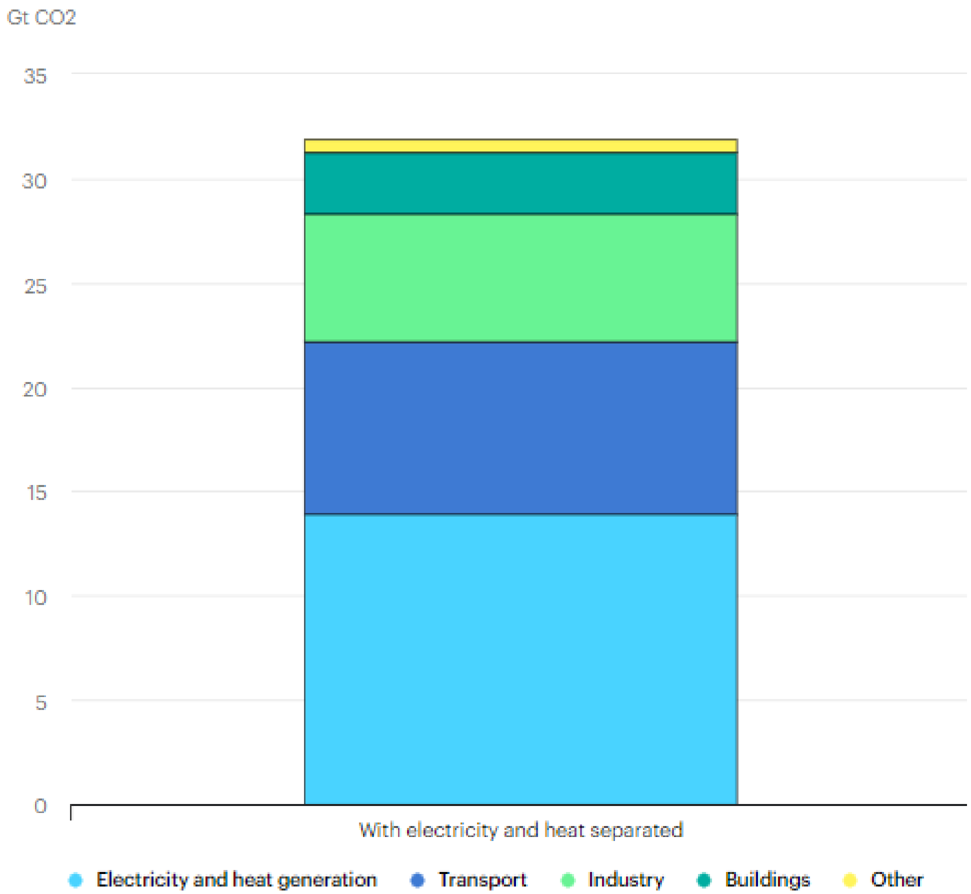

Figure 1: Global CO2 emissions per sector 2018 [1]

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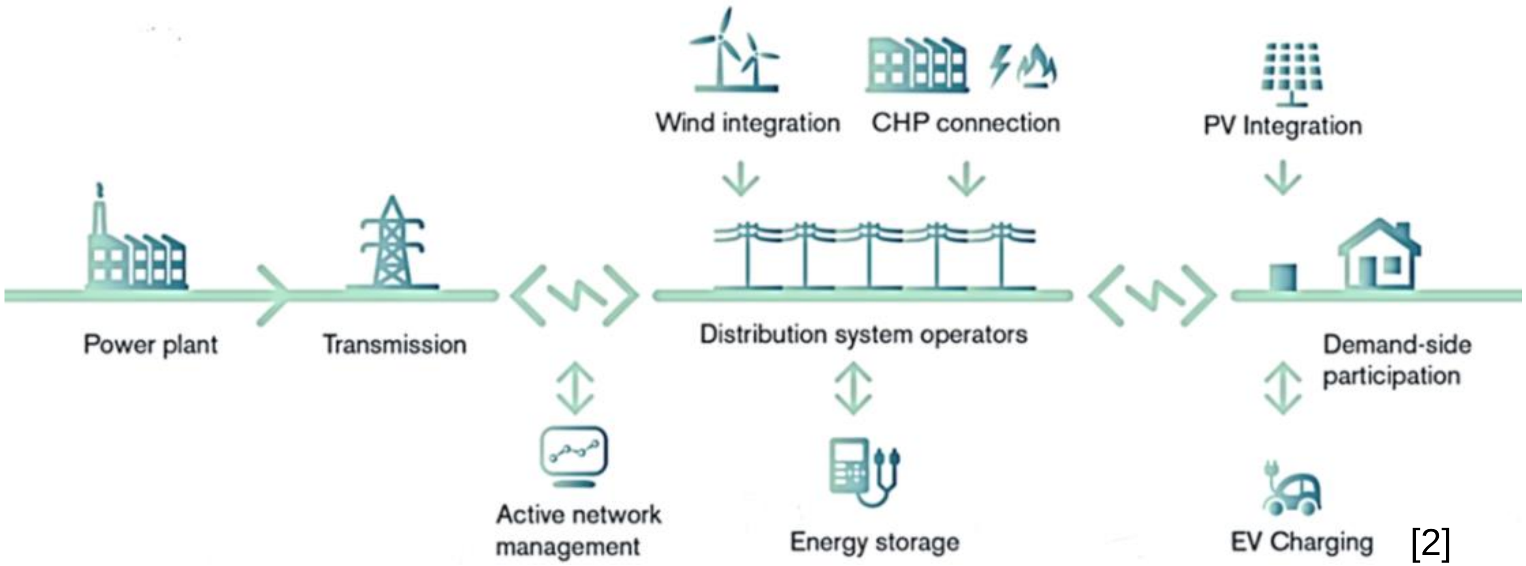
Problem statement

- New contracts such as Demand Side Management, RE surplus injection, EV charging, etc.
- Increase uncertainty on the distribution grid
- Discounted Cashflows methods are not sufficient



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Real Options

- Analogy of managerial flexibility with financial options
- Includes uncertainty in the analysis
- Values future information to resolve uncertainty

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Long-term distribution grid investment

- DSO’s responsibility to maintain quality of distribution and electrify new clients
- Two steps:
  - Step 1: Technical optimization
  - Step 2: Economic optimization
- Real options are added as an additional layer to economic analysis

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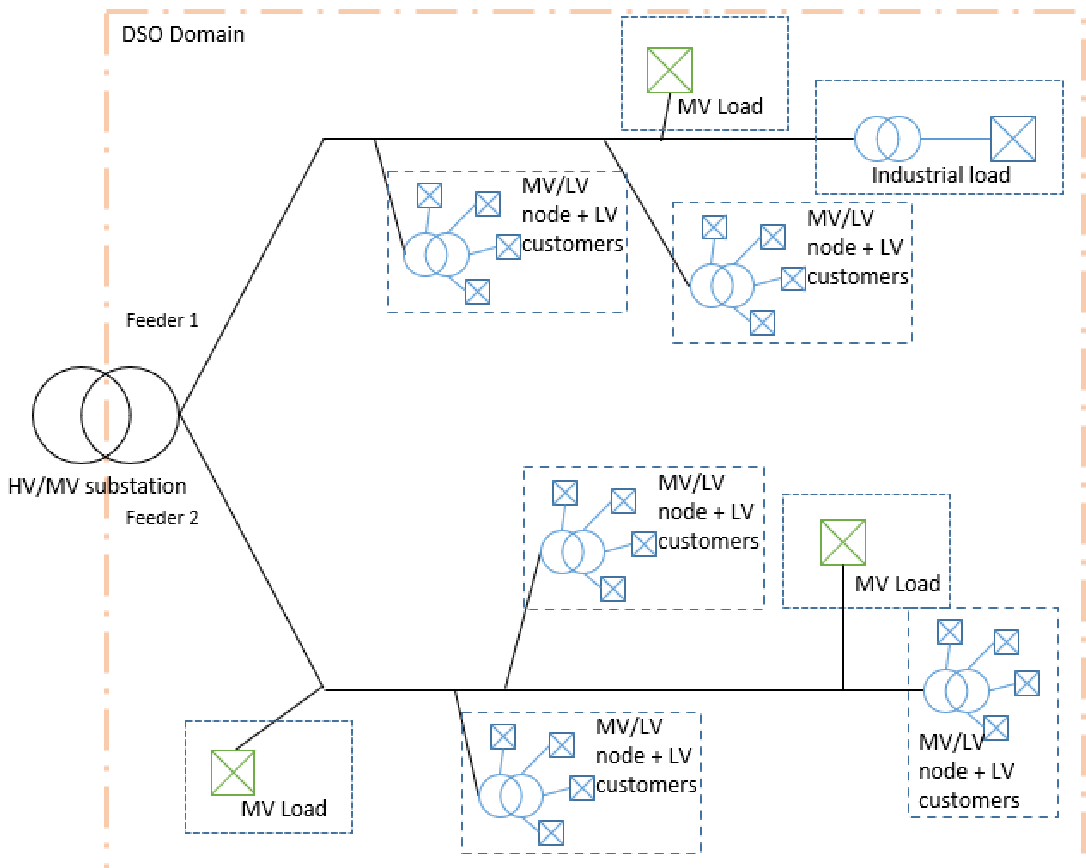
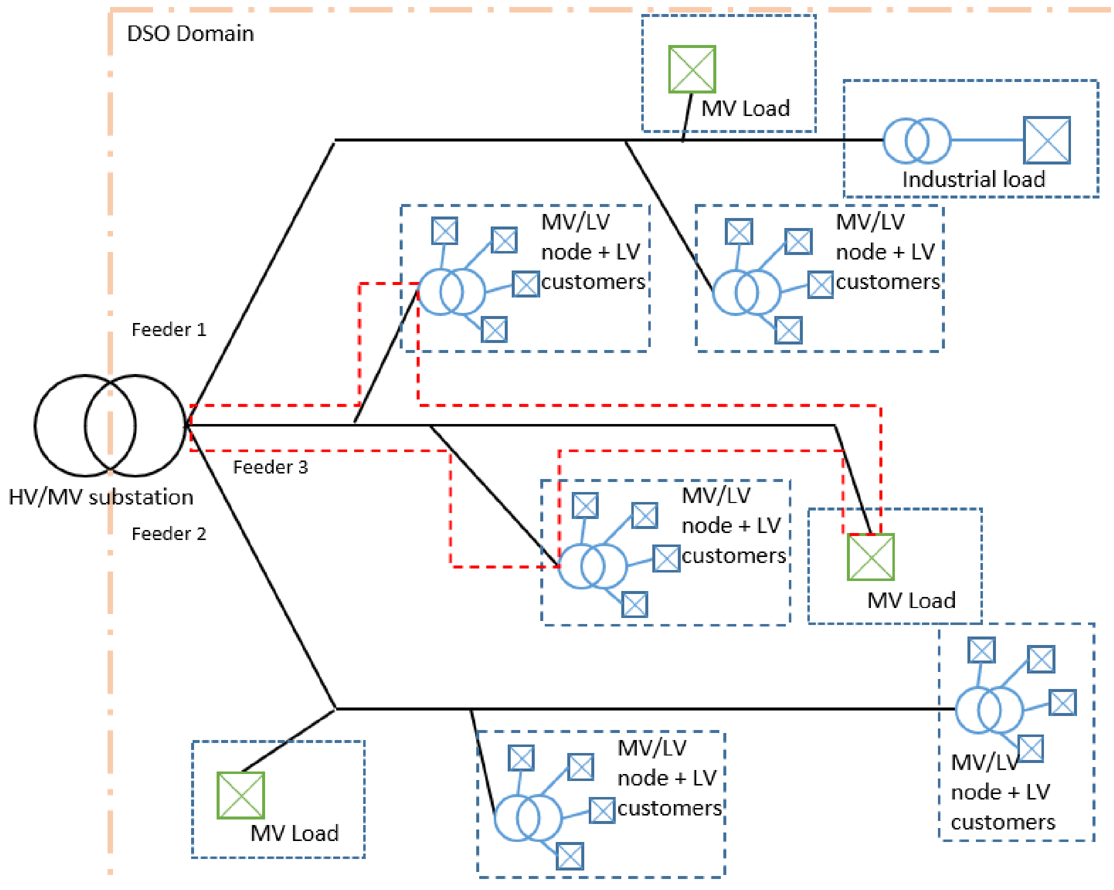
Definition of case study



Initial network topology (year 0)

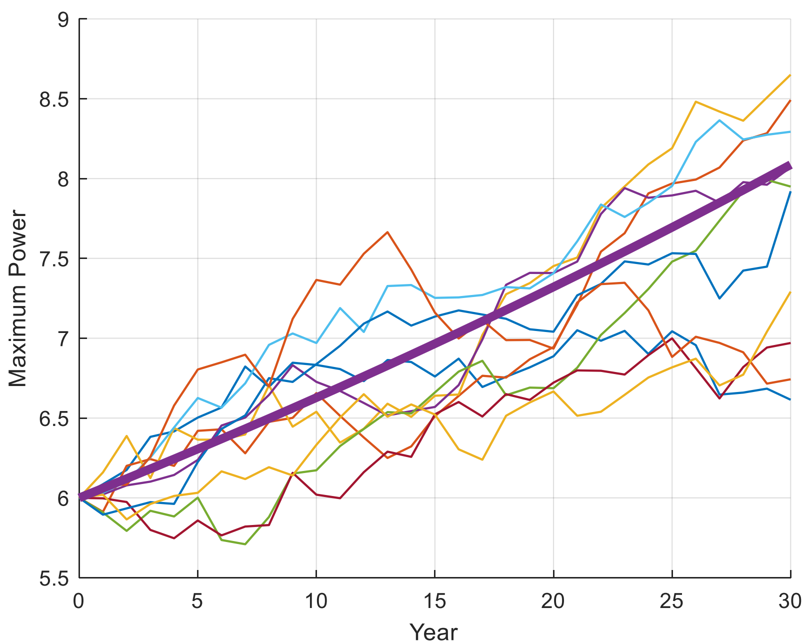
Definition of case study

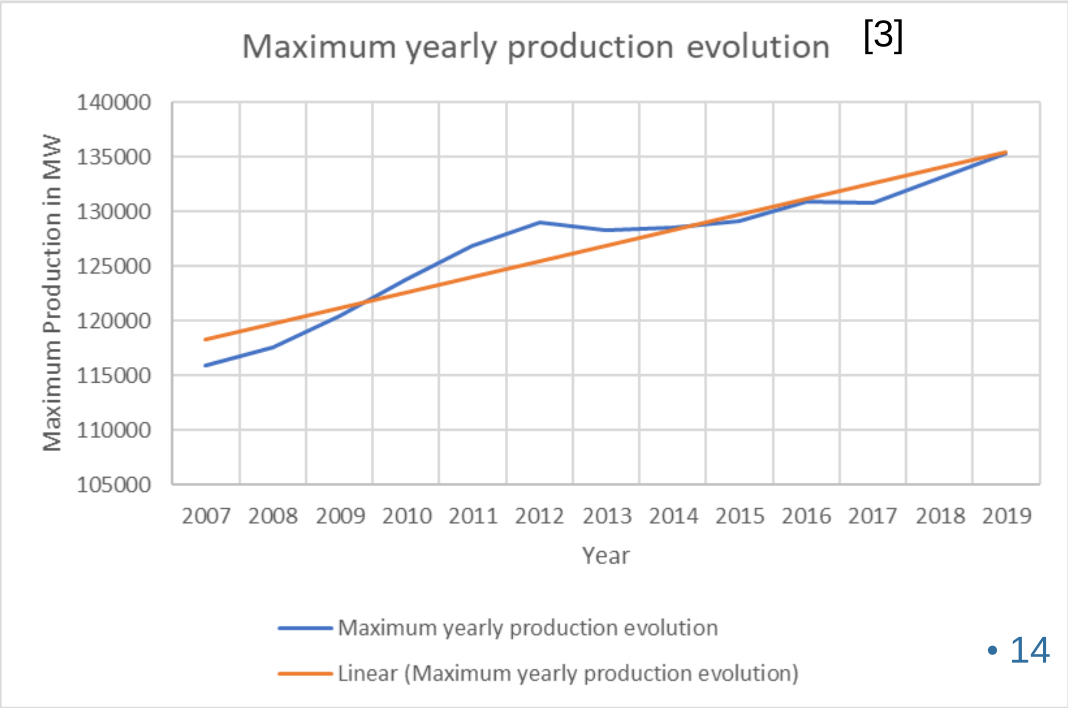


Final network topology (year T)

Definition of case study

- The source of uncertainty is $P_{max}(t)$
- Follows a geometric Brownian motion





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Methodology

Economic modelling including uncertainty

- Identifying relative DSO cost models
- Identification of the stochastic variable and its model, and determination of expected discounted value

Optimal investment threshold and timing computation

- Stochastic optimization of the option value (Bellman's principle)
- Determining the optimal investment threshold triggering investment
- Calculation of the option value

Results analysis, sensitivity analysis and conclusions

- Comparison with the time continuous results without uncertainty
- Sensitivity analysis for economic and technical parameter variation

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Modelling

- Cost model incorporating uncertainty

$$OPEX_k(P_{max}) = E[\int_0^T e^{-rt} \sum_{i=1}^{N_k} C_{losses} \xi_{i,k} \, \lambda_{i,k}^2 \, P_{max}(t)^2 \; dt$$

Power losses cost

Modelling

- Cost model incorporating uncertainty

$$OPEX_k(P_{max}) = E[\int_0^T e^{-rt} \sum_{i=1}^{N_k} C_{losses} \xi_{i,k}\, \lambda_{i,k}^2\, P_{max}(t)^2 \; dt + \boxed{\int_0^T e^{-rt} \sum_{i=1}^{N_k} C_{END} (\tau_o l_{o,i,k} + \tau_u l_{u,i,k}) \lambda_{i,k} T_{out,i,k} \frac{H_{max}}{8760} P_{max}(t)\, dt}$$

Cost of not supplied energy

Modelling

- Cost model incorporating uncertainty

$$OPEX_k(P_{max}) = E[\int_0^T e^{-rt} \sum_{i=1}^{N_k} C_{losses} \xi_{i,k} \lambda_{i,k}^2 P_{max}(t)^2 \, dt + \int_0^T e^{-rt} \sum_{i=1}^{N_k} C_{END} (\tau_o l_{o,i,k} + \tau_u l_{u,i,k}) \lambda_{i,k} T_{out,i,k} \frac{H_{max}}{8760} P_{max}(t) \, dt + \int_0^T e^{-rt} \sum_{i=1}^{N_k} C_{out} (\tau_o l_{o,i,k} + \tau_u l_{u,i,k}) \lambda_{i,k} \frac{H_{max}}{8760} P_{max}(t) \, dt \,|\, P_{max}(0) = P_{max}]$$

Cost of power outages

Modelling

- Cost model incorporating uncertainty

$$
\begin{aligned}
&OPEX_{\mathrm{k}}(P_{max}) \\
&= C_{losses}\frac{P_{max}^2}{r-2\mu-\sigma^2}\left(1-e^{-(r-2\mu-\sigma^2)T}\right)\sum_{i=1}^{N_k}\xi_i\lambda_{i,k}^2 \\
&+ C_{END}\frac{P_{max}}{r-\mu}\left(1-e^{-(r-\mu)T}\right)\frac{H_{max}}{8760}\sum_{\mathrm{i}=1}^{N_k}T_{out,i,k}\left(\tau_u l_{u,i,k}+\tau_o l_{o,i,k}\right)\lambda_{i,k} \\
&+ C_{out}\frac{P_{max}}{r-\mu}\left(1-e^{-(r-\mu)T}\right)\frac{H_{max}}{8760}\sum_{\mathrm{i}=1}^{N_k}(\tau_u l_{u,i,k}+\tau_o l_{o,i,k})\lambda_{i,k}
\end{aligned}
$$

- Capital expenditures depend only on line length and installation costs

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Modelling

- $NPV(P_{\max}) = \begin{cases} OPEX_{\mathrm{wr}}(P_{max}) - F(P_{max}) & for\ P_{max} < P^*_{max} \\ OPEX_{\mathrm{r}}(P_{max}) + CAPEX & for\ P_{max} \geq P^*_{max} \end{cases}$

Modelling

- $NPV(P_{\max}) = \begin{cases} OPEX_{\mathrm{wr}}(P_{max}) - F(P_{max}) & for\ P_{max} < P^*_{max} \\ OPEX_{\mathrm{r}}(P_{max}) + CAPEX & for\ P_{max} \geq P^*_{max} \end{cases}$

- $F(P_{max}(t), t) = argmax(e^{-rdt} E_t[F(P_{max}(t + dt), t + dt)]$

Modelling

- $NPV(P_{\max}) = \begin{cases} OPEX_{\mathrm{wr}}(P_{max}) - F(P_{max}) & for\ P_{max} < P^*_{max} \\ OPEX_{\mathrm{r}}(P_{max}) + CAPEX & for\ P_{max} \geq P^*_{max} \end{cases}$
- $F(P_{max}(t), t) = argmax(e^{-rdt} E_t[F(P_{max}(t + dt), t + dt)]$
- $F(P_{max}) = AP^{\beta}_{max}, \beta = \frac{\sigma^2 - 2\mu + \sqrt{(\sigma^2 - 2\mu)^2 + 8r\sigma^2}}{2\sigma^2}$

Modelling

- $NPV_{wr}(P^*_{max}) = NPV_r(P^*_{max})$

- $\frac{\partial NPV_{wr}}{\partial P^*_{max}}(P^*_{max}) = \frac{\partial NPV_r}{\partial P^*_{max}}(P^*_{max})$

- $P^*_{max} = \frac{(1-\beta)(G_{END}+G_{out}) - \sqrt{\frac{(\beta-1)^2(G_{END}+G_{out})^2}{r-\mu} - \frac{4\beta(\beta-2)CAPEXG_{losses}}{r-\mu-\sigma^2}}}{2(\beta-2)G_{losses}}$

- $A = -\frac{2G_{losses}\frac{P^{*2-\beta}_{max}}{r-2\mu-\sigma^2} + (G_{END}+G_{out})\frac{P^{*1-\beta}_{max}}{r-\mu}}{\beta}$

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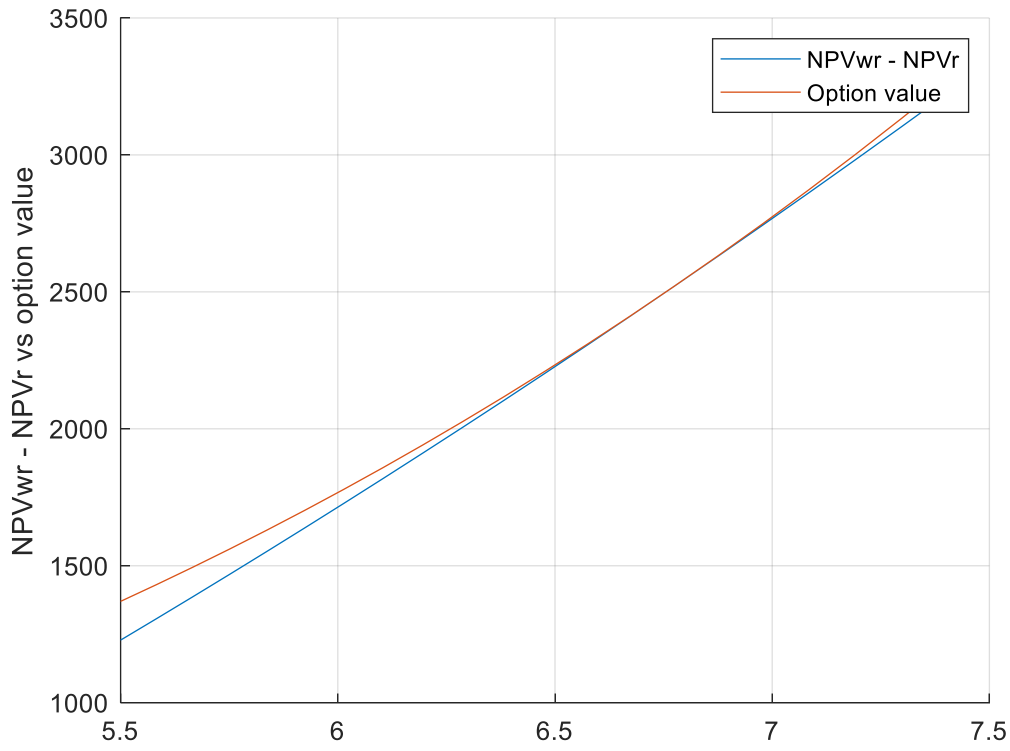
Threshold behavior



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Comparative results

Project Valuation in Continuous Time Framework	Symbol	Unit	Value
Continuous time cost-benefit analysis $(\mu \neq 0, \sigma = 0, T = \infty)$			
Investment trigger	P_{max}^{**}	MW	6.67
NPV	NPV^{**}	k€	1705.71
Min Expected time to invest	Min T^c	years	6.53
Max Expected time to invest	Max T^c	years	7.02
Continuous time with uncertainty on load evolution $(\mu \neq 0, \sigma \neq 0, T = \infty)$			
Investment trigger	P_{max}^{*}	MW	6.75
NPV	NPV^{*}	k€	2347.58
Expected time to invest	T^{*}	years	7.99
Option value to wait constant (A)	A	k€	9.36
Current max power for reference	$P_{max}(0)$	MW	6

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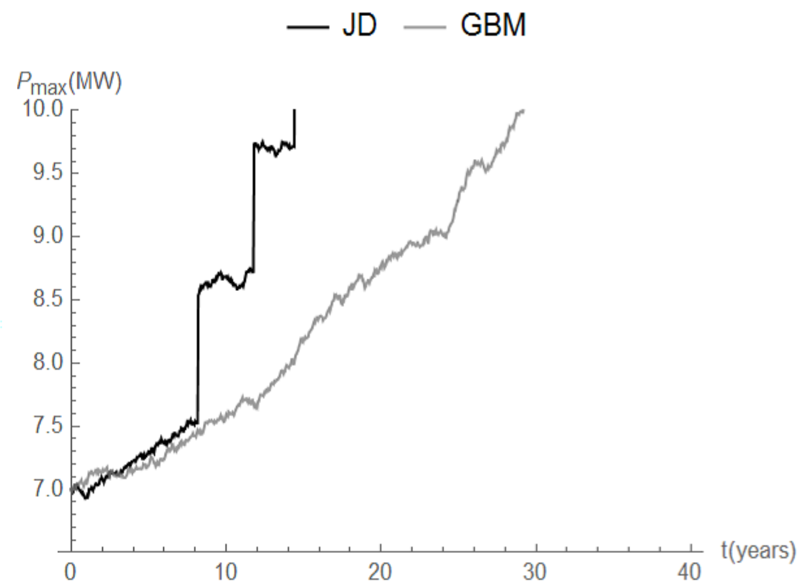
First extension: Jump diffusion process

- Captures the connection of large loads
- $dP_{max}(\mathrm{t}) = \mu P_{max}(t)dt + \sigma P_{max}(t)dz + P_{max}(\mathrm{t})\mathrm{dq},$

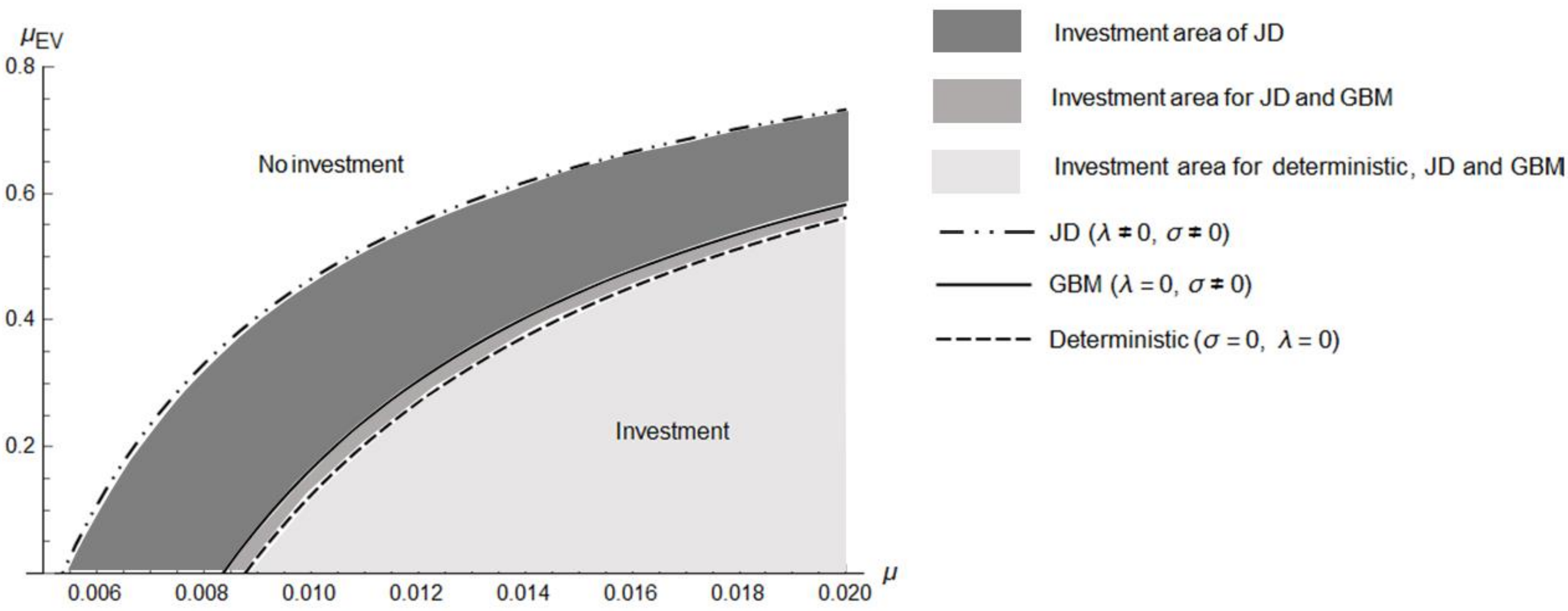
$$\mathrm{dq} = \begin{cases} \theta \text{ } with\ probability\ \lambda dt \\ 0 \text{ } with\ probability\ 1 - \lambda dt \end{cases}$$

- $NPV_{DCF} < NPV_{JD} < NPV_{GBM}$



Second extension: EV integration

- $\mu_{real} = \mu(1 - \mu_{EV})$



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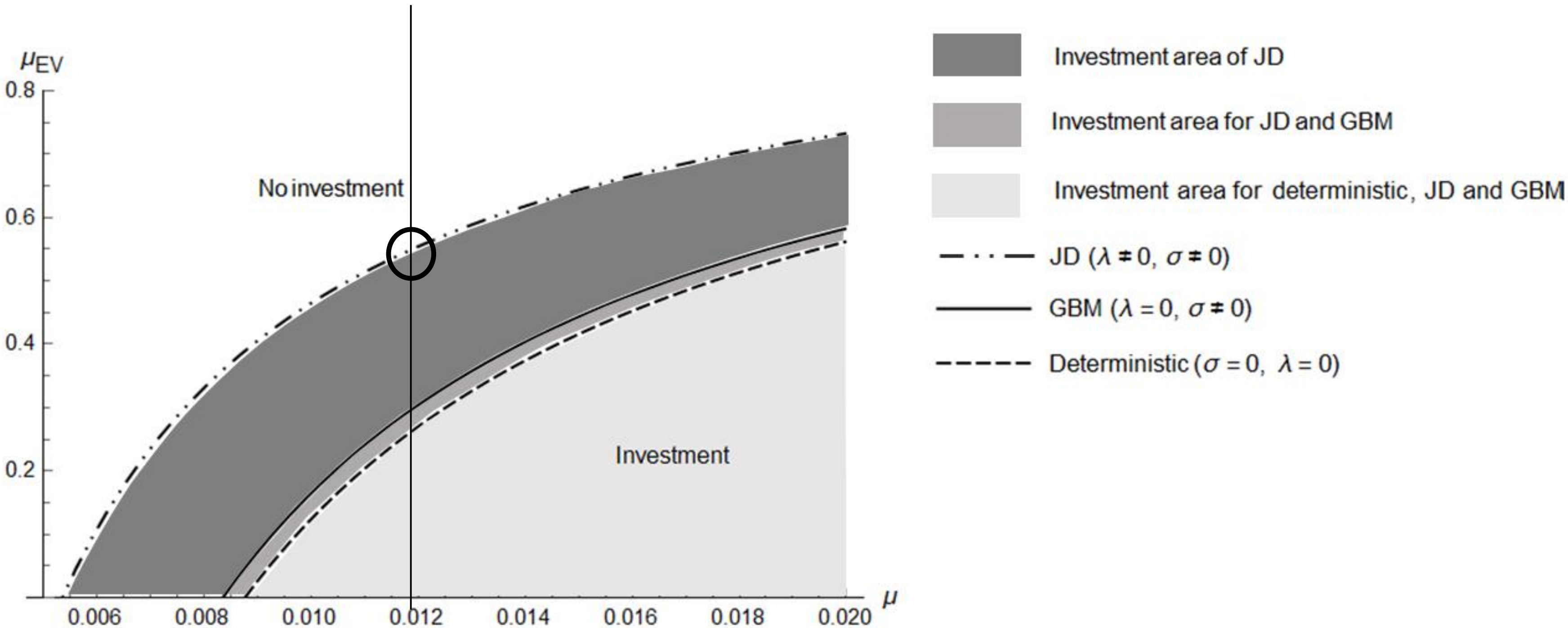

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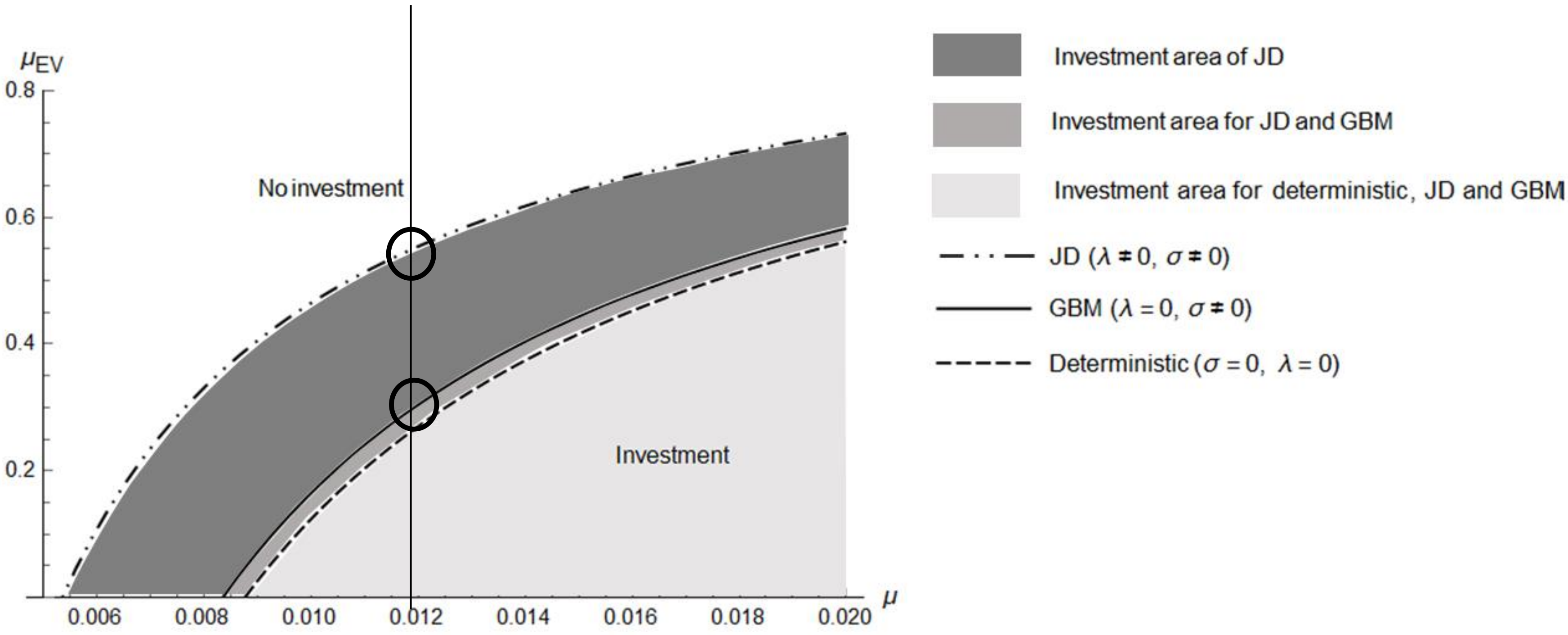
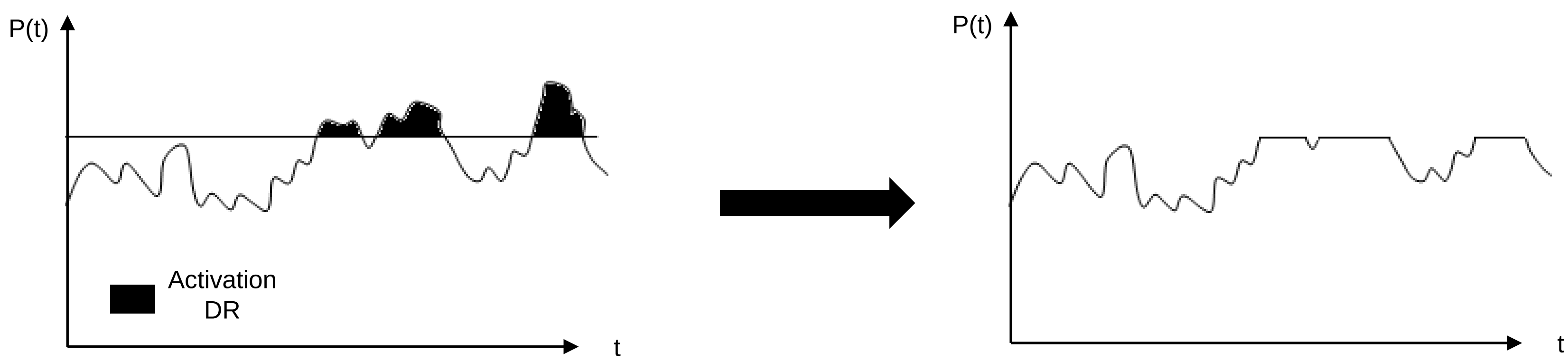


Third extension: DR modelling



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Conclusions

- This work complements existing literature by adding to it a continuous time analytical model in the context of distribution grid investments

- Dynamic decision making tool that includes uncertainty and represents decision making flexibility

- The presented solution allows for finer analysis of the investment decision and has a low computational cost

- Optimal strategy determination by determining optimal investment thresholds for the load power and expected investment timing.

G2ELab Grenoble Génie Electrique Grenoble Electrical Engineering

THANK YOU

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References

[1] - IEA (2020), CO2 Emissions from Fuel Combustion: Overview, IEA, Paris https://www.iea.org/reports/co2-emissions-from-fuel-combustion-overview

[2] - https://www.edsoforsmartgrids.eu/home/why-smart-grids/

[3] - https://opendata.reseaux-energies.fr/explore/dataset/parc-prod-par-filiere

[4] – Investment under uncertainty, A. Dixit, R. Pindyck, 1994

[5] – The art of smooth pasting, A. Dixit, 1992

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$$OPEX_k(P_{max}) = E\left[\int_0^T e^{-rt} \sum_{j=1}^{n} a_j P_{max}^{\gamma_j}(t)\, dt \,\middle|\, P_{max}(0) = P_{max}\right]$$

$$= \sum_{j=1}^{n} \frac{a_j {P_{max}}^{\gamma_j}}{r - \mu\gamma_j - \frac{\sigma^2}{2}\left(\gamma_j^2 - \gamma_j\right)} \left(1 - e^{-\left(r - \mu\gamma_j - \frac{\sigma^2}{2}\left(\gamma_j^2 - \gamma_j\right)\right)T}\right)$$

$$with\ \mu < \frac{r}{\gamma_j} - \frac{\sigma^2}{2}\left(\gamma_j - 1\right)$$

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$$G_{losses} = C_{losses}\left(\sum_{i=1}^{N_{\mathrm{wr}}} \xi_{i,2}\lambda_{i,\mathrm{wr}}^2 - \sum_{i=1}^{N_{\mathrm{r}}} \xi_{i,1}\lambda_{i,\mathrm{r}}^2\right)\left(1 - e^{-(r-2\mu-\sigma^2)T}\right)$$

$$G_{END} = C_{END}\left(\sum_{i=1}^{N_{\mathrm{wr}}}(\tau_u l_{u,\mathrm{i,wr}} + \tau_o l_{o,\mathrm{i,wr}})\lambda_{i,\mathrm{wr}} T_{out,i,\mathrm{wr}} - \sum_{i=1}^{r}(\tau_u l_{u,\mathrm{r}} + \tau_o l_{o,\mathrm{i,r}})\lambda_{i,1} T_{out,i,\mathrm{r}}\right)\frac{H_{max}}{8760}\left(1 - e^{-(r-\mu)T}\right)$$

$$G_{out} = C_{out}\left(\sum_{i=1}^{wr}(\tau_u l_{u,\mathrm{i,wr}} + \tau_o l_{o,\mathrm{i,wr}})\lambda_{i,\mathrm{wr}} - \sum_{i=1}^{N_{\mathrm{r}}}(\tau_u l_{u,\mathrm{i,r}} + \tau_o l_{o,\mathrm{i,r}})\lambda_{i,\mathrm{r}}\right)\frac{H_{max}}{8760}\left(1 - e^{-(r-\mu)T}\right)$$