

*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**

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

- **Introduction**
- Case Study
- Conclusion
- References
- Appendix

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

## ■ Introduction

- **Problem statement**
- Real Options
- Long-term investment

## ■ Case Study

## ■ Conclusion

## ■ References

## ■ Appendix

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

## ■ Problem statement

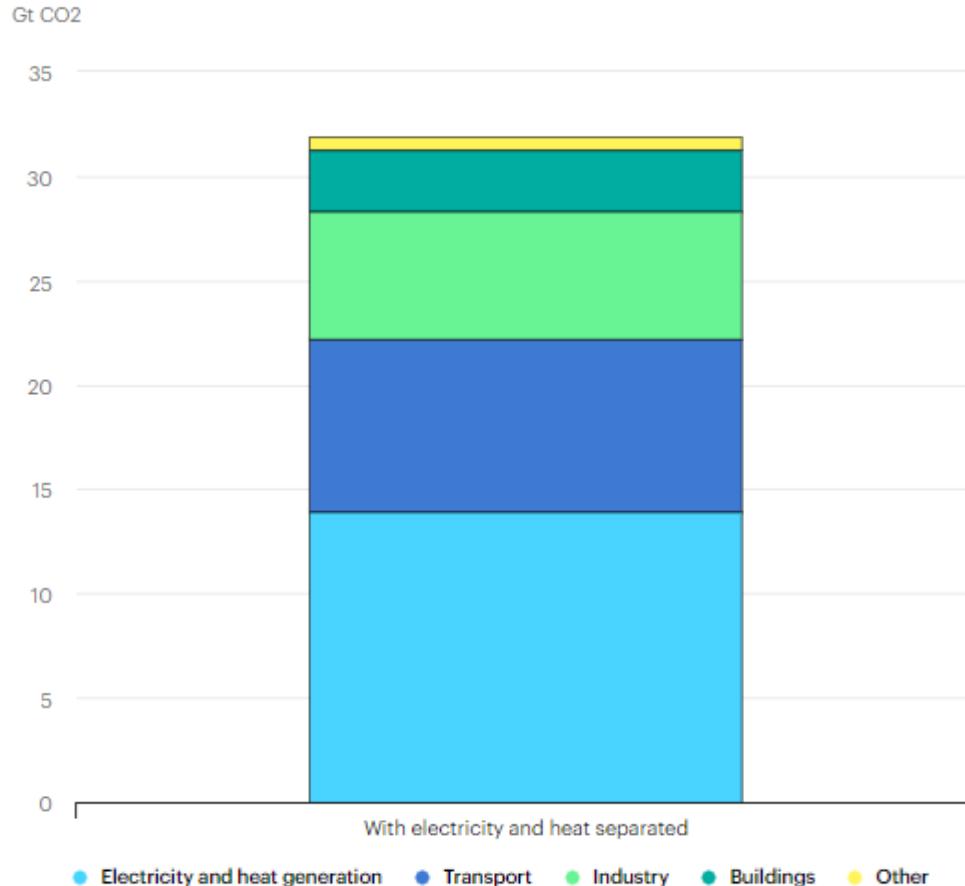
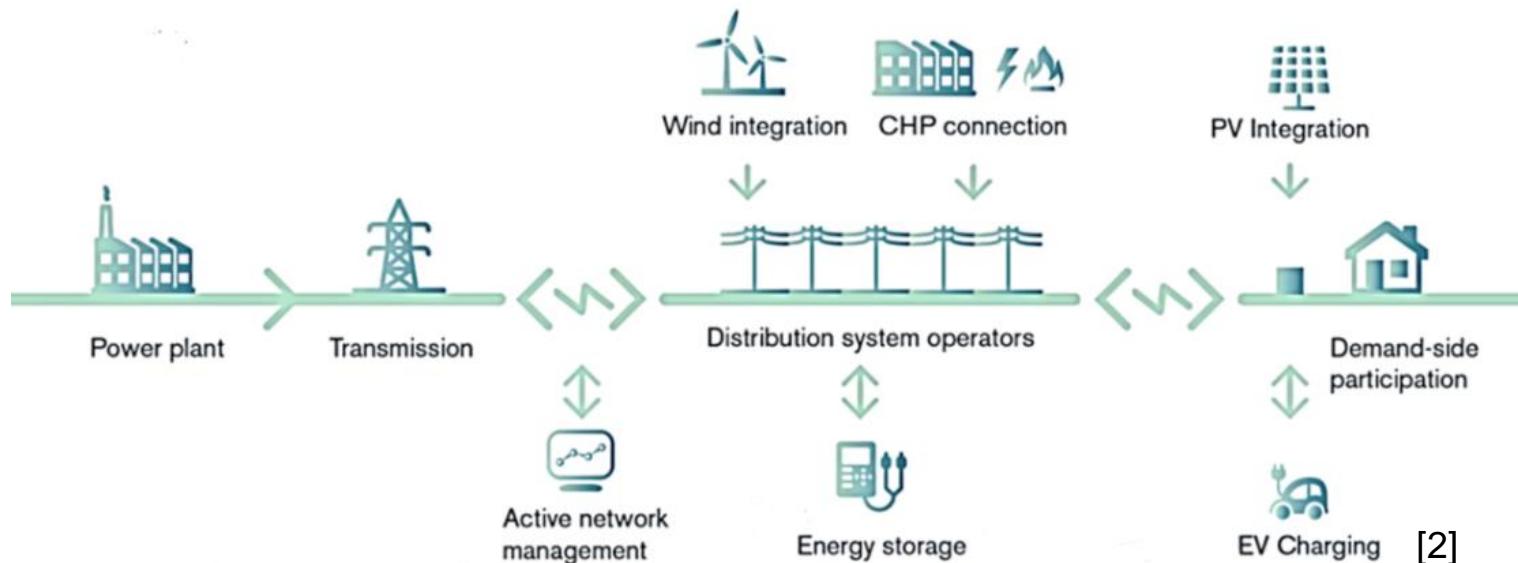


Figure 1: Global CO2 emissions per sector 2018 [1]

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

## ■ 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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## ■ Introduction

- Problem statement
- **Real Options**
- Long-term investment

## ■ Case Study

## ■ Conclusion

## ■ References

## ■ Appendix

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

## ■ Real Options

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

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

## ■ Introduction

- Problem statement
- Real Options
- **Long-term investment**

## ■ Case Study

## ■ Conclusion

## ■ References

## ■ Appendix

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

## ■ 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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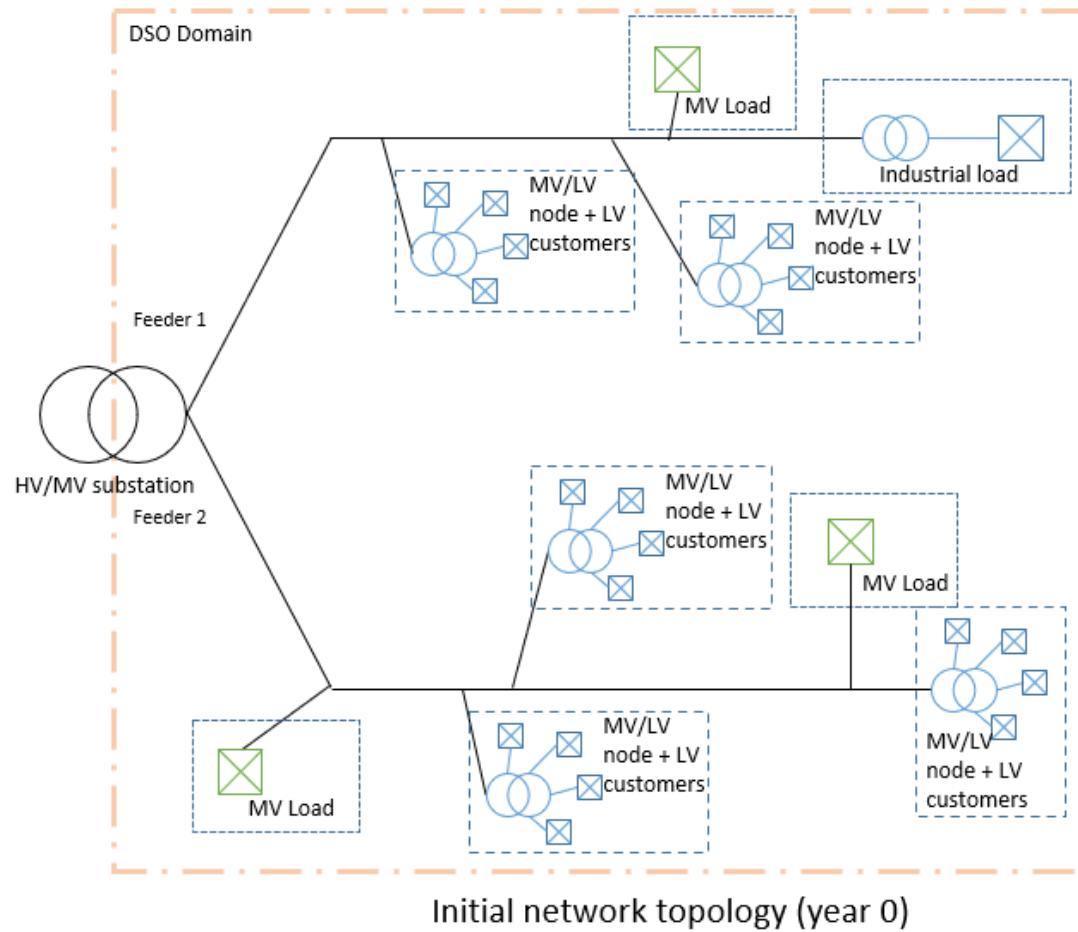
- Introduction
- **Case Study**
- Conclusion
- References
- Appendix

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

- Introduction
- **Case Study**
  - Definition of case study and methodology
  - Modelling
  - Results and sensitivity analysis
- Conclusion
- References
- Appendix

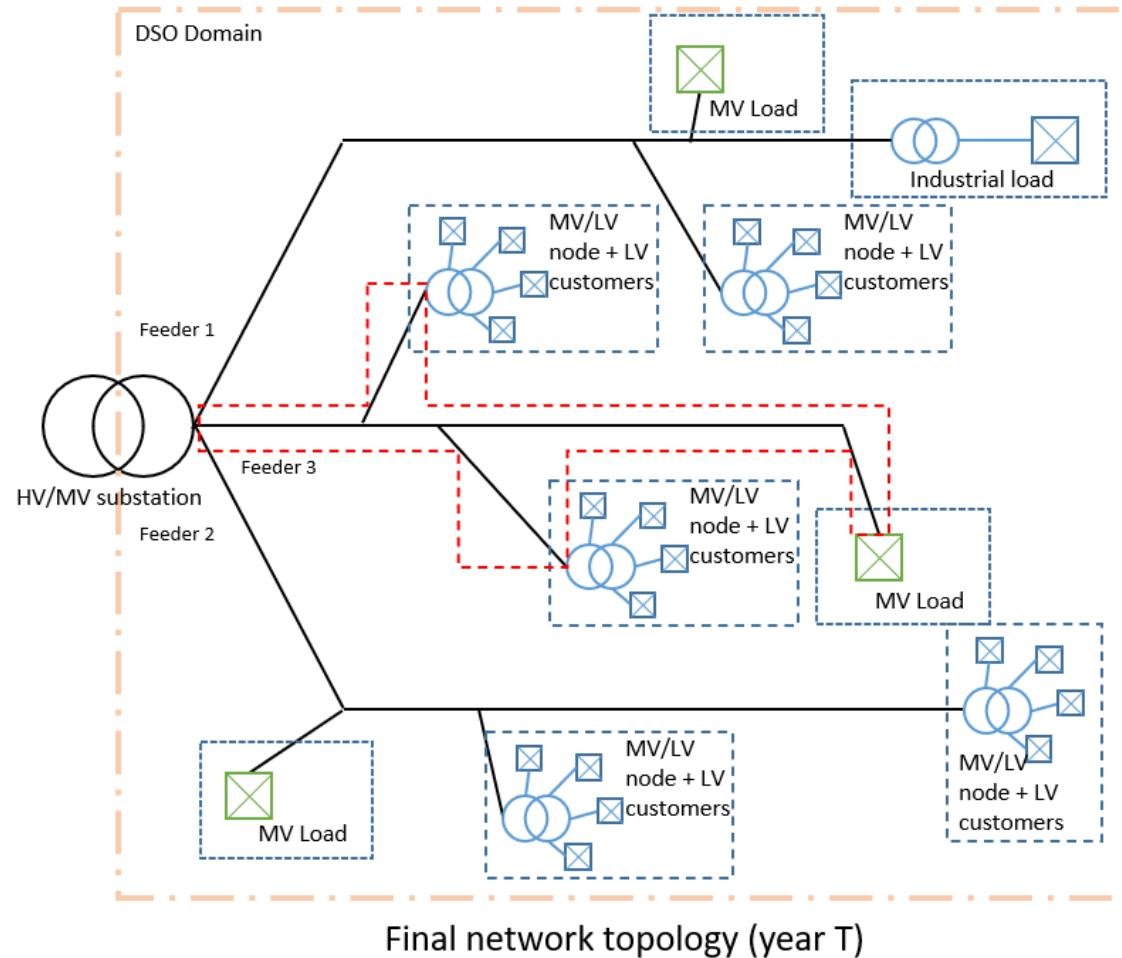
# Long-term investments in electrical distribution grids: a real options approach

## ■ Definition of case study



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

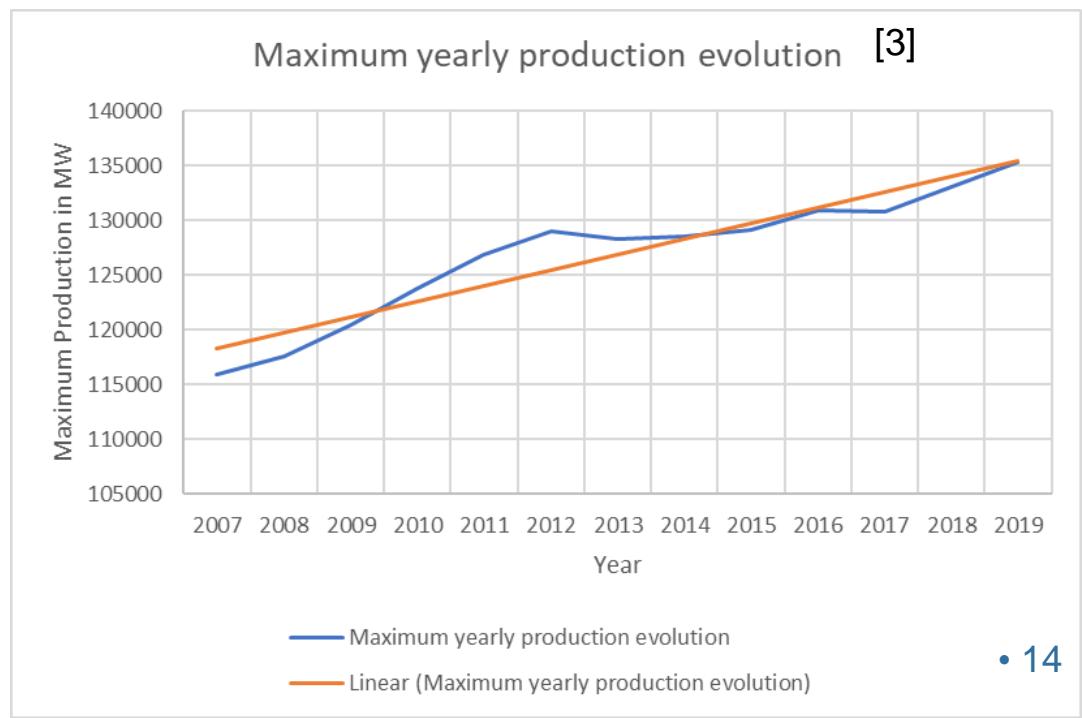
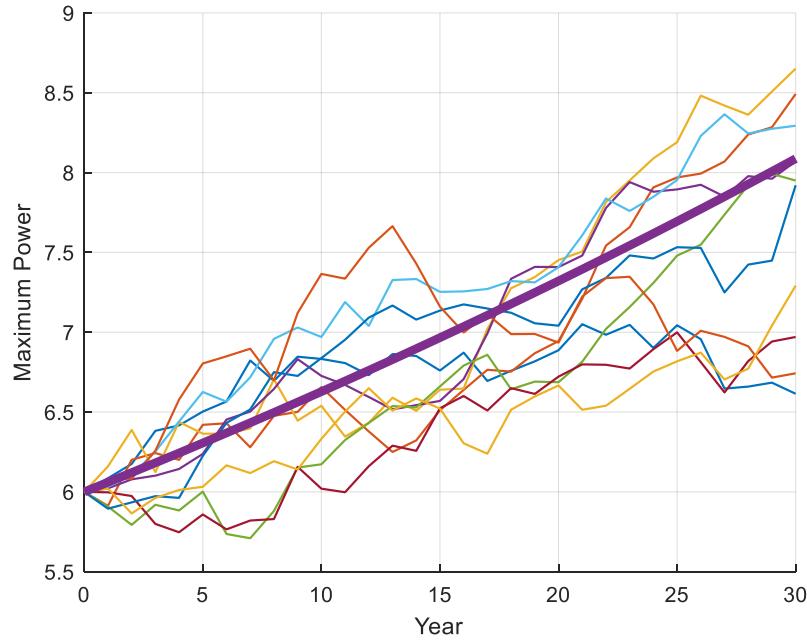
## ■ Definition of case study



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

## ■ Definition of case study

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



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

## 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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- Introduction
- **Case Study**
  - Definition of case study and methodology
  - **Modelling**
  - Results and sensitivity analysis
- Conclusion
- References
- Appendix

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

## ■ Modelling

- Cost model incorporating uncertainty

$$OPEX_k(P_{max}) = E \left[ \int_0^T e^{-rt} \sum_{i=1}^{N_k} C_{losses} \xi_{i,k} \lambda_{i,k}^2 P_{max}(t)^2 dt \right] \longleftrightarrow \text{Power losses cost}$$

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

## ■ Modelling

- Cost model incorporating uncertainty

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

Cost of not supplied energy

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

## ■ Modelling

- Cost model incorporating uncertainty

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

Cost of power outages

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

## ■ Modelling

- Cost model incorporating uncertainty

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

- Capital expenditures depend only on line length and installation costs

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

## ■ Modelling

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

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

## ■ Modelling

- $NPV(P_{max}) = \begin{cases} OPEX_{wr}(P_{max}) - F(P_{max}) & \text{for } P_{max} < P_{max}^* \\ OPEX_r(P_{max}) + CAPEX & \text{for } P_{max} \geq P_{max}^* \end{cases}$
- $F(P_{max}(t), t) = argmax(e^{-rdt} E_t[F(P_{max}(t + dt), t + dt)])$

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

## ■ Modelling

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

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

## ■ Modelling

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

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

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

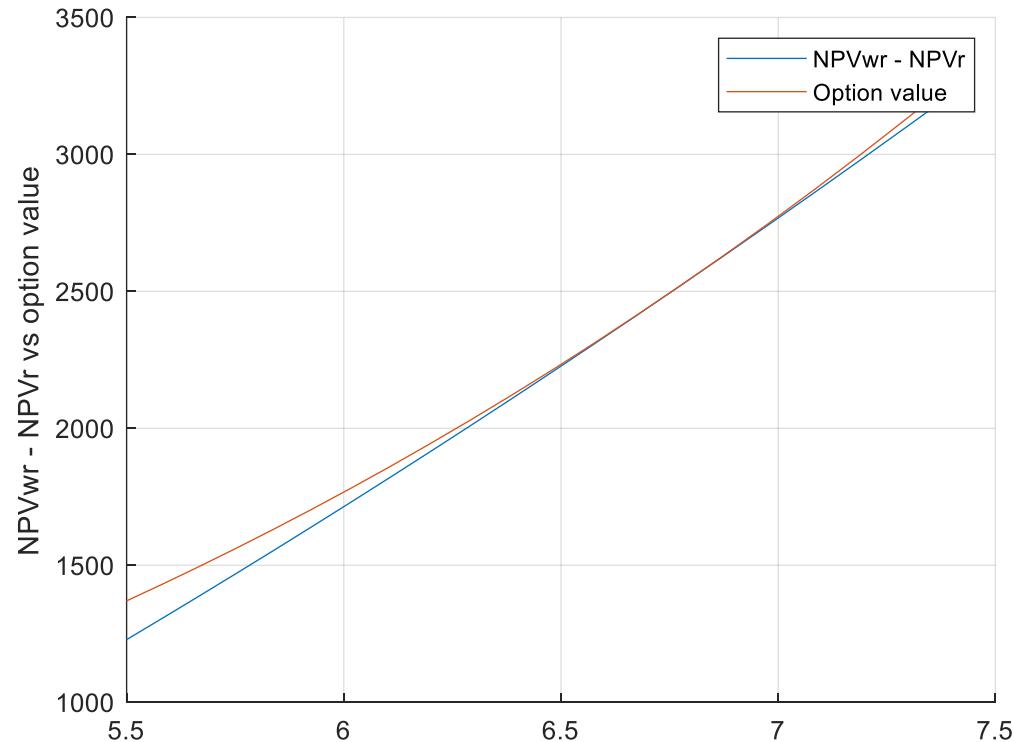
- $A = -\frac{2G_{losses}\frac{P_{max}^{*2-\beta}}{r-2\mu-\sigma^2} + (G_{END}+G_{out})\frac{P_{max}^{*1-\beta}}{r-\mu}}{\beta}$

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

- Introduction
- **Case Study**
  - Definition of case study and methodology
  - Modelling
  - **Results**
  - Extensions
- Conclusion
- References
- Appendix

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

## ■ Threshold behavior



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

## Comparative results

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

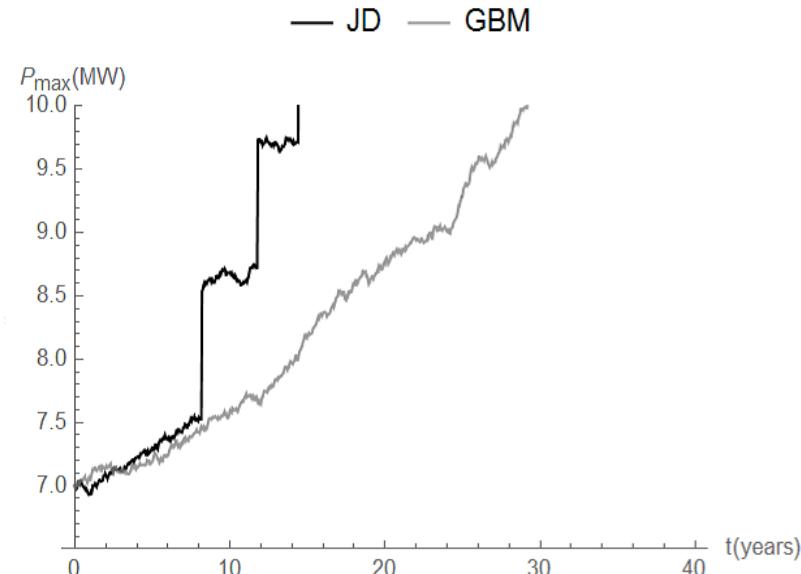
# Long-term investments in electrical distribution grids: a real options approach

- Introduction
- **Case Study**
  - Definition of case study and methodology
  - Modelling
  - Results
  - **Extensions**
- Conclusion
- References
- Appendix

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

## ■ First extension: Jump diffusion process

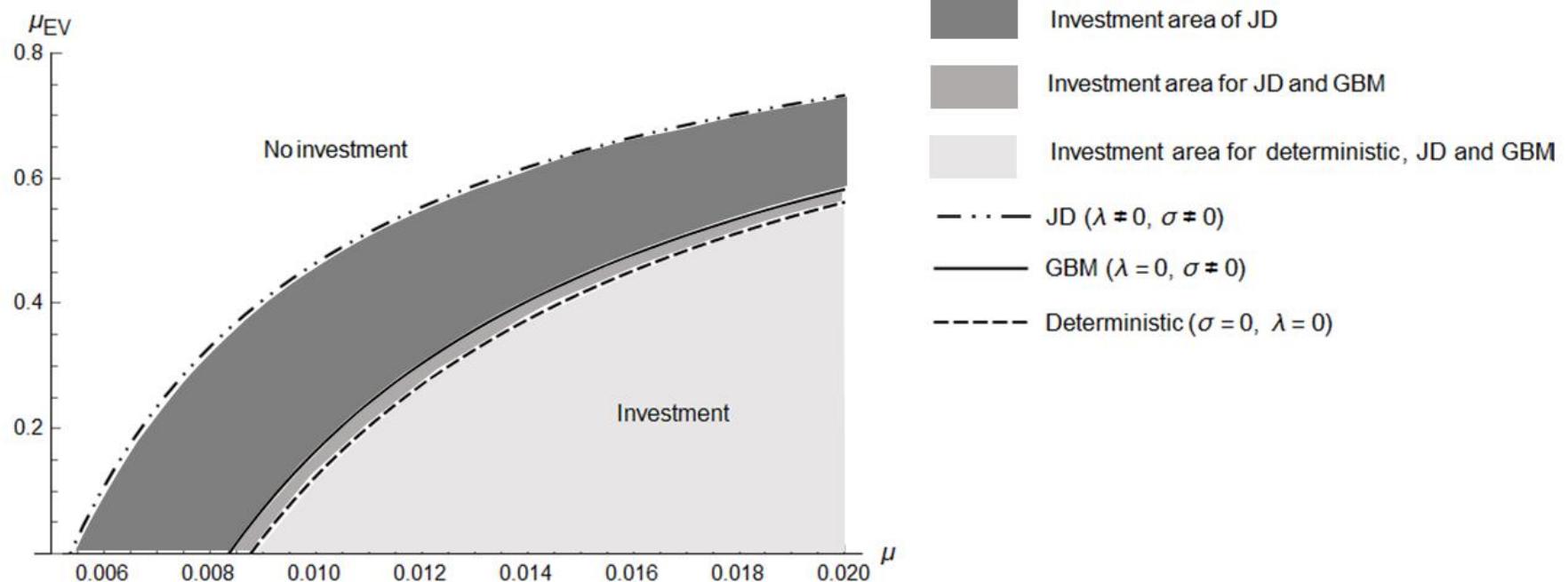
- Captures the connection of large loads
- $dP_{max}(t) = \mu P_{max}(t)dt + \sigma P_{max}(t)dz + P_{max}(t)dq,$   
 $dq = \begin{cases} \theta & \text{with probability } \lambda dt \\ 0 & \text{with probability } 1 - \lambda dt \end{cases}$
- $NPV_{DCF} < NPV_{JD} < NPV_{GBM}$



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## ■ Second extension: EV integration

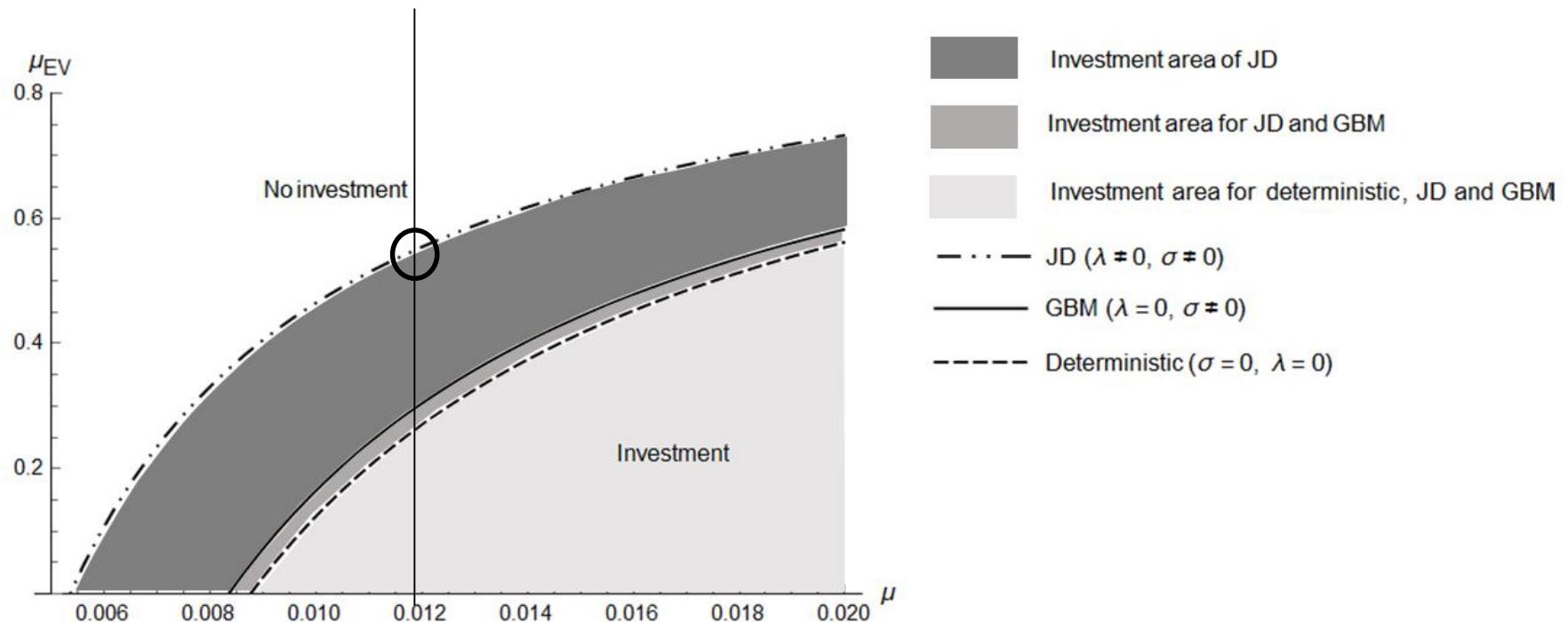
- $\mu_{real} = \mu(1 - \mu_{EV})$



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

## ■ Second extension: EV integration

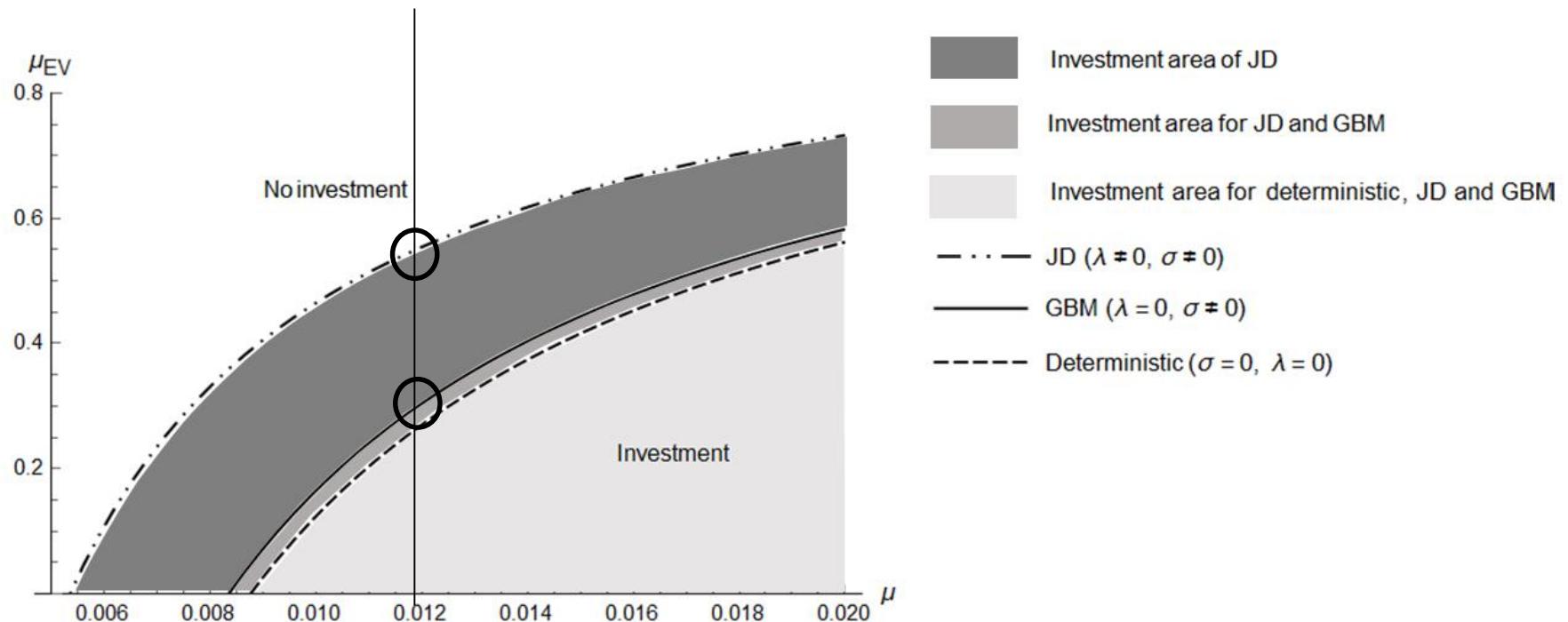
- $\mu_{real} = \mu(1 - \mu_{EV})$



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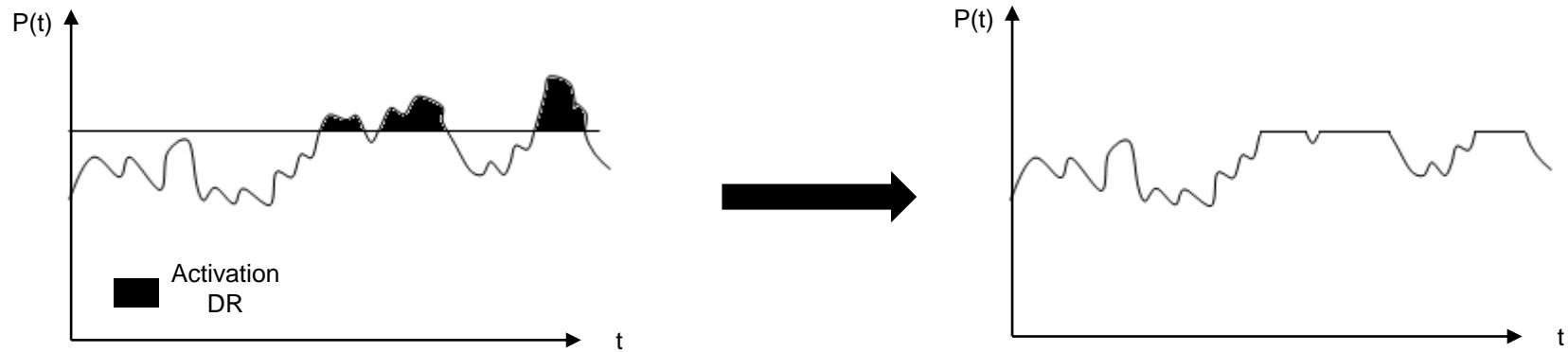
## ■ Second extension: EV integration

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



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## ■ Third extension: DR modelling



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

- Introduction
- Case Study
- **Conclusion**
- References
- Appendix

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

## ■ 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.

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

## THANK YOU

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

- Introduction
- Case Study
- Conclusion
- **References**
- Appendix

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

## ■ References

- [1] - IEA (2020), CO<sub>2</sub> 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

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

- Introduction
- Case Study
- Conclusion
- References
- **Appendix**

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

## ■ Appendix

$$\begin{aligned}
 OPEX_k(P_{max}) &= E \left[ \int_0^T e^{-rt} \sum_{j=1}^n a_j P_{max}^{\gamma_j}(t) dt \middle| P_{max}(0) = P_{max} \right] \\
 &= \sum_{j=1}^n \frac{a_j P_{max}^{\gamma_j}}{r - \mu\gamma_j - \frac{\sigma^2}{2}(\gamma_j^2 - \gamma_j)} \left( 1 - e^{-\left(r - \mu\gamma_j - \frac{\sigma^2}{2}(\gamma_j^2 - \gamma_j)\right)T} \right) \\
 &\quad \text{with } \mu < \frac{r}{\gamma_j} - \frac{\sigma^2}{2}(\gamma_j - 1)
 \end{aligned}$$

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

## Appendix

$$\begin{aligned}
 G_{losses} &= C_{losses} \left( \sum_{i=1}^{N_{wr}} \xi_{i,2} \lambda_{i,wr}^2 - \sum_{i=1}^{N_r} \xi_{i,1} \lambda_{i,r}^2 \right) (1 - e^{-(r-2\mu-\sigma^2)T}) \\
 G_{END} &= C_{END} \left( \sum_{i=1}^{N_{wr}} (\tau_u l_{u,i,wr} + \tau_o l_{o,i,wr}) \lambda_{i,wr} T_{out,i,wr} - \sum_{i=1}^r (\tau_u l_{u,r} + \tau_o l_{o,r}) \lambda_{i,1} T_{out,i,r} \right) \frac{H_{max}}{8760} (1 - e^{-(r-\mu)T}) \\
 G_{out} &= C_{out} \left( \sum_{i=1}^{wr} (\tau_u l_{u,i,wr} + \tau_o l_{o,i,wr}) \lambda_{i,wr} - \sum_{i=1}^{N_r} (\tau_u l_{u,i,r} + \tau_o l_{o,i,r}) \lambda_{i,r} \right) \frac{H_{max}}{8760} (1 - e^{-(r-\mu)T})
 \end{aligned}$$