Quantum Computing at EDF

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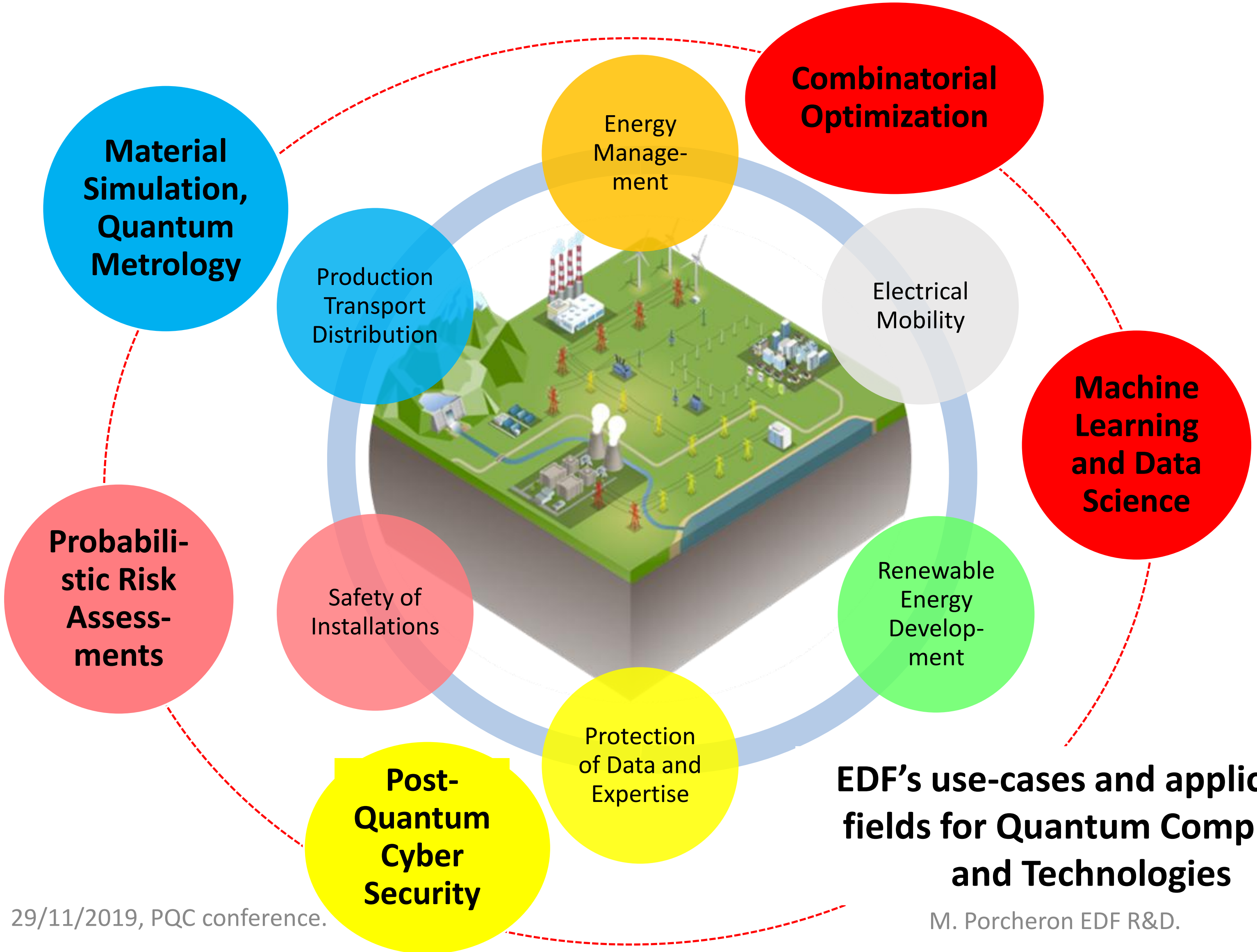
Where do we stand and where do we want to go ?

Many hard problems to solve



EDF's use-cases and application fields for Quantum Computing and Technologies

Lots of them untractable on conventional computers for large instances : no known *polynomial* algorithms !

Typical example : large size combinatorial/discrete optimization problems

Today, in the classical computing world

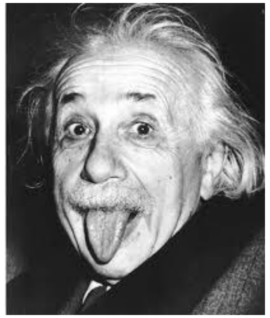
Hard Problems

Exact methods available, but only for “small” instances

Super computers are needed … and expansive

Heuristics are nice, but where is the optimum ?

Will it work ?



Tomorrow, in the quantum computing world

Hard Problems

Exact methods available for much larger instances

Quantum computers/ QPU are needed … and less expansive (?)

Heuristics are less necessary

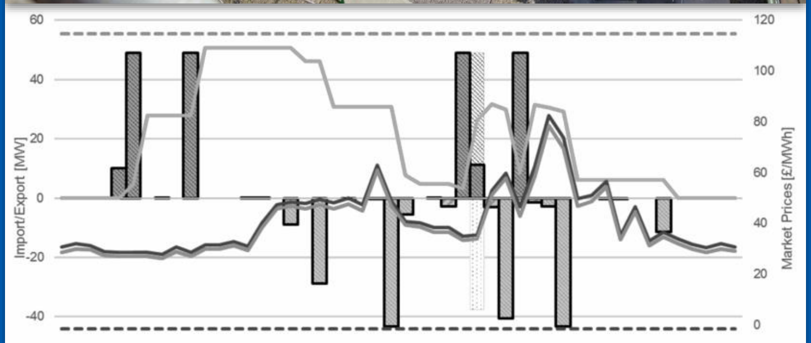
We must work seriously on real use-cases to make our mind !!!

A focus on some use-cases and ongoing works

- **Battery revenue optimization**
  - Work carried out by EDF’s UK research center with Ecole Polytechnique, under advice of Pr A. Montonaro/Bristol University.
- **Smart-charging of electrical vehicles**
  - Ongoing works in collaboration with Loria/Mocqua Université de Nancy (Margarita Veshchzerova’s PhD thesis co-advised with Pr. E. Jeandel and Simon Perdrix), Institut d’Optique, Atos, European Project PASQuanS (Programmable Atomic Large-Scale Quantum Simulation), and the startup Pasqal (spin off from Institut d’Optique)
- **Probabilistic Risk Assessment Studies**
  - Future work in collaboration with LIPN/Université Paris XIII (Ahmed Zaiou’s PhD thesis co-advised with Pr. Y. Bennani), and Atos

Quantum Algorithm for Optimal Battery Operation

April - August 2019 **[2]**



To integrate higher volume of renewables, EDF plans to install large batteries on national scale. The goal is to optimize the investment and the life time operation of these storage systems

- Every battery model has a capacity, a power range and a lifetime (charge cycles).
- When a battery is used, either to deliver capacity or frequency response, it ages.
- Before investing, the financial scenarios are investigated using forecasted prices.

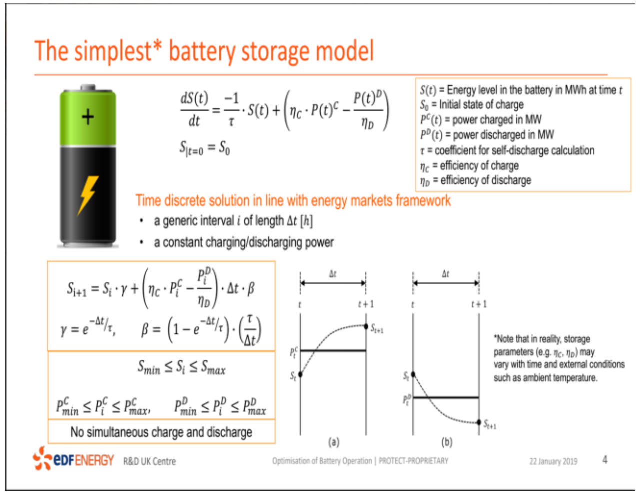
Decision are binaries : do we sell or not battery energy on the markets at a given time-step ?

Typical integer program, which can be modeled as a "Knapsack problem" (NP-Complete)

Project overview

#1 **FORMULATION**

Working with business experts to reformulate the problem in a standard form



#2 **DEVELOPMENT**

Adapting the "Quantum Approximate Optimization algorithm" (QAOA) [6]

Developing the quantum circuit architecture and subroutines

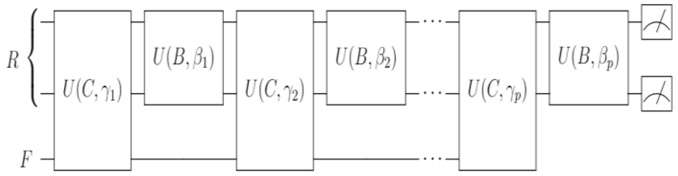


Table 13: Overview of the circuit

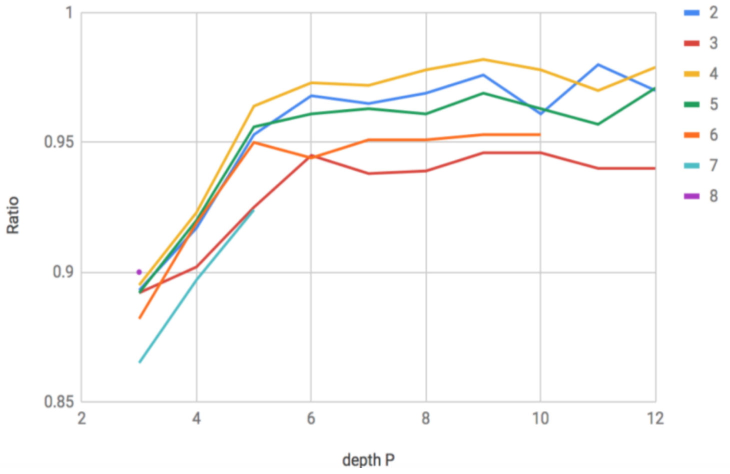
Technique	Depth	Number of ancillary qubits
1	$O(n)$	$O(\log_2 n)$
2	$O(\log_2 n)$	$O(n)$

Table 11: Performances of each technique

#3 **IMPLEMENTATION**

Porting the circuit to IBM QisKit programming language

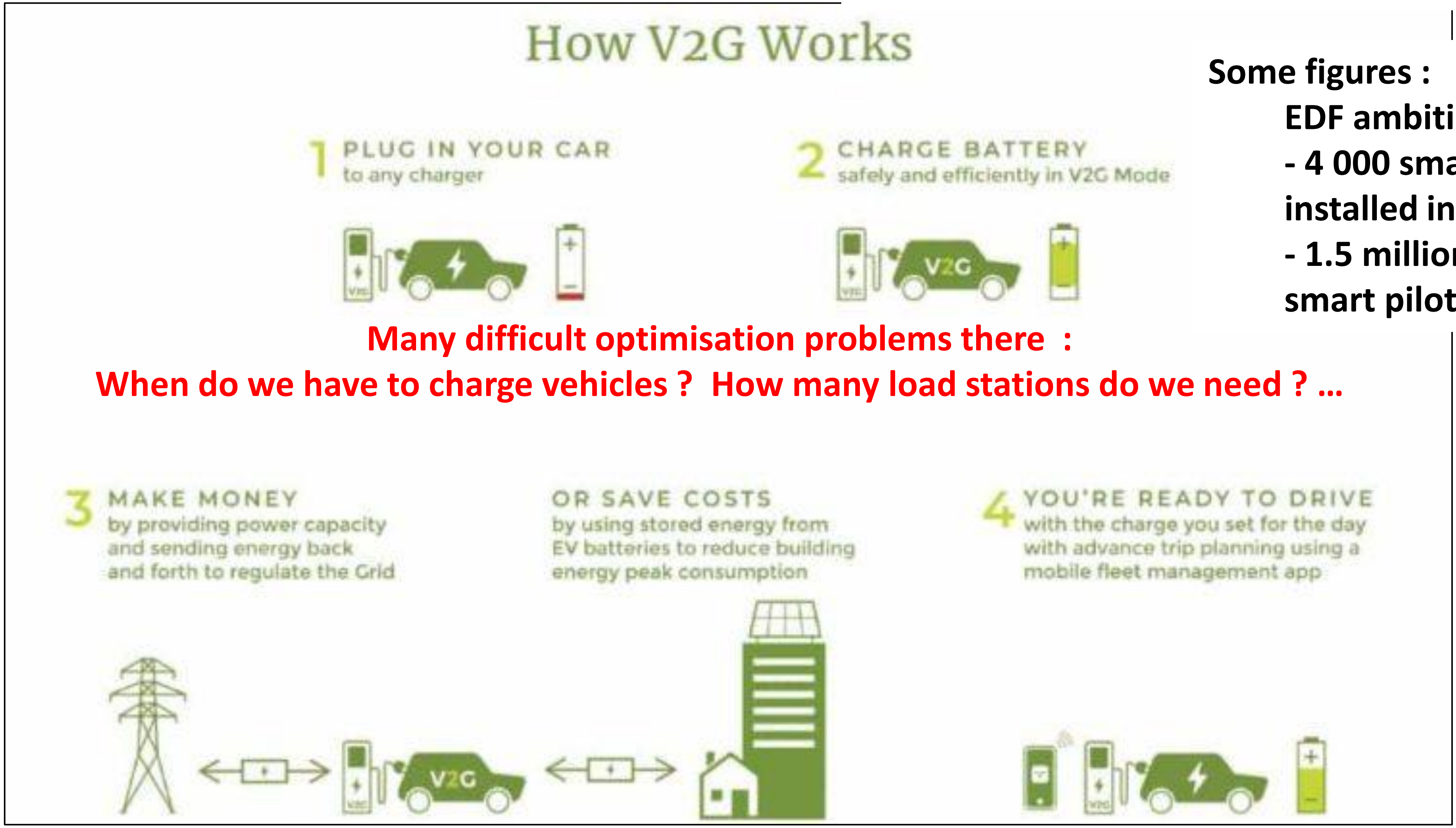
Experimenting with a simulator to evaluate behaviour and sensitivity



Results published [2]

Smart-charging of electrical vehicles

https://les-smartgrids.fr/dreev-edf-smart-charging-v2g/



Many difficult optimisation problems there :

When do we have to charge vehicles ? How many load stations do we need ? …

Some figures :

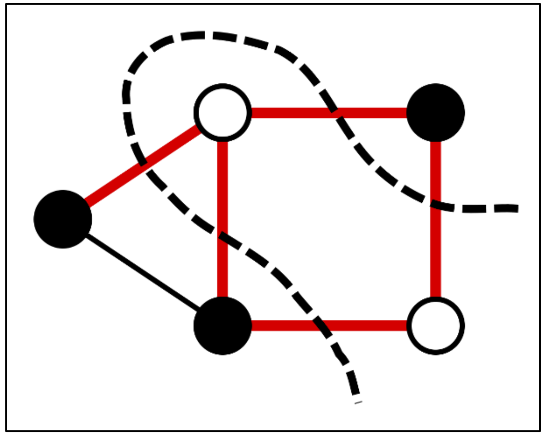
EDF ambition in Europe :

- 4 000 smart load-stations installed in 2020

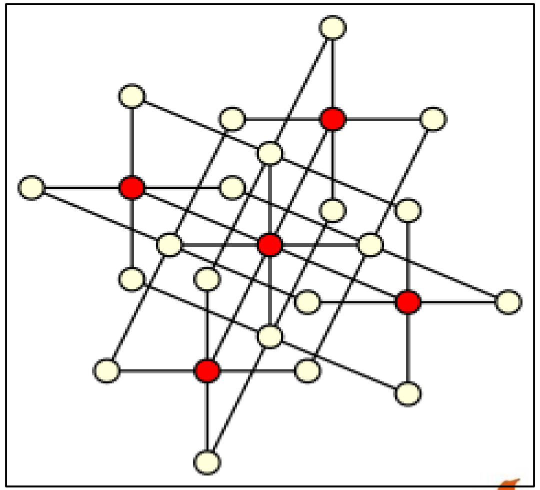
- 1.5 million of vehicles with a smart piloted load in 2035

Smart-charging of electrical vehicles

- **Minimization of total charging time**
  - **Can be modelled as a Max-Cut graph problem (NP-Complete)**
  - A “classical” application of the “Quantum Approximate Optimization Algorithm” (QAOA) [5]
  - Our current research topic : **extending QAOA from Max-cut (2 load stations) to Max-K-cut (K load stations)**



- **Minimization of the number of charging stations**
  - **Can be modelled as a Colouring/Maximum Independent Set graph problem (NP-Complete)**
  - “Quantum Approximate Optimization Algorithm” (QAOA) , “Quantum Adiabatic Algorithm” (QAA) [3][4], “Quantum Annealing” (QA) are quantum candidates
  - Promising results on Unit-Disk graphs of **Rydberg atoms arrays** [8], reproduced with Atos and Institut d’Optique teams on Atos’s QLM
  - Our current research topic: **from graphs of load intervals to Unit-Disk graphs of Rydberg atoms arrays**

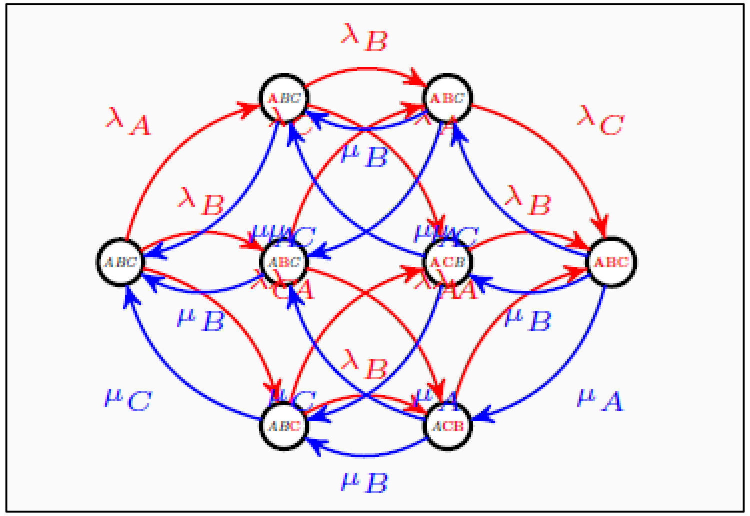


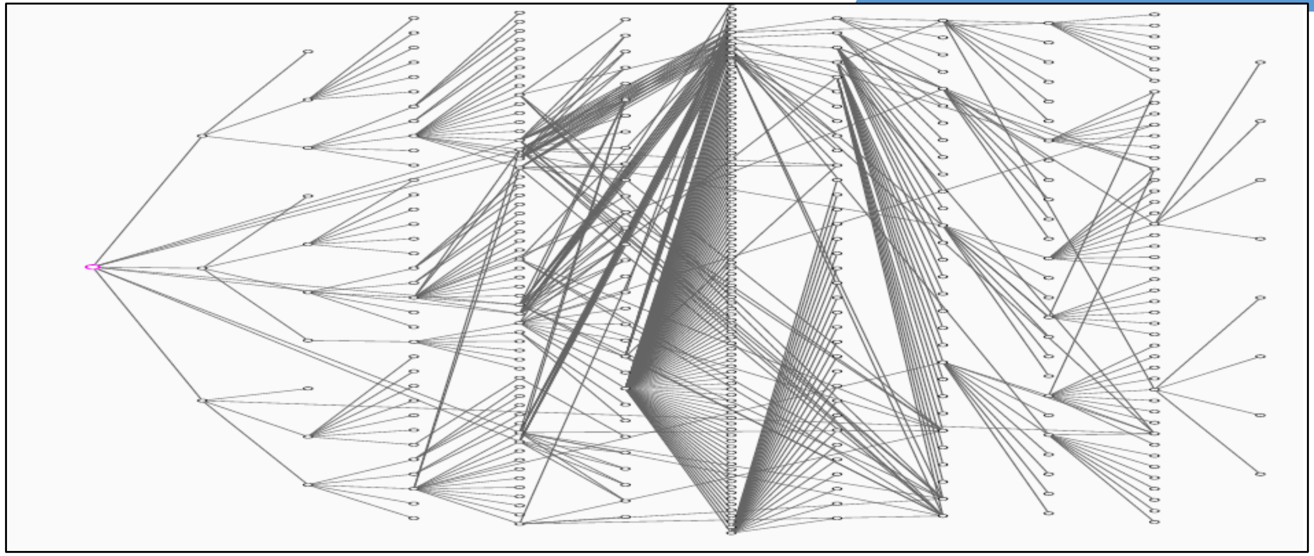
Probabilistic Risk/Safety Assessment Studies

- Determining potential **undesirable consequences** associated with use of systems and processes
- **Identifying ways** that such consequences could materialize
- Estimating the **likelihood (e.g., probability)** of such events
- Providing input to **decision makers** on optimal strategies

Solve SAT-like problems (NP-Complete)

Compute probabilities of paths in huge fault trees and Markov chain transition graphs





Probabilistic Risk/Safety Assessment Studies

- **Quantum walk algorithms** [1][6][7]
  - Can detect the presence of a marked vertex on a graph with a **quadratic speedup** on the corresponding **random walk algorithm**
  - Can obtain **speedups on backtracking based classical algorithms**
  - **Can speed up** the most efficient **SAT solvers** used in practice.

Conclusion

A significant technical investment

- **Two PHD starting**
  - **“Quantum computing for combinatorial optimization : application to hard problems in the field of energy management”** (with Loria Université de Lorraine)
  - **“Exploring Risk Analysis Using Quantum Algorithms”** (with LIPN Université Paris Nord)

- **European projects**
  - End-user of the European Project **PASQuanS** (Programmable Atomic Large-Scale Quantum Simulation) H2020 FET-Quantum Flagship
  - Member of the consortium **NEASQ** (NExt ApplicationS of Quantum Computing) in response to the H2020 FET-Quantum Flagship “Complementary call on Quantum Computing”

- **Collaborations, internships, with our foreign R&D centers:**
  - **EDF Energy UK-Center** : Quantum Algorithms for optimal management of a battery (**first published paper, in 2019)**
  - **EDFInc, PaloAlto** : Quantum Algorithms for long term nodal prices computation (to begin in 2020)

A proactive involvement in the academic and industrial "ecosystem" under construction

- Partner of « **Quantum** » the **center of quantum sciences and technologies of Université Paris-Saclay**, just created
- Member of **CCRT/TERATEC/Quantum Initiative** : EDF, TOTAL, CEA, DASSAULT, AIRBUS, ATOS, CERFACS, Université de Reims ...
- Member of **CIGREF** quantum computing work group
- Collaboration with the **Pasqal** startup spin off from Institut d'Optique
- Exchanges with **Paris Center for Quantum Computing**
- PhD co-advising with **Loria/Nancy** and **LIPN/Paris**
- Collaboration under construction with **CEA**, **Enedis**, **Renault**, …
- …

- Collaboration with **ATOS** on two use-cases
- Access to the **ATOS's Quantum Learning Machine** of the CEA's Center of Computing, Research and Technologie (CCRT)

- Contacts with foreign quantum companies
  - QCWare
  - **D-Wave : planned POC on smart-charging optimization problems**
  - IBM
  - Intel

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Thank you !