LIRIMA Team MOHA

Mixed Multi-objective Optimization using Hybrid Algorithms Application to smart grids

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LIRIMA

Inria
INVENTORS FOR THE DIGITAL WORLD

EMI
المدرسة المحمدية للمهندسين
Ecole Mohammadia d'Ingénieurs

Outline

- Who are we?
- Main scientific achievements over the period
- Some elements of visibility
  - Publications
  - Organization of events
  - Keynotes and tutorials
- Perspectives and Self assessment

Who are we?

MOHA members

- **Principal investigator (Inria):**
  - El-ghazali TALBI, DOLPHIN → BONUS, Inria Lille Nord Europe
- **Principal investigator (Main team):**
  - Rachid ELLAIA, LERMA, EMI Mohammadia School of Engineers, Mohamed V University, Rabat
- INRIA Lille Nord Europe, France
  - Prof. E-G. Talbi
  - Mrs O. Bahri (Phd student)
  - Prof. N. Melab
  - Dr. R. Todosijevic, Postdoc , INRIA
- EMI Rabat, Morocco
  - Prof. R. Ellaia, Professor
  - Prof. M. Ouassaid, Associate Professor
  - Mrs A. Gannouni (Phd student)
  - Mrs Z. Garroussi (Phd student)
  - Mrs J. Serrar (Phd student)
  - Mrs F. Daqaq (Phd student)
- Visits
  - 3 Phd students / year, average of 2,5 months
  - 1 senior visit / year

INVENTEURS DU MONDE NUMÉRIQUE

ECOLE MOHAMMADIA D'INGÉNIEURS

Where are we coming from?

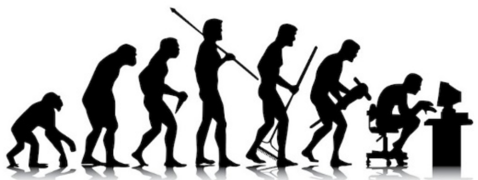
- Culture, Motivation

Culture

- Operations Research
  - Multi-objective optimization
  - Continuous Optimization
  - Combinatorial optimization

$$
\begin{aligned}
\min \quad & \sum_{k=1}^{K} \sum_{(i,j)\in A} c_{ij} x_{ij}^{k} + \sum_{(i,j)\in A} f_{ij} y_{ij} \\
\text{s.t.} \quad & \sum_{j:(i,j)\in A} x_{ij}^{k} - \sum_{j:(j,i)\in A} x_{ji}^{k} = b^{k} \qquad \forall i, k = 1, \ldots, K \\
& \sum_{k=1}^{K} x_{ij}^{k} \leqslant u_{ij} + v_{ij} y_{ij} \qquad \forall (i,j) \in A \\
& x_{ij}^{k} \geqslant 0 \qquad \forall (i,j) \in A,\ k = 1, \ldots, K \\
& y_{ij} \in \{0, 1\} \qquad \forall (i,j) \in A \qquad (1)
\end{aligned}
$$

- Computational Intelligence
  - Metaheuristics
  - Evolutionary algorithms

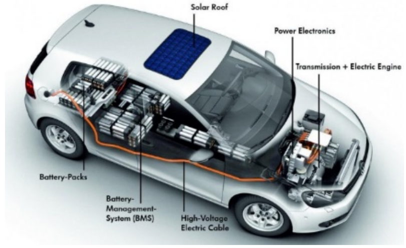


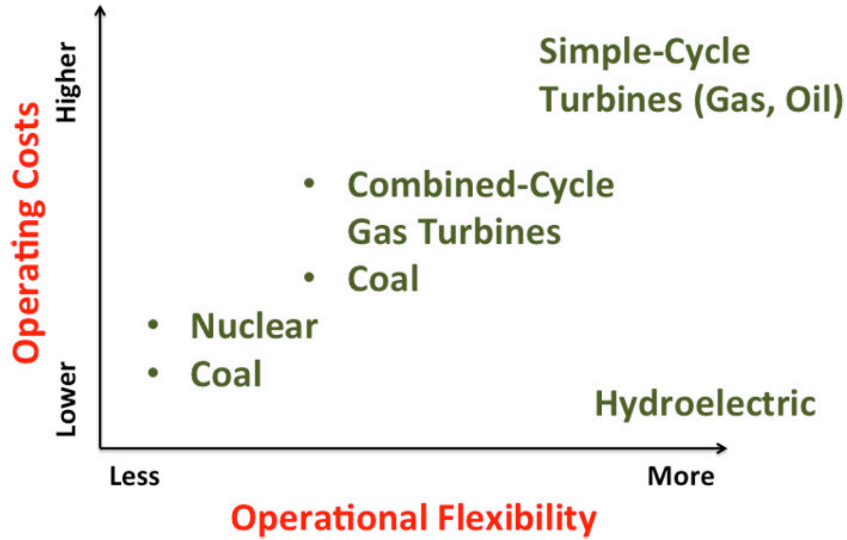
- Parallel and Distributed Computing
  - Parallel algorithms
  - Cluster & Cloud computing
  - GPU and multi-core computing

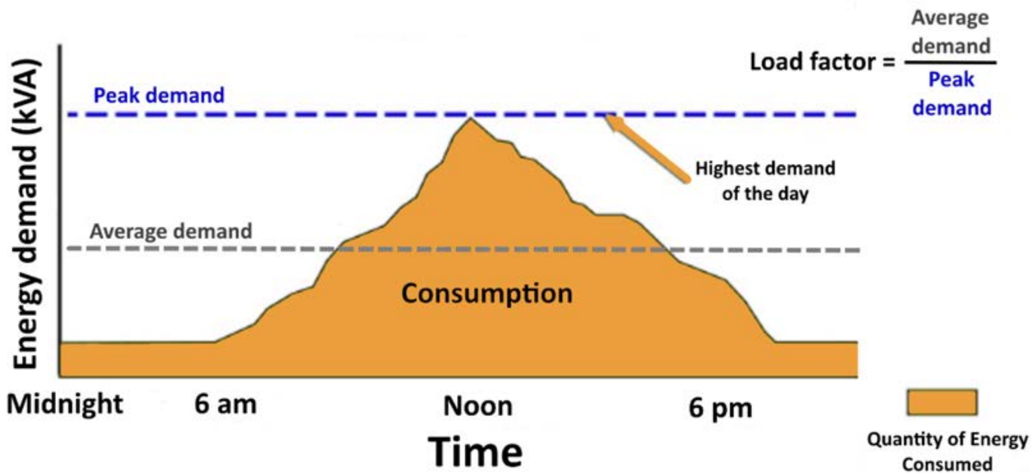
- Cover spectrum from Theory to Applications

Challenges and constraints

- Electricity difficult to store
  - Advances in battery design
  - Electrical vehicles (EVs)
- **Flexibility**: Energy production is very hard to change quickly
  - Most of the flexibility is provided by fossil fuel power stations
- Energy demand fluctuates widely during the day/seasons/weather
- Electricity generation must match consumer demand every minute (power flow equations)
- Peak load versus off-peak load
  - Low utilization of the grid during off-peak times
- Volatility in prices

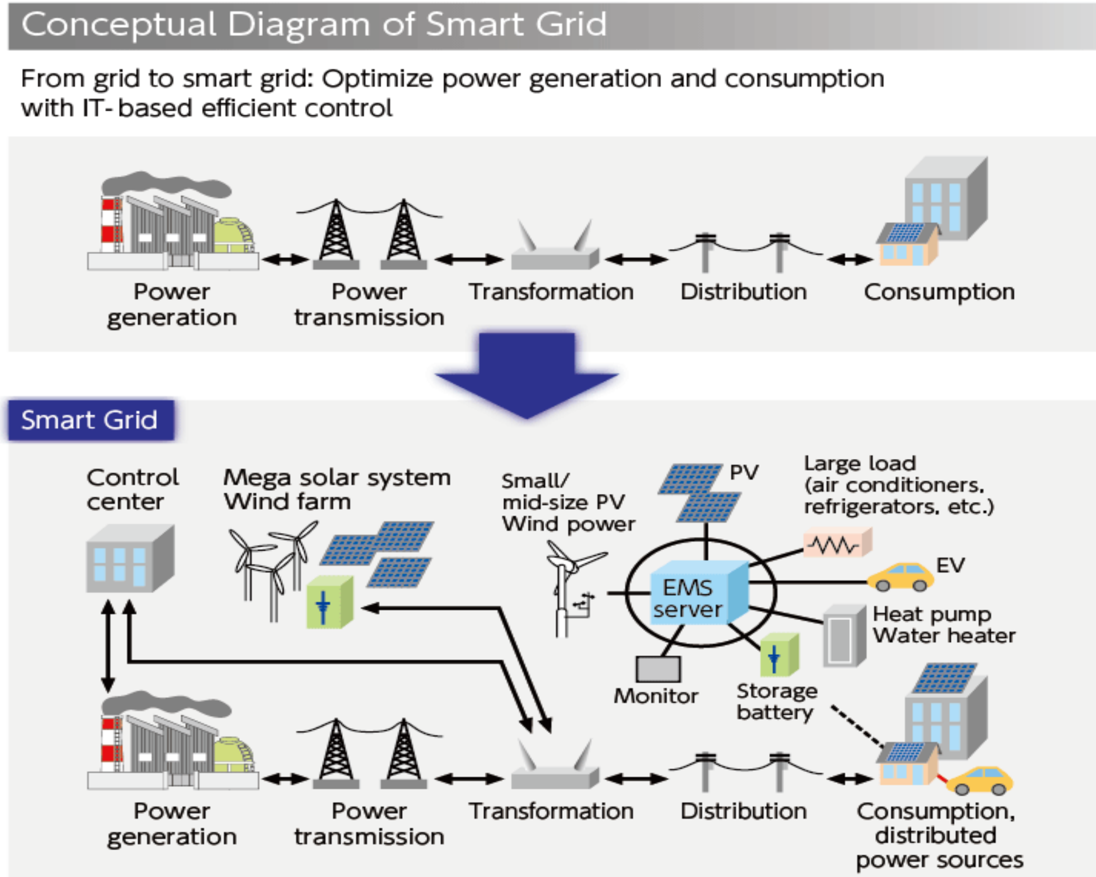






From Traditional Grid to Smart grids

- Distributed heterogenous efficient reliable generation
  - Plants are distributed almost the same way the consumers are
  - Minimal transmission of power to distant consumers
- Two-way information flow
  - Real-time demand, …
- Two-way power flow
- Smart meters: usage data
- Flexible controllable load & generation
- Renewable energy
- Energy storage
  - Plug in electric vehicles
- Smart appliances
  - Customers can respond to price signals sent from the utility

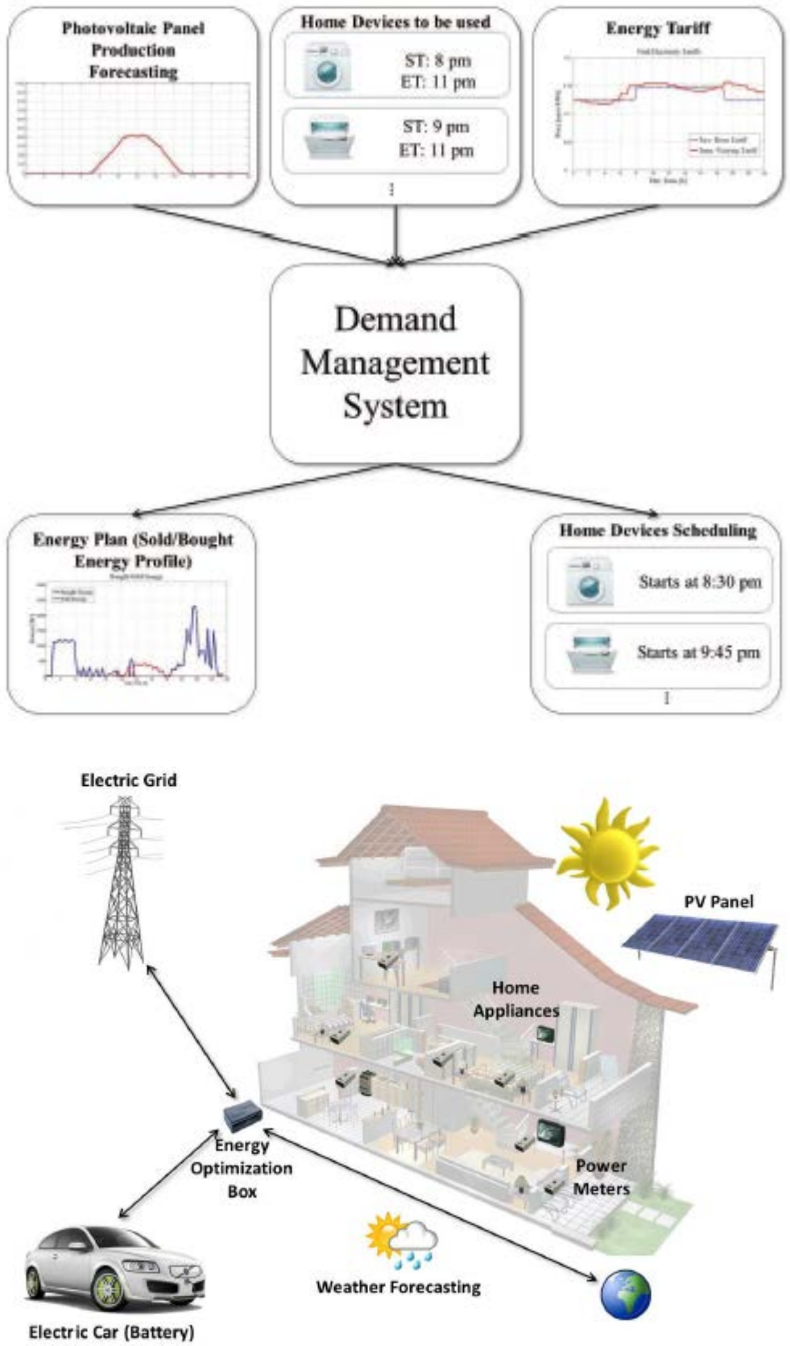


"A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies."

– Schneider Electric (2010)

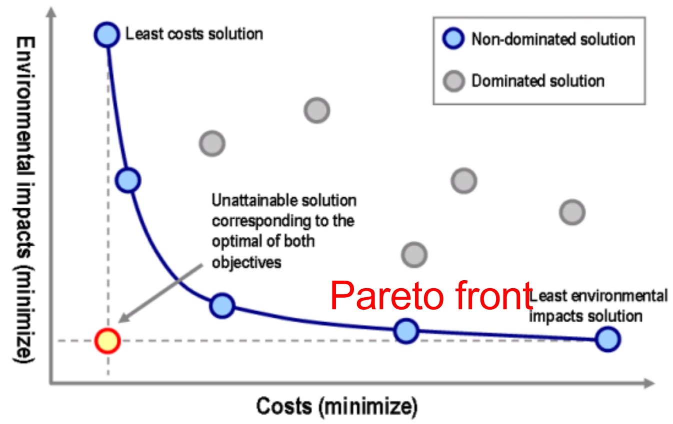
House energy demand response

- Given
  - Local production (wind, solar, …)
  - Local load
  - Energy tariff
- Find
  - Home devices scheduling
  - Energy plan
    - Buy/sold/store
- Objectives
  - Min Bill, Max Profit
  - Min Peak demand, Max Confort, …
- Constraints
  - Production
  - Batterie constraints
  - Home devices scheduling
    - Time windows



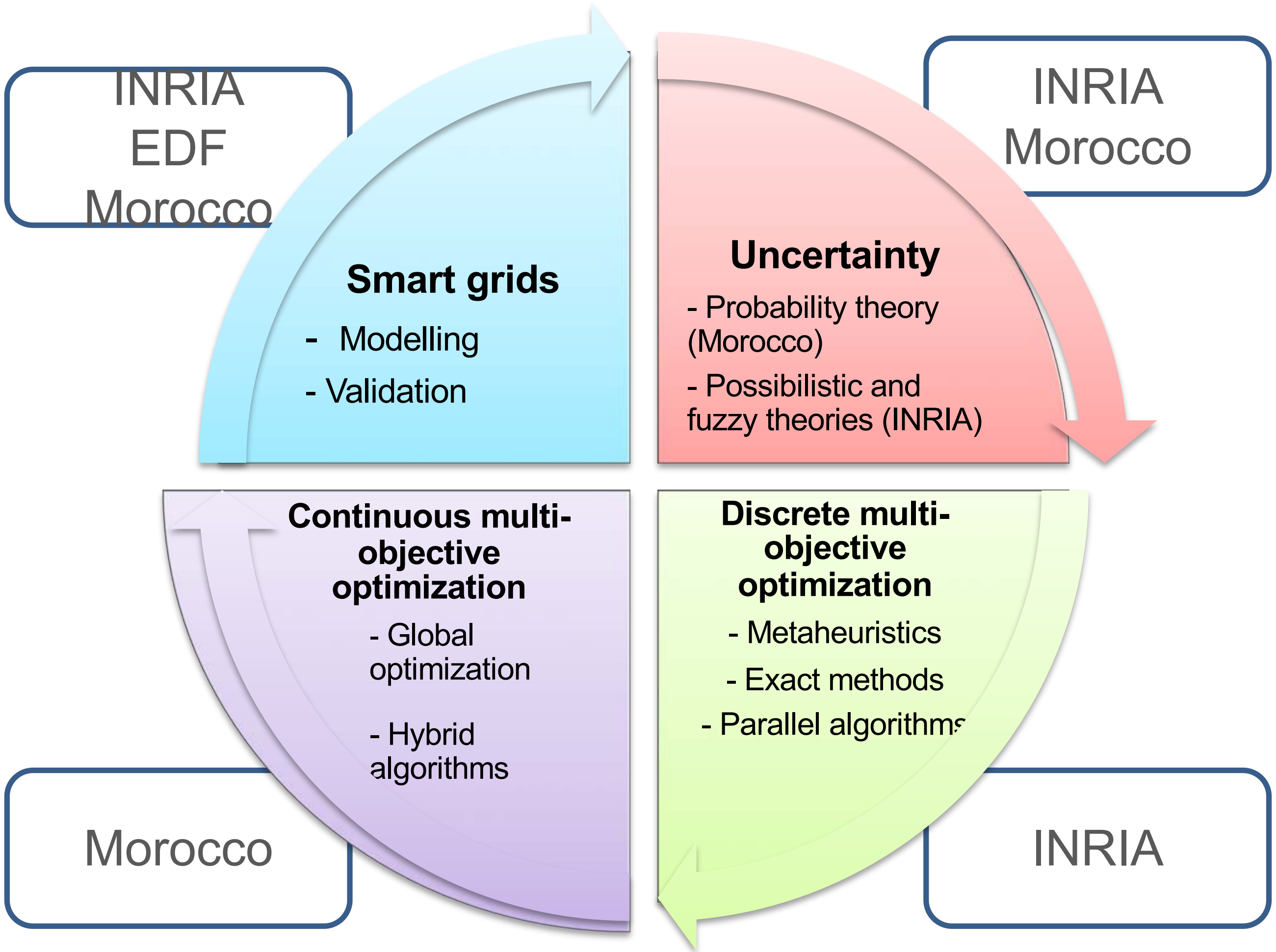
Optimization Challenges

- **Large scale problems**
  - Huge number of smart appliances, clients, …
- **Multi-objective problems**
  - cost, quality of service, sustainability.
- **Mixed optimization**
  - Continuous and discrete variables
- **Optimization under uncertainty**
  - Uncertain data
    - *Ex: wind and solar production (weather), demand, prices, …*



NP-hard, non convex, multi-modal, non continuity

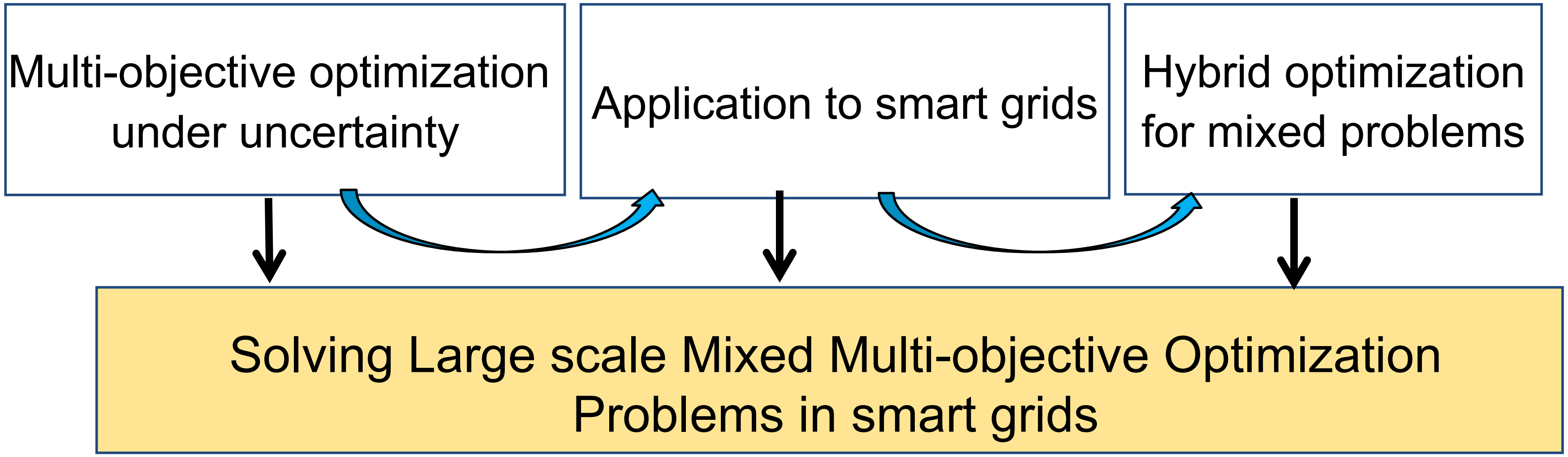
Complementarities between partners



Main achievements over the evaluation period

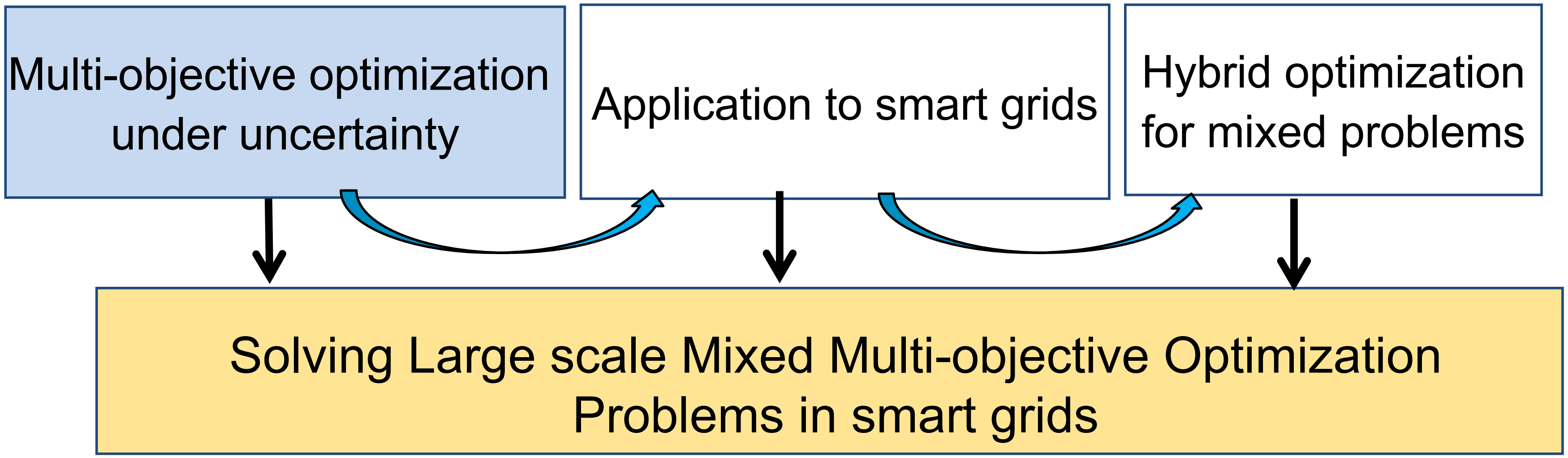
- Originality, coherence, impact

Roadmap



- Comprehensive approach to complex problem solving
- Genericity (different application domains)

Multi-objective optimization under uncertainty

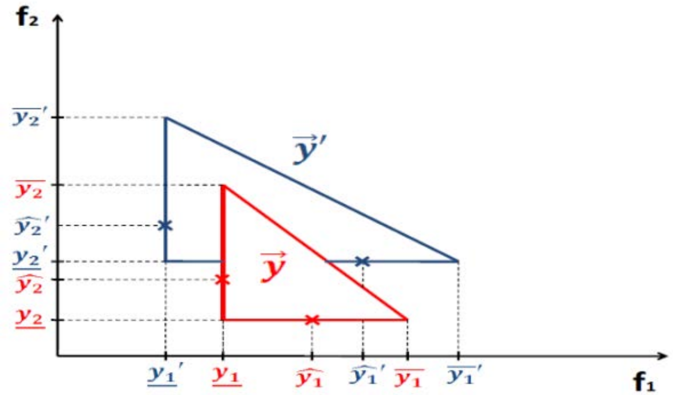


Contributors: O. Bahri, A. Gannouni, R. Ellaia, E-G. Talbi, R. Todosijevic

- Real-life problems are strongly connected to some uncertainties in inputs, parameters and environmental data
- Propagation of inputs uncertainty through the optimization process rises as a major obstacle
- Most methods in the literature simply transform such problems into crisp or single-objective
- Used framework: Fuzzy sets and Probability theories

Main contributions: optimization under uncertainty

- **New dominance relations**
  - Ranking the generated uncertain valued objectives.
  - New generic fuzzy dominance relations
  - Integration in ParadisEO software framework

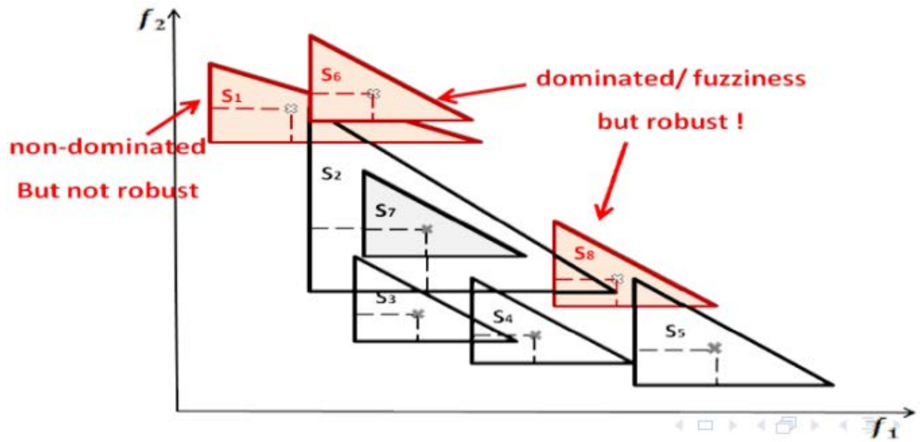


- **New Pareto algorithms**
  - Generic Pareto evolutionary algorithms
  - Extension of popular optimization algorithms (NSGA-II, SPEA2, …)

	SPEA2 [Ziztler, 2001]	Extended SPEA2
Fitness Assignment	Pareto dominance	Fuzzy Pareto dominance
Diversity Preservation	Nearest Neighbor technique	Nearest Neighbor technique based on Bertoluzza distance
Elitism	Fixed size archive	Triangular fixed size archive

- **New robustness measure**
  - Sensitivity analysis of the obtained solutions

- Uncertainty in smart grids
  - Production from renewable sources (ex. solar, wind)
  - Consumption, price, …

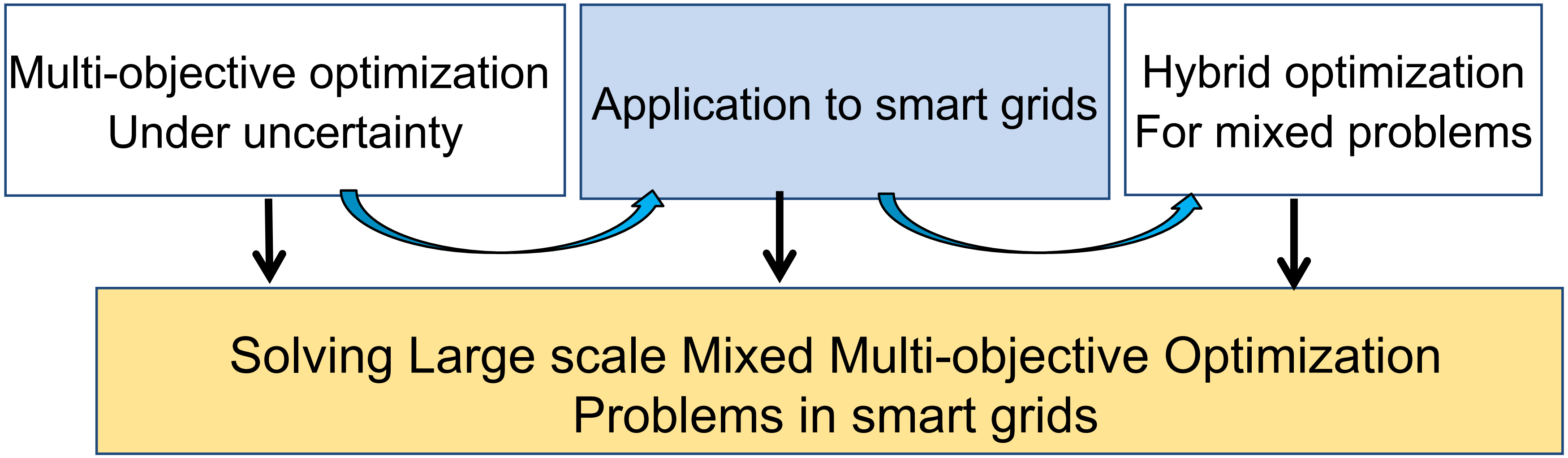


Main contributions: multi-objective models

- **Collaborations with common publications**
  - **University of Tunis (Tunisia):** N. Benomar et al. on multi-objective modeling under uncertainty using possibility theory and belief functions for vehicle routing problems.
  - **University of Oviedo (Spain):** R. Varela and I. Gonzalez Rodriguez on multi-objective modeling of fuzzy job-shop scheduling problems.
  - **University of Cadiz (Spain):** B. Dorronsoro and P. Ruiz for energy-aware scheduling in multi-core parallel systems .
  - **University of the Republic (Uruguay):** S. Nesmachnow in multi-objective scheduling in cloud computing systems.
  - **University of Luxembourg (Luxembourg):** P. Bouvry on scheduling in clouds under uncertainty.

- **Other related external support**
  - **EDF (Electricite de France)** provider: demand side management in smart grids
  - **Beckman&Coulters** bio-medical company: scheduling under uncertainty
  - **ANR** national project NumBBO: analysis, improvement and evaluation of numerical blackbox multi-objective optimizers

Application to smart grids



Contributors: Z. Garroussi, R. Ellaia, J. Serrar, E-G. Talbi, M. Ouassaid, F. Daqaq

- Development of efficient and realistic models for the demand side management problem in smart grids.

Main contributions: Approximate algorithms

- Single home demand management
  - Mixed integer non linear programming problem
  - Optimal starting times of appliances under time-varying electricity prices and time windows
  - Minimize two conflicting objectives
    - Electricity cost
    - User Discomfort
  - Validation by simulation

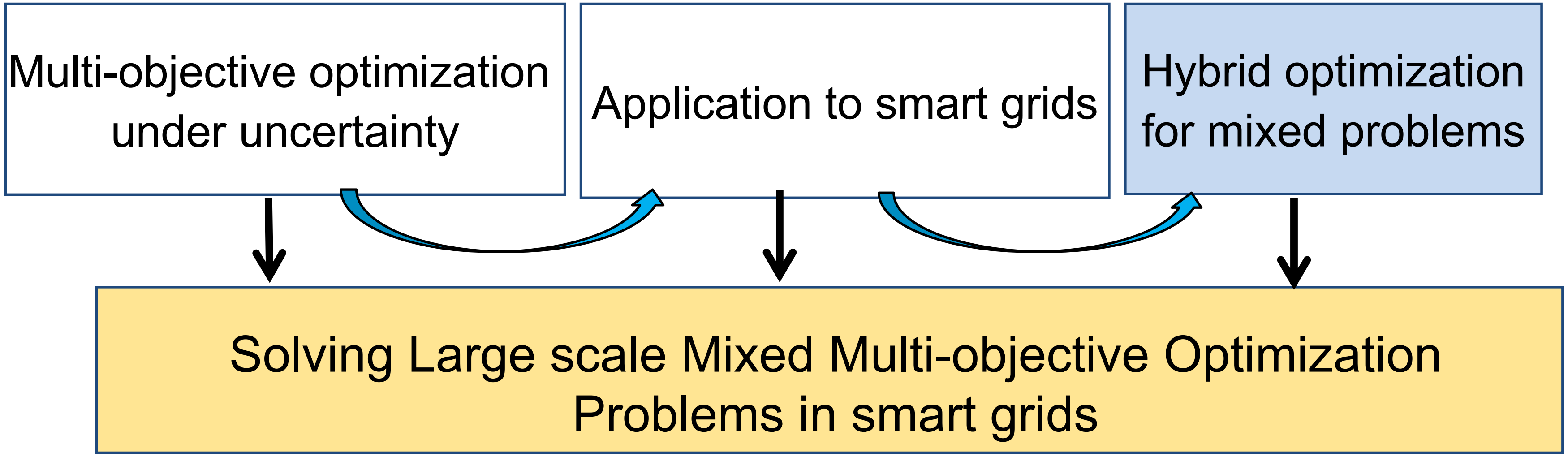
- Multiple home demand management
  - **Realistic models:** smart homes includes heating and power system, photovoltaic panel, battery, thermal energy storage, electric vehicle, controllable and non-controllable loads.
  - **4 objectives**: standard deviation from the ideal load curve, cost, thermal discomfort, timing discomfort

Main contributions: Approximate algorithms

- Collaborations with common publications
  - **EDF R&D (Electricite de France):** J-Y. Lucas on demand side management in smart grids
  - **DGA (Direction Generale des Armees):** N. Dupin on unit commitment and scheduling nuclear power plants under uncertainty

- Externel related support
  - **EDF Contract (2015-2017):** demand side management in a single smart home.
    - A multi-objective model and a solver based on evolutionary algorithms have been developed.
  - **EDF contract (2017-2019):** jointly optimizing multiple houses energy smart management systems located in the same sub network.
    - Project a database of householders demand signals, including various types of flexibility.

Hybrid optimization



Contributors: Z. Garroussi, R. Ellaia, E-G. Talbi, N. Melab

- Hybridize = Cooperation of complementary algorithms
- Better solutions for some generic and real-life problems in smart grids

Hybrid optimization

- Mixed optimization problems with continuous LP sub-problems
- Decomposition-based methodologies
  - Decision space: continuous and discrete variables
- Matheuristic design
  - Combination between exact mathematical programming algorithms and metaheuristics
  - Indirect (incomplete) representation of the search space
- Hyper-matheuristic scheme
  - Best design for a set of cooperative metaheuristics and exact optimization algorithms

Main contributions: Large-scale exact optimization

- Collaborations with common publications
  - **University of Elche (Spain):** J. Aparicio on hybrid optimization for mixed optimization and application to DEA
  - **University of Paris Est (France):** A. Nakib on fractal based decomposition for continuous optimization problems
  - **University of Luxembourg (Luxembourg):** G. Danoy on hybrid optimization algorithms for multi-objective payload satellite conguration

- Externel related support
  - **PHC project** (Hong-Kong/France international project): decomposition-based multi-objective evolutionary optimization
  - **ANR BigMO**: Big multi-objective optimization" - Bilateral Hong-Kong/France international project, funded by RGC and ANR
  - **SES engineering company**: Satellite payload reconfiguration optimization

Scientific production

- Visibility, training, self-assessment

Publications and software

- **Journals**
  - International Journal of Mathematical Modelling & Numerical Optimisation
  - Computers & Industrial Engineering
  - International Transactions in Operational Research
  - Swarm Optimization Journal
  - Journal of Computational Applied Mathematics

	2016	2017	2018
PhD Thesis		1	2
Journal	2	3	3
Conference proceedings (**)	4	4	2
Book chapter		1	1
Book (edited)	1	1	2

- **Conferences**
  - International Renewable and Sustainable Energy Conference
  - MIC Metaheuristics International Conference
  - IEEE WCCI World Congress on Computational Intelligence
  - IPMU Int. Conf. On Information Processing and Management on Uncertainty in Knowledge-based Systems
- **Software**
  - Benchmarking aspects and data availability.
  - Generate and collect various data related to the different elements composing a smart grid (e.g. smart appliances, weather, electric vehicles, batteries, production, consumption, prices, …).
  - The developed Smart Home Data database provides all the data that decision makers need for a thorough study and analysis of energy management in a smart home https://ocm.univ-lille1.fr/~talbi/smartgrid/

Some elements of visibility

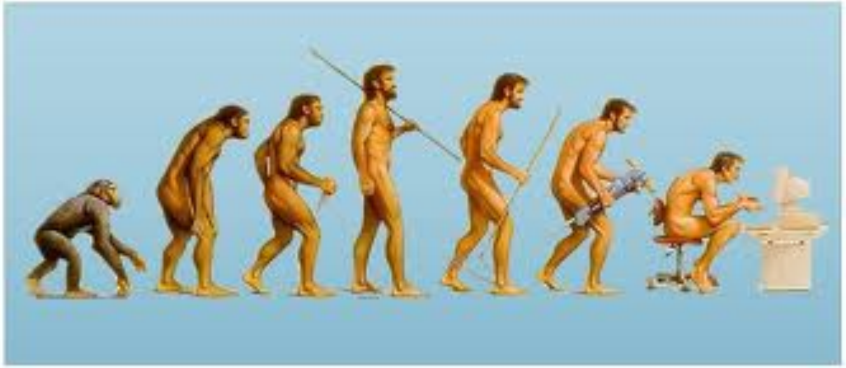
- ## Organization of conferences
  - **MOSSYS'2017** Workshop on Modelling, Optimization and Simulation of Systems, 3-4 Nov 2017, Rabat, Morocco. 75 participants.
  - **BIOMA'2018**, International Conference on bioinspired Optimization and their Applications, Paris, France, May 2018. 56 participants. See http://bioma2018.sciencesconf.org
  - **META'2018** International Conference on Metaheuristics and Nature Inspired Computing, 27-31 Oct 2018, Marrakech, Morocco. See http://meta2018.sciencesconf.org
  - MOPGP'2019 Int. Conf. On Multi-objective Programming and Goal Programming, Marrakech, Oct 2019. http://mopgp.org

- ## Organization of summer schools
  - Co-Organization of the summer school MESS'2018 Metaheuristics School, Taormina, Italy, July 2018. See https://www.ants-lab.it/mess2018/
  - Co-Organization of the summer school SYNERGY'2018 High-performance multi-objective optimization", Ljubljana, Slovenia 27-31 Aug 2018. See http://summerschool.synergyttwinning.eu

SYNERGY
FOR SMART MULTI-OBJECTIVE OPTIMISATION

Some elements of visibility

- Keynotes and tutorials
  - **A survey of hybrid metaheuristics with exact methods and machine learning**, Tutorial, META'2016 Int. Conf. on Metaheuristics and Nature Inspired computing, Marrakech, Morocco, Oct 2016.
  - **Optimization of smart grids: opportunities and directions**, Keynote speaker ICOA'2017, International Workshop on Optimization and Applications, Kenitra, Morocco, April 2017.
  - **Evolutionary multi-objective algorithms under uncertainty**, Invited seminar, Jozef Stefan Institute, Ljubljana, Slovenia, Oct 2017.
  - **Smart grids: challenges and opportunities**, Invited seminar, Ecole Centrale de Casablanca, Casablanca, Morocco, Nov 2017.
  - **Complex optimization problems in smart grids**, Keynote speaker, Workshop MOSSYS'2017 Modelisation, Optimisation et Simulation des Systemes, Rabat, Morocco, Oct 2017.
  - **Big optimization in smart grids**, Invited seminar, Jozef Stefan Institute, Ljubljana, Slovenia, Nov 2017.
  - **How machine learning can help metaheuristics**, Invited keynote, LOPAL'2018 International Conference on Learning and Optimization Algorithms: Theory and Applications, Rabat, Marrakech, May 2018.
  - **Synergy between metaheuristics and machine learning**, Invited Tutorial, BIOMA'2018 International Conference on Bioinspired Optimization and their Applications, Paris, France, May 2018.



Research perspectives

MOHA-2: Learning-based optimization for big problems

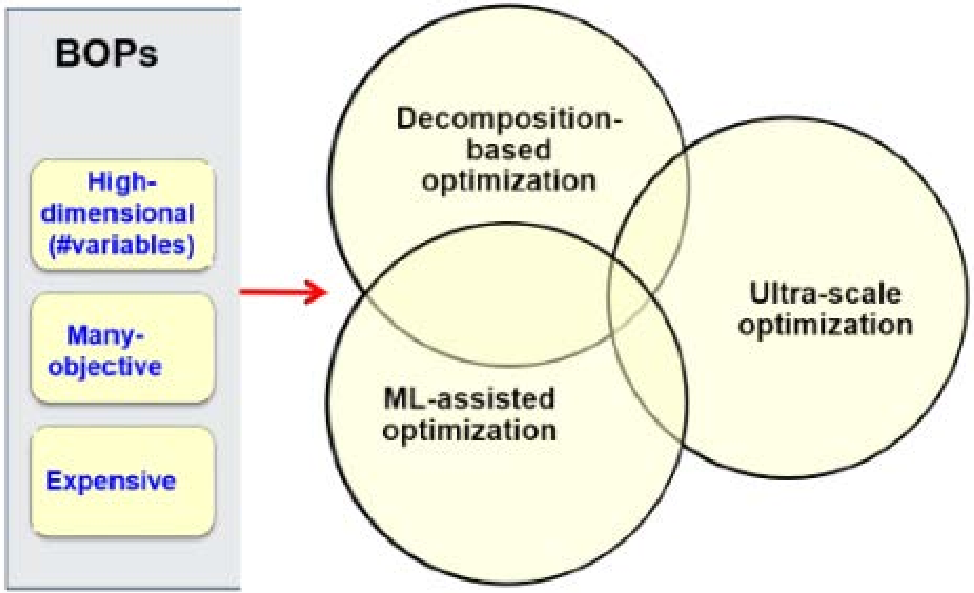
Application to smart grids and smart charging of electrical vehicles

Big (Yet another one!) optimization and motivations

- Optimization problems are increasingly **big**: **large** and subject to **uncertainty** in many application areas:
  - Smart grids (Nb. consumers, appliances, electric vehicles, suppliers, …)
  - Smart cities (Electrical vehicles, …)

- On the road to the **exascale** era, HPC techno. increasingly large (and heterog.) and subject to uncertainty

- Two challenges to be addressed at different levels

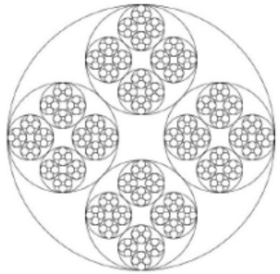
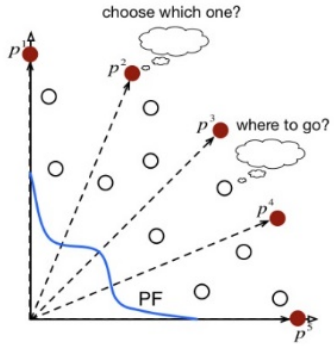


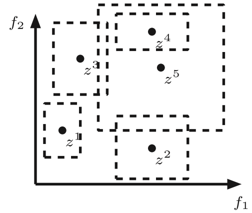
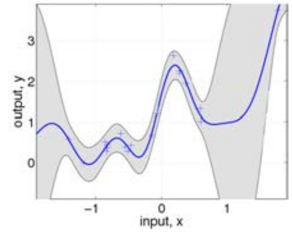
Research challenges/objectives

- Dealing efficiently with scalability: Design and analysis of **scalable** optimization algorithms able to deal with …
  - Data parameter space (10s of parameters, 1000s of scenarios)
  - Variable space (10s to 1000s of variables)
  - Objective space (>3 objectives)
  - Parallel hardware space (millions of cores, hybrid devices - Top500)
- Handling efficiently uncertainty …
  - Considering ≠ types of uncertainties $\tilde{f}[f(x+\delta,\alpha)]$
  - Modeling and its efficient integration in (MO) metaheuristics
    ➔ Trade-off Robustness/Performance

Research roadmap

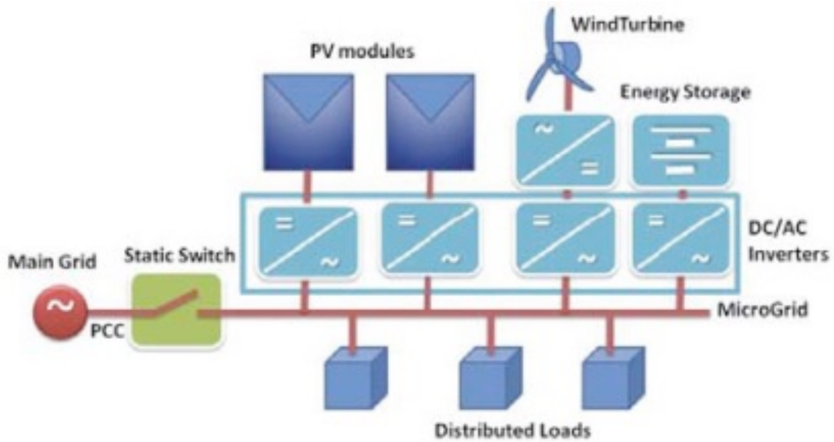
- Decomposition-based optimization
  - Hierarchical decomp. in the 3 spaces
  - New decomp. schema and cooperation mechanisms
- Optimization under uncertainty
  - Expensive optimization
  - Meta-modeling for expensive **mixed-variable** multi-objective optim.
- Ultra-scale optimization
  - Axes 1,2 = sources of massive parallelism
  - Design and implementation of optimization algos. for ultra-scale supercomputers
    - Ultra-scale and hybrid (Multi-core, GPUs, …)

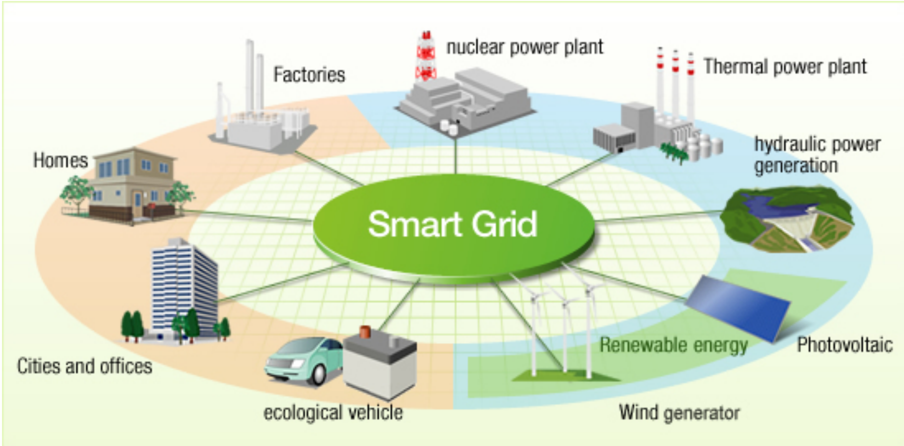



Research roadmap: Applications

- Smart grids
  - Demand side management in large scale **autonomous micro-grids**
  - Unit commitment problems under uncertainty
    - Integration of **green** criteria
- Smart grids & smart transportation/logistic systems
  - Smart charging of electrical vehicles
  - Electric vehicle routing problem [J. Serrar, E-G. Talbi, R. Ellaia, 2017]





Self-assessment

- We met the objectives that we proposed
  - Make “Mixed Multi-objective hybrid optimization for smart grids” the central topic of the associated team
  - Keep the balance between theory, algorithms and applications

- Strengths
  - Scientific production
  - Socio-economic and scientific impact
  - International visibility
- What could have been better
  - Industrial partner from Morocco

- Opportunities & Risks
  - Data availability

Strategic plan: Europe to Inria

- Relevance to H2020 European Projects
  - Creating industrial leadership and competitive frameworks (ICT)
    - FETHPC 2: **Extreme scale computing** technologies, methods and algorithms for key applications and support to the HPC ecosystem
  - Tackling societal challenges (applications)
    - Energy: smart homes, smart grids
    - Digital manufacturing


thank you
danke
gracias
merci
obrigado
рахмат
謝謝
ngiyabonga
teşekkür ederim
Баярлалаа
спасибо
bedankt
dziękuję
sukriya
kop khun krap
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mochchakkeram
arigatô
dakujem
grazie
terima kasih
감사합니다
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kiitos
dankie
dhanyavad
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