Università di Cagliari

Probabilistic risk-based planning for enabling the competition between flexibility and grid upgrades in distribution systems

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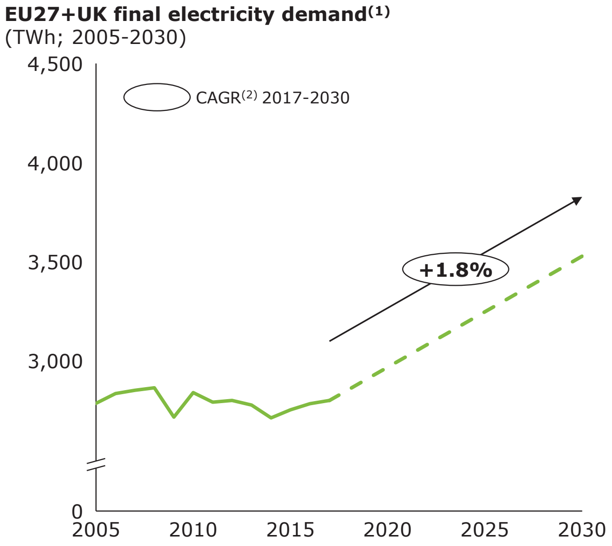
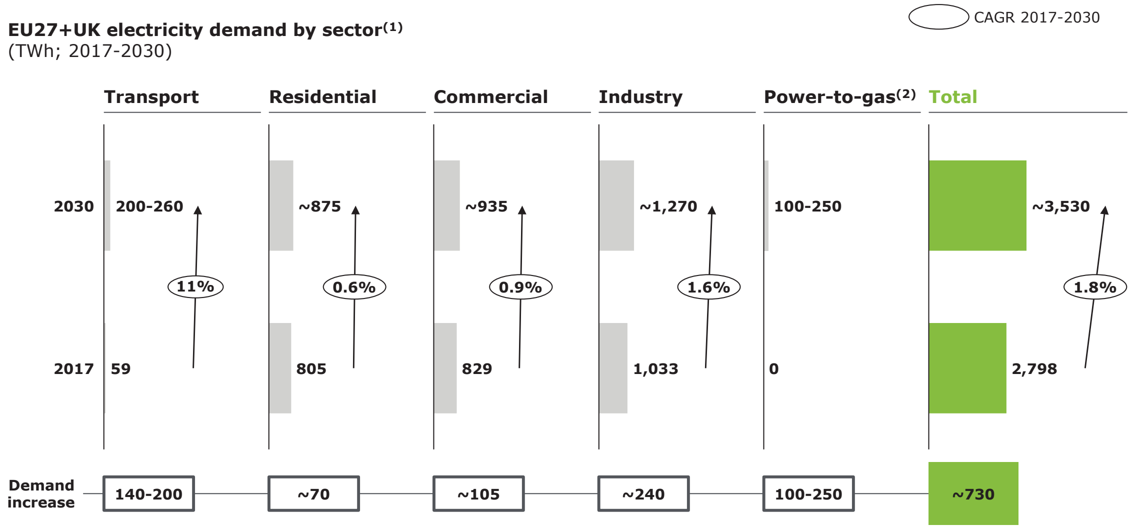
Presentation outline

- Introduction
- Value and benefits of flexibility
- Planning with flexibility
  - Uncertainty management and risk assessment
  - Optimal planning and operation
  - Project appraisal
- Country level study
- Hints on future research and application topics

Energy Transition

- Power generation based on intermittent non-programmable generation
- **Electrification of final uses of energy**
  - Heating
  - Cooking
  - Mobility
  - Industrial uses
- **Huge infrastructural investments** (+70% in distribution)
- **Security and adequacy** at risk
- Modern Planning
- **Flexibility**





https://www.edsoforsmartgrids.eu/connecting-the-dots-distribution-grid- investment-to-power-the-energy-transition-2/

Flexibility

Flexibility

- The Flexibility is *“the ability of the power system to manage changes”* by coordinating a multitude of actors
    - to provide support to bulk power system operation
    - to reduce distribution system bottlenecks
- The flexibility comes from
    - Flexible demand
    - Flexible generation
    - Energy Storage
    - The network reconfiguration

Flexibility for DSOs

- **Mostly flexible provision of active power**
    - Variation of generation
    - Reduction and increase of load
    - Moving load on time
    - Storage Operation
    - Combined with **reactive power regulation**
- **Flexibility providers**
    - Final customers (possibly aggregated)
    - Flexibility suppliers
    - Flexibility Service Providers (FSPs)
    - Free competition
- **Flexibility users**
    - Network Operators - Regulated Subjects
    - Private users

Value of flexibility

Usage and value for DSO (decentralized approach)

- ***Network reinforcement or extension avoided***
  Cost of network reinforcement or extension and cost that incur until the network is extended.
  - *Valid for easier integration of charging of electric vehicles.*
  - *Valid if the network reinforcement or extension is required due to stability problems and not due to voltage or current problems.*
- ***Network reinforcement or extension delayed***
  The value is given by the present value of delay effect of reinforcement or extension.
  - *Easier and faster integration of electric vehicles and other loads will be possible.*
- ***Payment of curtailed generation***
  Cost for redispatch measures to keep the balance and to compensate the generation operators for the lost income.
- ***Penalties** for reduced reliability, if load is curtailed or disconnected.*
  Reduction of supply interruptions if load can be reduced in case of a fault and such some interruptions could be avoided. To determine the value of the flexibility a probabilistic reliability investigation is necessary. For the network operator the value is the penalty for reduced reliability. For the customers the value is determined by the cost of lost load which usually is much higher than the penalty.
- *Cost of **losses***
  Loss reduction (hopefully!) due to a more even load could be possible. Reactive power flows can be reduced with flexible active power.
- ***Redispatch** cost*
  Redispatch in this or a higher network level is avoided due to the use of the flexibility.

Values of flexibility

Deferred Grid reinforcement or extension		
	Explanation	**The flexibility is used to flatten the sum of load and generation curve to avoid overloading. Cost of network reinforcement/extension and cost until the network is extended are avoided.**
	Beneficiary	Network operator
	Source of value	Saved network reinforcement or extension cost
	Typical amount of value	Estimations for Germany and Spain: 60 000 Euro/km cable (MV, LV), 40 000 Euro/km overhead line (MV, LV), 6 000 Euro per transformer MV/LV, 20 000 Euro/ring main unit.
	Applications, Examples, Research projects from literature	Existing flexibility products in the UK as Sustain or Secure could replace new investments.
	Influence on hosting capacity	Increase
	Challenges, Risks	Flexibility must be reliably available during the full lifetime of the network equipment; that means for more than 50 years. If not, network reinforcement or extension is still needed. The use of flexibility cannot be extended on time too long. Losses can increase

Deferred Network reinforcement or extension		
	Explanation	**Flexibility is used to relieve the load on the network. Therefore, network reinforcement or extension can be delayed until there is a stronger load/generation growth.**
	Beneficiary	Network operator
	Source of value	Present value of delay effect of reinforcement or extension.
	Typical amount of value	Difference of net present value of delayed network reinforcement or extension. This is more interesting when interest rates are high.
	Application, Examples, Research projects from literature	Existing flexibility products in the UK as Sustain or Secure could allow new investments to be delayed.
	Influence on hosting capacity	Increase
	Challenges, Risks	If network reinforcement or extension is required due to wind power plants or load, high "storage capacity" of flexibilities is required

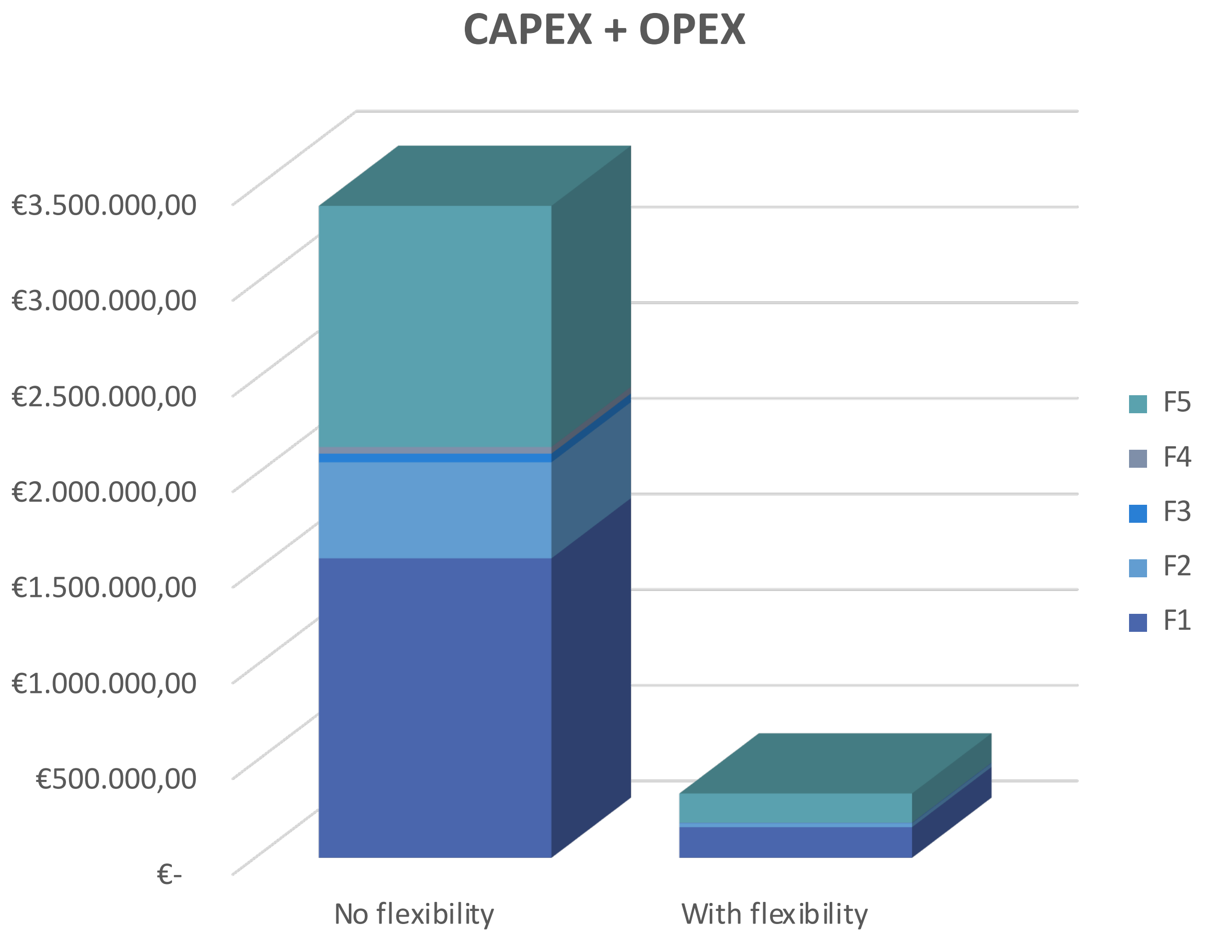
Deferred Network reinforcement or extension		
	Explanation	**Urgent loads can be integrated without having to wait until the network reinforcement or extension is realised. Easier and faster integration of electric vehicles and other loads possible.**
	Beneficiary	Owner of load, e-car; politics
	Source of value	New contracts being awarded earlier in time. As in delaying network reinforcement, value comes from the difference of net present value: earlier cashflow with later investment
	Typical amount of value	Reinforcements or new reinforcement or extensions could have various budgets.
	Applications, Examples, Research projects from literature	ANM solutions to allow flexible connections are being tested in Spain and the UK.
	Influence on hosting capacity	Increase
	Challenges, Risks	Very useful strategy, if flexible loads are the source of the problem (e.g. electric vehicles)

Source: CIRED WG on Flexibility

Flexibility and grid development

Flexibility vs Grid Expansion

- Modern planning tools for distribution systems should consider flexibility procurement (*CEER distribution System WG*).
- DSO should acquire non-frequency ancillary services needed for its systems through transparent, non-discriminatory and market-based procedures (*EU directive 2019/944*).
- DSOs have to cost-efficiently integrate new renewable energy sources and new loads (*EU directive 2019/944*).
- DSOs should be enabled and incentivised to use services from distributed energy resources to avoid costly network expansions (*EU directive 2019/944*)
- Such alternative solutions should be validated by estimating long-term benefits and costs through probabilistic models and risk calculations.



Distribution expansion and planning

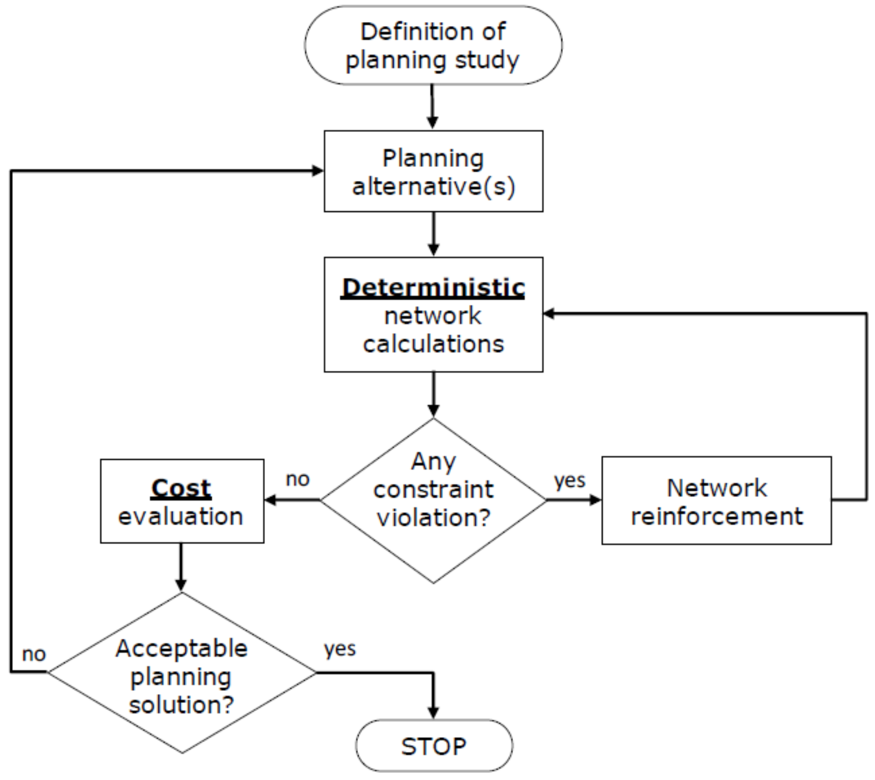
Before EU 944

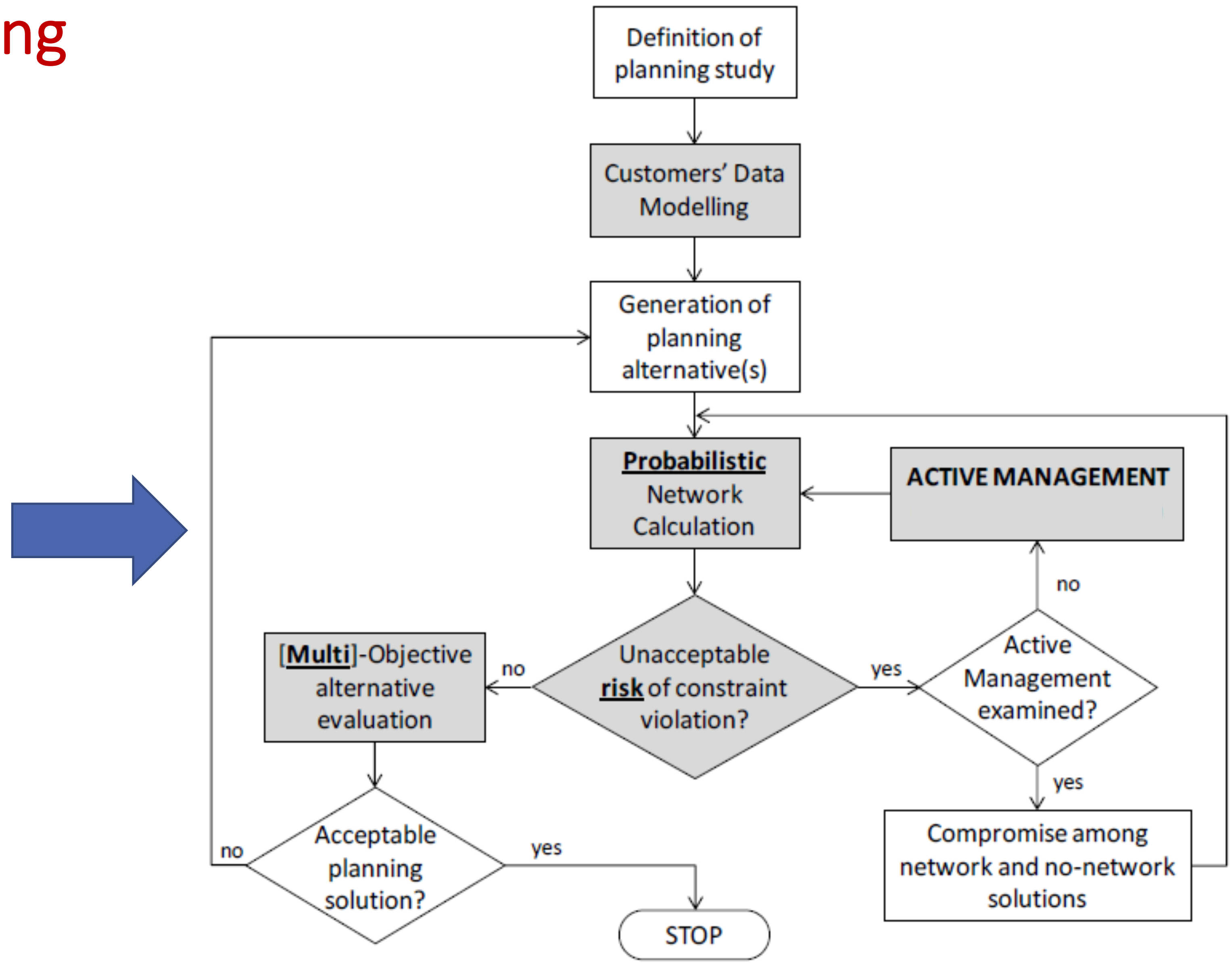
- Fit & Forget
- Risk-averse (worst case)
- Deterministic calculations
- Distribution automation, no operation of generation and demand
- Smart grids confined in pilot projects, laboratories and papers

After EU 944

- **Planning**
  - Forecasting
  - Management of Uncertainty
  - Risk oriented
  - Probabilistic calculations
  - Operation in planning
  - TSO/DSO
- **Operation**
  - Distributed energy resources management systems
  - Forecast
  - TSO/DSO
- **Markets**
  - Markets for local and global ancillary services
  - Aggregators, Balance Service Providers
  - TSO/DSO

Trends in distribution planning





Distribution planning @UniCA

1) Probabilistic Load Flow

2) Calculation

   a. All operating conditions occurrence probability (N-1 analyses): p_{bf}

   b. Technical constraints violation occurrence probability: p_{vv}

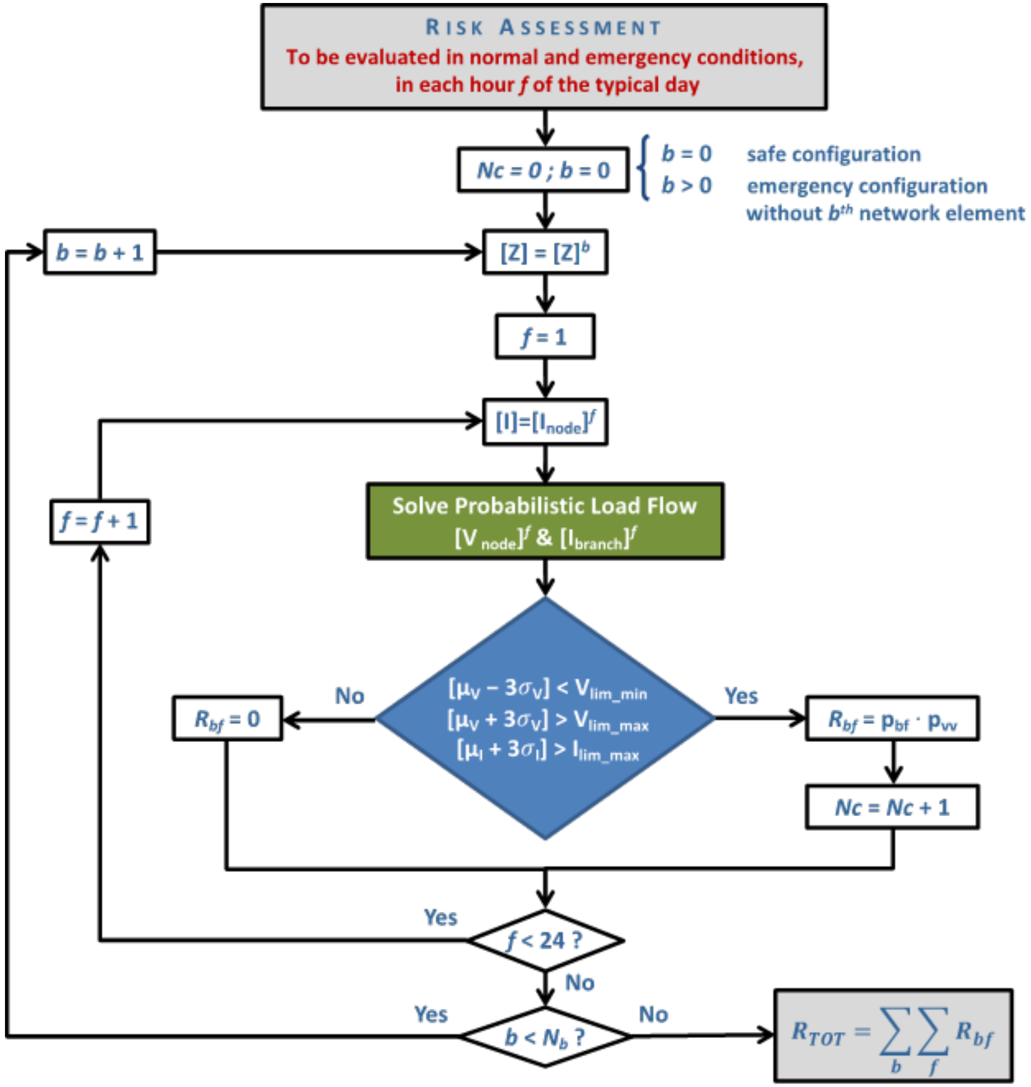
3) Save all cases with possible contingency ($R_{bf} = p_{bf} \cdot p_{vv} > 0$)

4) If $R_{TOT} > R_A$ (acceptable risk)

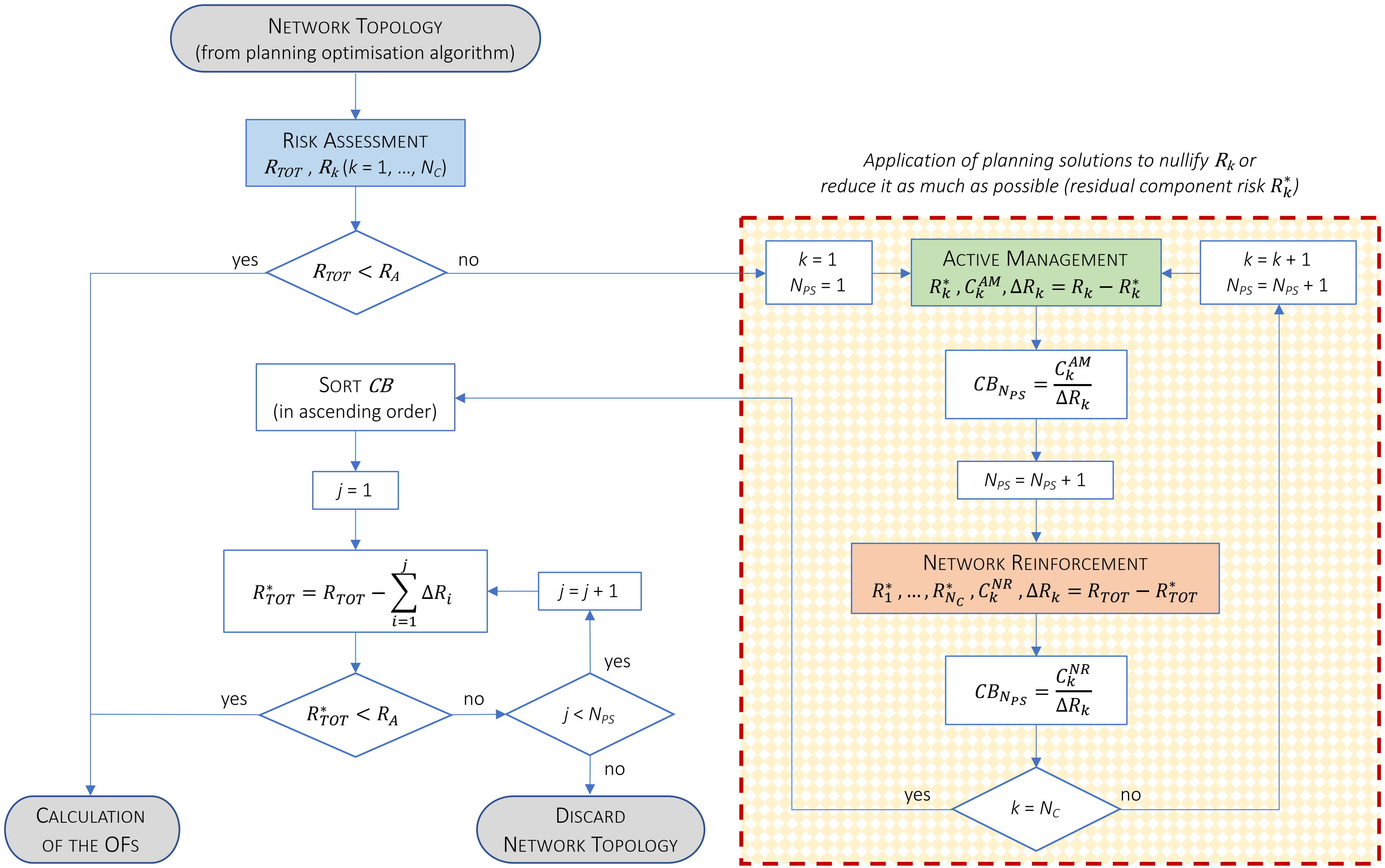
   a. Flexibility services (lower cost, effect on single case, higher residual risk)

   b. Network reinforcement (higher cost, effect on multiple cases, lower residual risk)

5) Selection of best alternatives (cost/benefit ratio)



Risk Assessment and Network Development



1. Given a network, calculate the total risk of technical limit violation
2. If the risk is greater than the allowable value
   1. Use Active Management
   2. Calculate cost benefit ratio
   3. Use Network Option
   4. Calculate cost benefit ratio
3. Use remedial actions by following the relative list of merit to make the risk below the acceptable level (if possible) and spend the minimum.
4. Calculate objective functions or discard the examined network

Reference

- Gianni Celli, Fabrizio Pilo, Giuditta Pisano, Simona Ruggeri, Gian Giuseppe Soma,
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Risk-oriented planning for flexibility-based distribution system development

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A B S T R A C T

The paper presents a risk-based distribution network planning procedure to perform a comparison (in terms of costs and associated residual risks) among conventional planning solutions and the exploitation of flexibility purchased from distributed energy resources through bilateral contracts or local markets. The procedure has been integrated within software developed by the Authors in the past decades for distribution network expansion planning. The software already includes many of the main distinctive characteristics for a modern planning tool, such as abandoning the traditional worst-case approach, resorting to non-network planning options, and implementing the stochastic network assessment to consider generation and demand uncertainties. Since many flexibility resources are connected to the low voltage system, both medium voltage and low voltage networks have to be jointly analysed to account for their mutual interactions. The planning process has been applied to distribution networks representative of the Italian distribution system. The low voltage system has been represented by replicating few real networks provided by the leading Italian Distribution System Operator. Consumption and generation patterns have been modelled from real anonymised measurements.

1. Introduction

Modern trends in power systems have changed the way distribution systems are planned and designed. The worldwide impulse to the integration of a massive amount of Renewable Energy Sources (RES) for carbon neutrality [1–3], supported by new technologies (e.g., Energy Storage Systems (ESS), fast communication, bidirectional smart meters, etc.) are making flexibility not only a need but also a real opportunity to be explored in distribution system planning and operation. Particularly if high power — highly coincident demand (e.g., electric vehicles (EV) charging stations, heat pumps, induction cooking) and RES have to be accommodated on the system. Unfortunately, the distribution system was designed with minimum observability and controllability, privileging economy and simplicity with almost no power generation connected. Thus, due to the increasing share of non-programmable generation from RES, Distribution System Operators (DSOs) are experiencing and facing issues caused by network exploitation non-coherent with the original design assumption (e.g., excessive voltage rises, sudden voltage variations, power congestions, reverse power flow on primary and secondary substation transformers, etc.).

International scientific organisations agree on the need for a new approach and new assumptions in distribution development, which can no longer be based on deterministic distribution planning for economical and quality reasons. Indeed, the most used deterministic *fit & forget* strategy aims to design a distribution network against the most critical operating conditions (even if extremely rare). The strict application of this planning philosophy with the intermitting, non-programmable RES, often non-homothetic with the demand, can induce the renovation of almost all the existing distribution networks, causing an unsustainable amount of network investments [4]. To change the planning paradigm and fairly compare the grid upgrades with the potential support from flexible demand and generation, new methodologies based on probabilistic or robust optimisation techniques are necessary.

By now, the literature is becoming to be richly populated with algorithms and methodologies to modernise distribution planning using Active Management (AM) of the distribution system based on the flexibility offered by consumers, producers and those that do both (prosumers) (e.g., [5–13]). The uncertainties of RES generation, demand and the available flexibility have been considered under different demand forecasting scenarios in the long-term planning (e.g., in [6]), while the robust optimisation is still not so extensively proposed, even if examples of application are increasing in the most recent literature [14,15].

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Results

Studies performed at the country level (ongoing)

Exploitation of flexibility is a new practice

On-field analyses
(flexibility market pilot projects)

Simulation studies
(real MV feeders' data and representative networks)

General Assumptions

- About 1000 distribution feeders from different European Countries, covering different geographical areas and different electricity demand.
- Realistic planning scenarios (EU targets 2030).
- Annual customers’ model with 12 daily curves.
- Bilateral contracts remunerated in Capacity and Energy. No remuneration for reactive flexibility that is used by DSO.

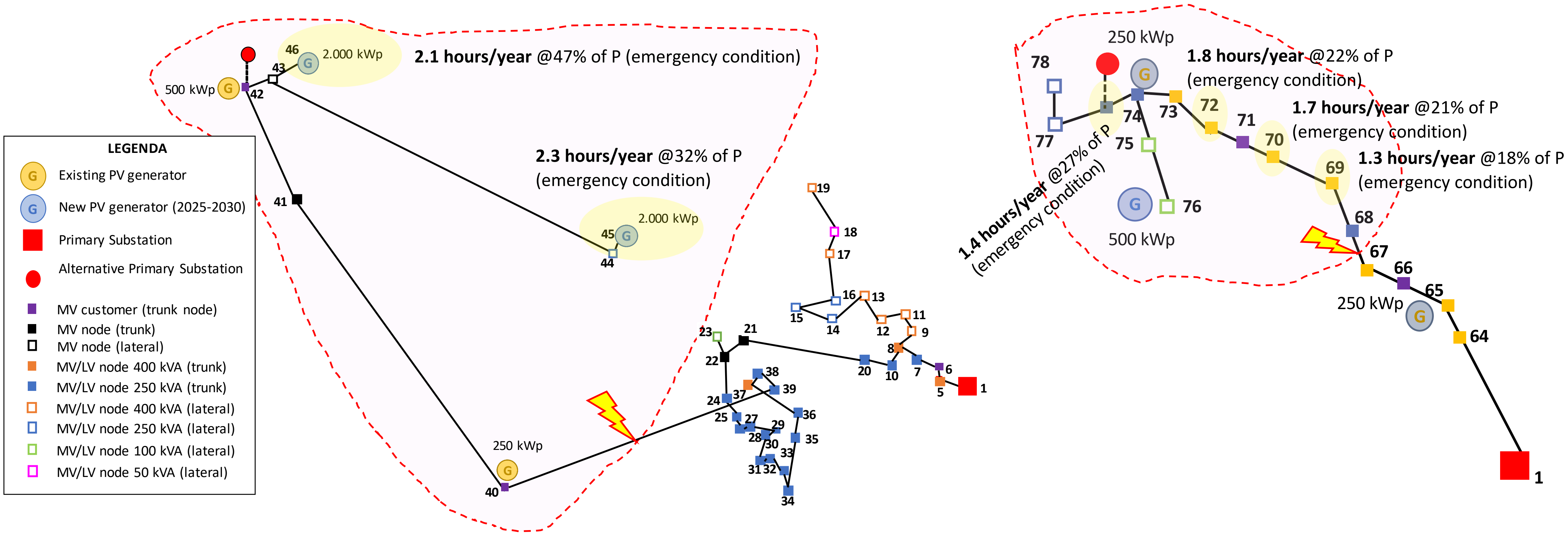
Technical Constraints		
Operating Conditions	*Type of violation*	*Admissible limits*
ordinary	voltage variation	±5 %
	line overload	none
emergency	voltage variation	±10 %
	line overload	+10 %
Risk Analysis		
Maximum Acceptable Risk (R_A)		5 hour/year
Objective Function terms		
OF_1	Net Present Value of network investment (upgrades)	
OF_2	Cost of Joule losses	
OF_3	Flexibility remuneration (fixed + variable)	

Flexibility services considered: →
- Variation of Active Power for voltage regulation
- Variation of Reactive Power for voltage regulation
- Variation of Active Power for line overload

DERs qualified: all active and passive customers with P_n > 25 kW

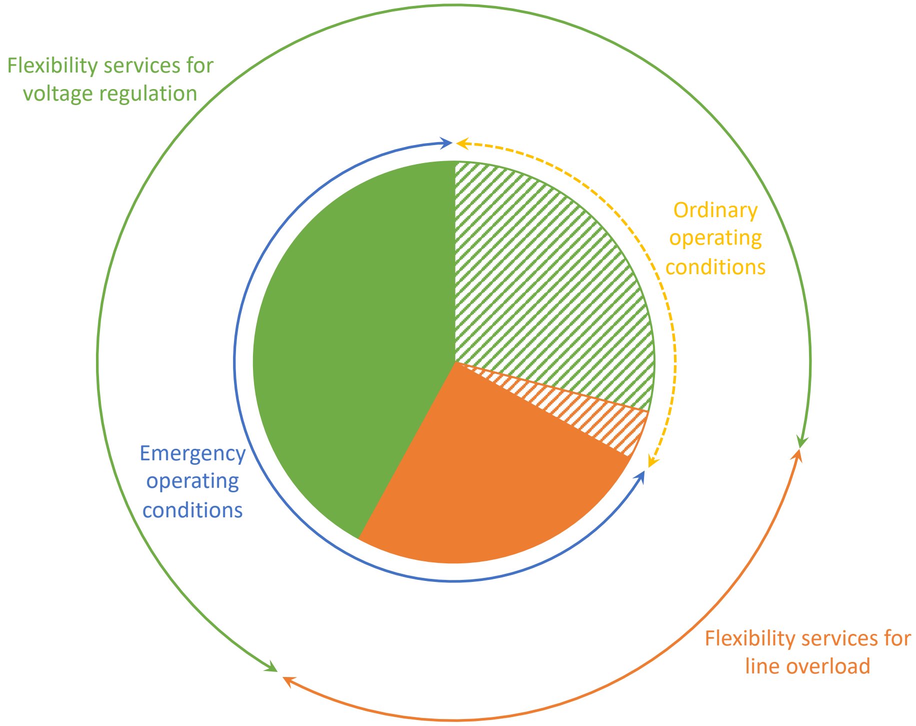
Planning studies (DSO's view). When, Where, and Why using the flexibility

CINELDI

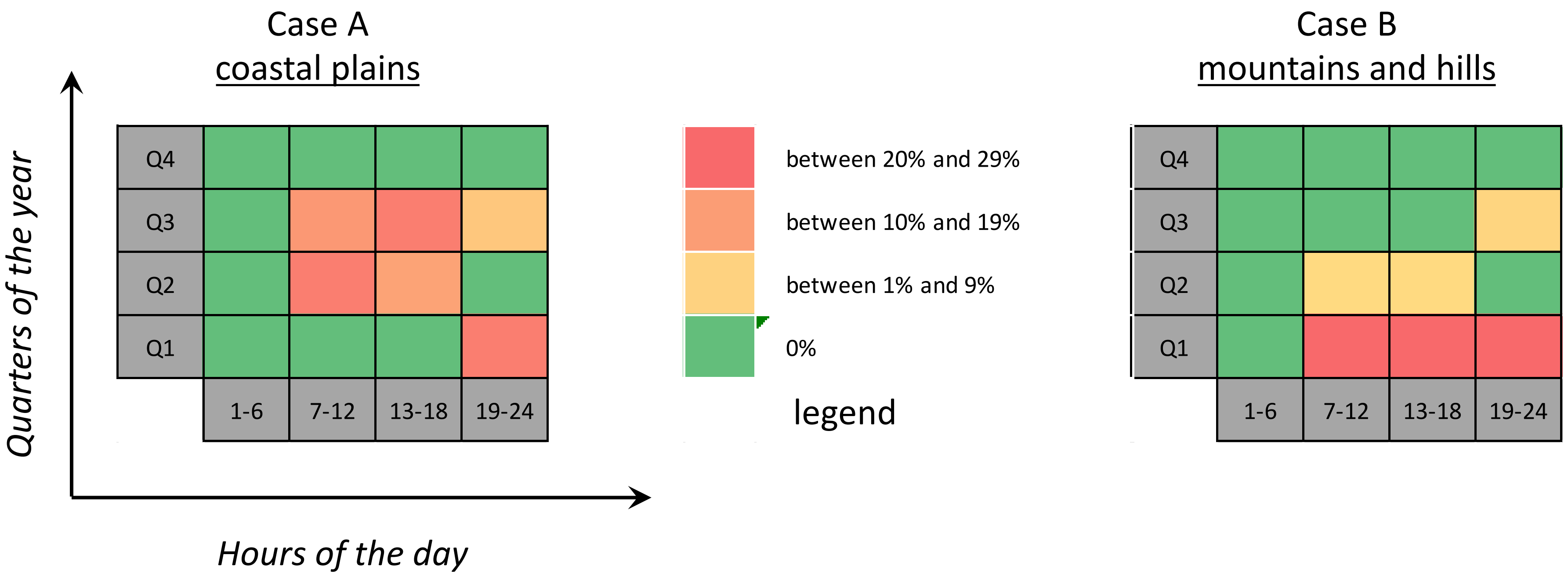


What flexibility service is most frequently required?

- ✓ More than 70% of the services are for solving voltage regulation issues,
- ✓ And around 2/3 of the services are requested in emergency configurations



When are flexibility services necessary?



In the daytime of spring and summer due to a surplus of PV generation.

During winter peak load hours.

Concentrated in winter almost all day due to the higher thermal demand and the hypothesis of electrification.

How much? How long?

CINELDI

How long does the flexibility service have to last?

- ✓ 90 % of the request lasts more than one hour (prevalently flexibility requested for solving technical issues during emergency configurations)
- ✓ On average, typical duration between 2 and 3 hours
- ✓ Longest events infrequent (5 % of the requests lasts 6 hours)

How much power variation is required?

Services classified in

UP: production increment or consumption decrement

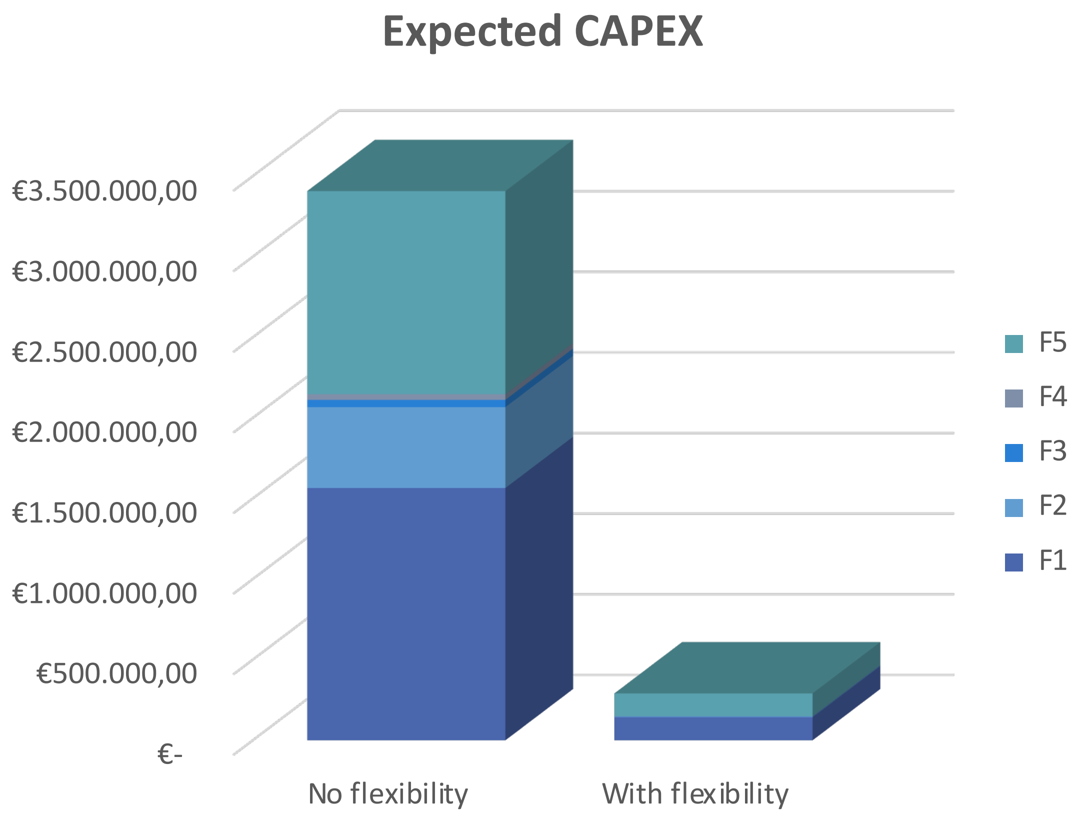
DOWN: production decrement or consumption increment

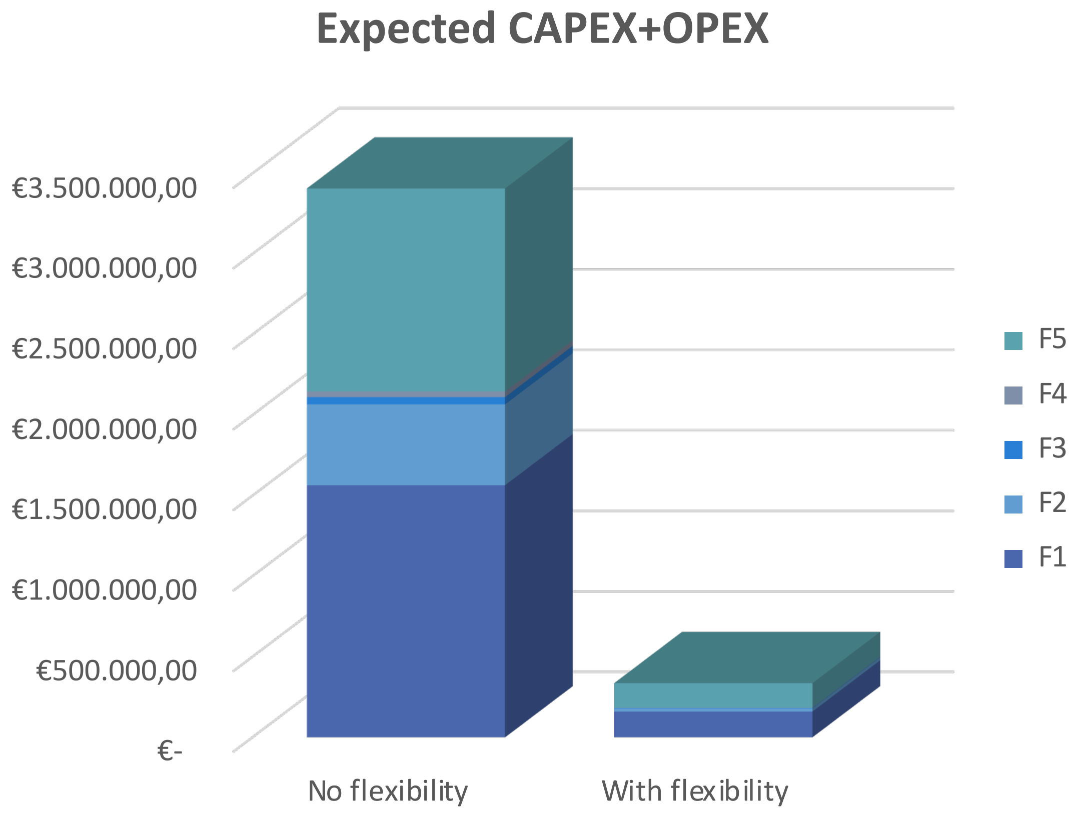
Maximum request < 300 kW

Local flexibility market to small consumers/producers

	Flexibility Service	
	Voltage Regulation	*Line overload*
ΔP^{up}	100 kW	175 kW
ΔP^{down}	130 kW	120 kW
ΔQ^{up} and ΔQ^{down}	100 kVAR	--

Economic benefits





Conclusions and future remarks

- The consideration of flexibility as a planning option is no longer an Academic idea good for writing papers.
- The electrification of final uses is a formidable driver for flexibility
- DSOs are redesigning how they operate and plan their systems, but there is the need for new Regulations (DSO’s role, tariffs and remuneration for DSOs’ regulated services, etc.)
- TSO and DSO: Competition? Coordination? Integration?
- Are markets for local flexibility necessary? What kind of markets? Are there the conditions for establishing a market?
- Hot research topics:
  - Uncertainties and risks management
  - Forecast (geospatial, different time scales, ….) for new demand and generation
  - DERMS
  - Optimisation tools capable to manage the new complexity (non-convex problems)
  - Sector coupling and holistic view of the energy increase the available flexibility and the complexity

Credits

- Prof. Gianni Celli
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