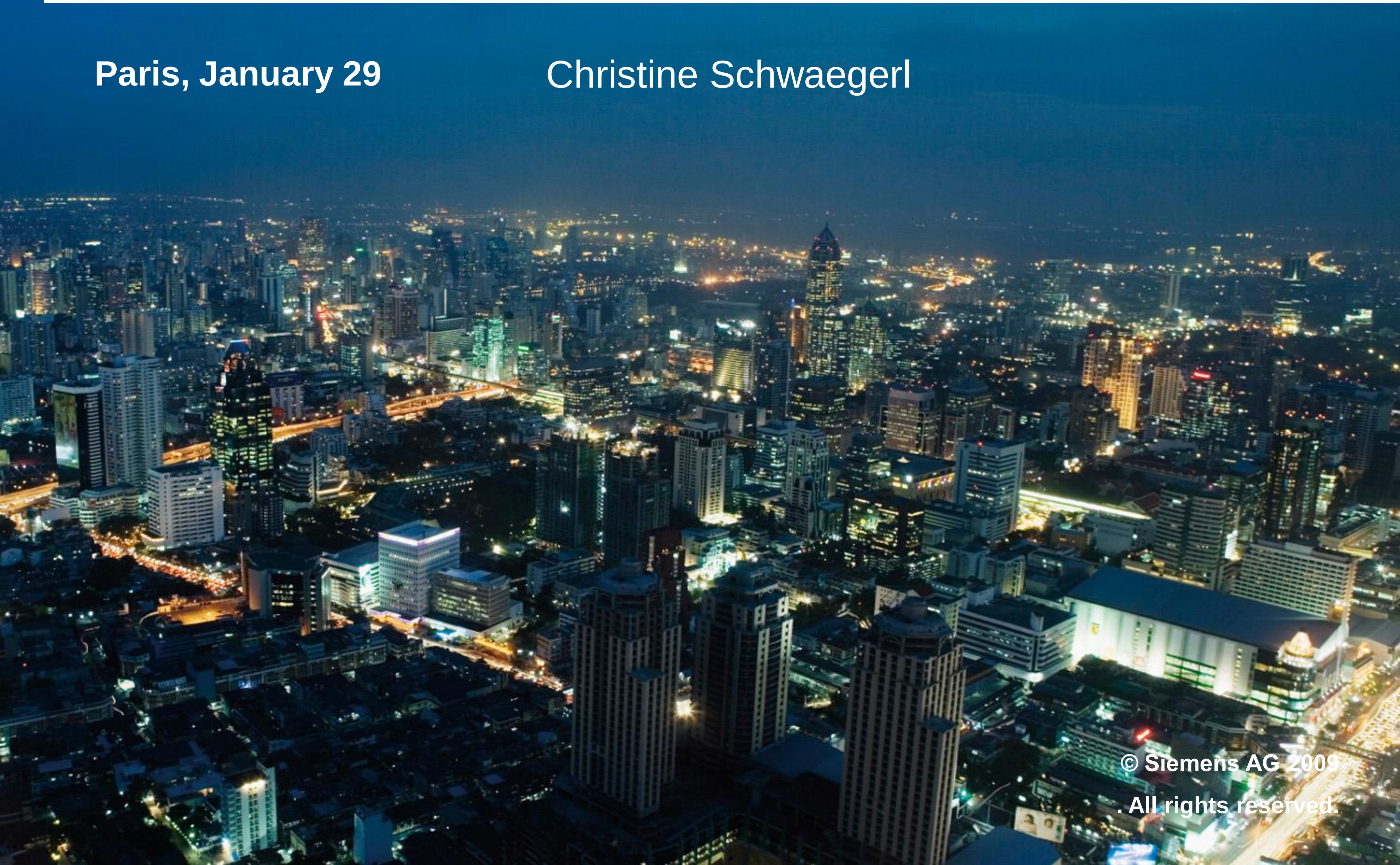
Technical, Economic and Environmental Benefits of Microgrids Operation

SIEMENS

Paris, January 29

Christine Schwaegerl



Agenda

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- Definition and Clarification of Microgrid Concept
  → *What is a Microgrid?*
  How is it different from concepts like VPP?
- Justification of Microgrid Deployment
  → *Why is Microgrid needed?*
  What kind of benefits can it offer?
- Market and Regulatory Settings for Microgrids
  → *How can a Microgrid become profitable?*
  Who owns/operates it?
- Control Elements and Control Methods of a Microgrid
  → *How is a Microgrid operated? Is islanding preferable?*
- Setup of European Microgrid Study Framework
- Methodology for Simulation and Analysis
- Summary of Evaluation Results
  → *What are the quantified benefits of Microgrids?*

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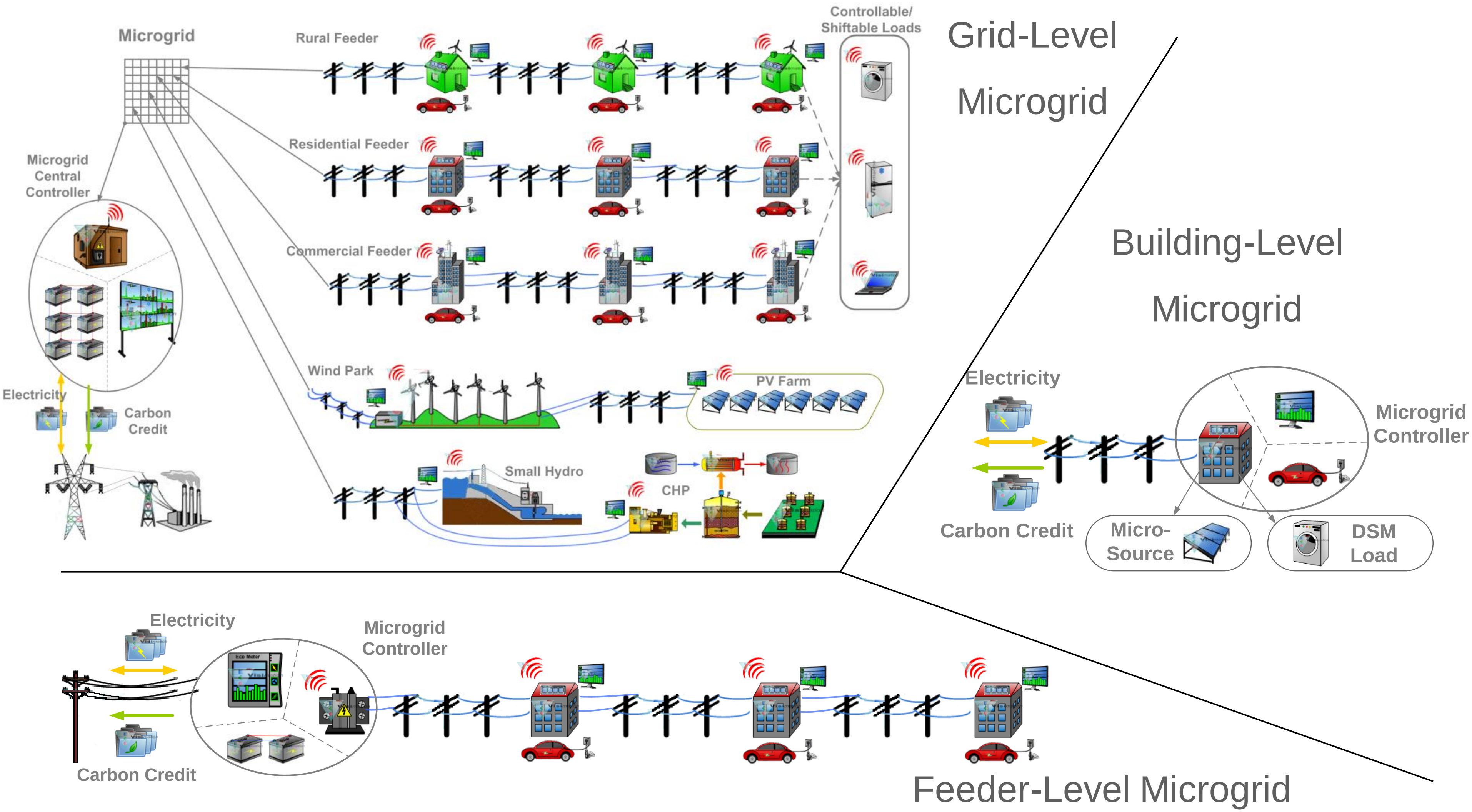
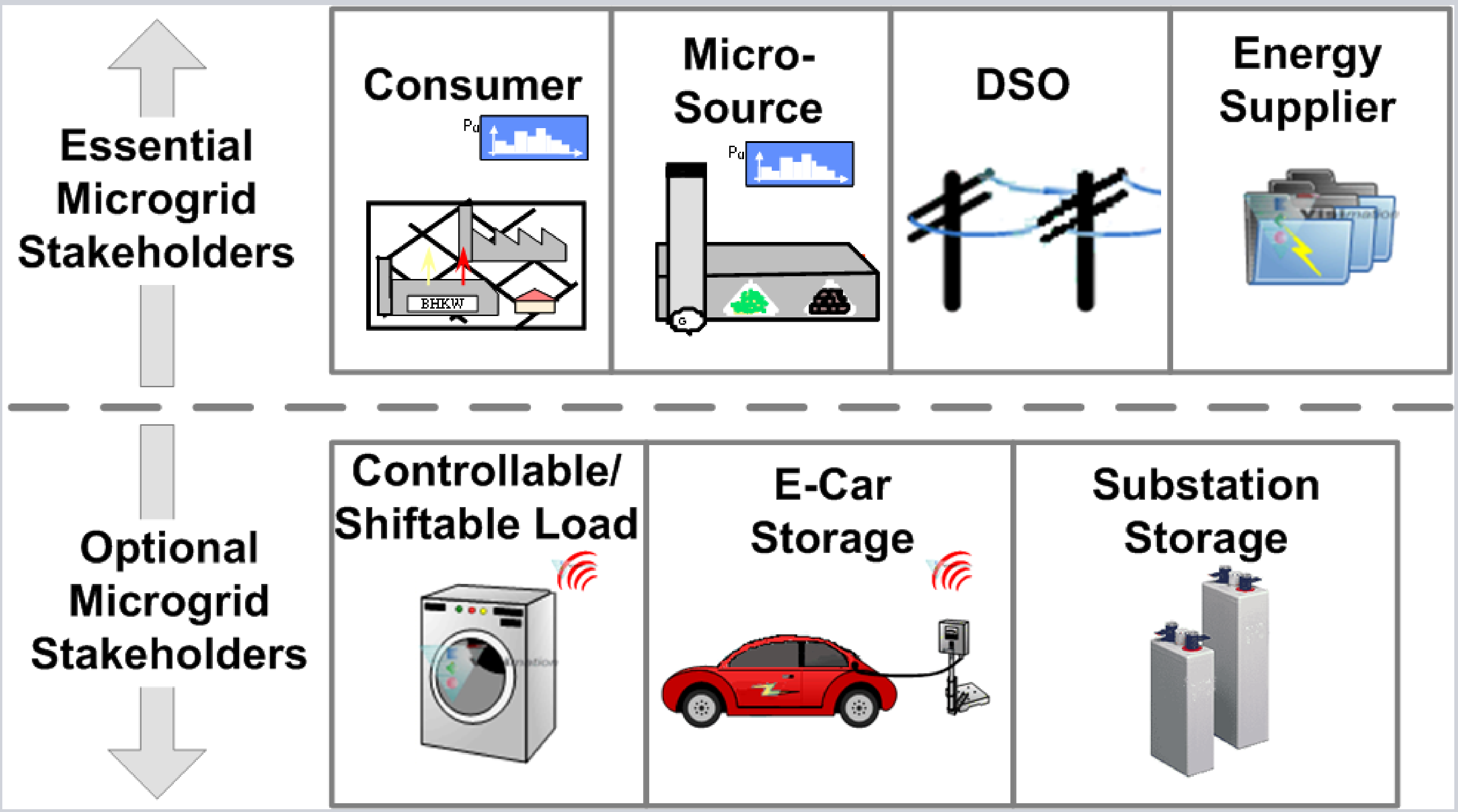
Pecularities of Microgrids

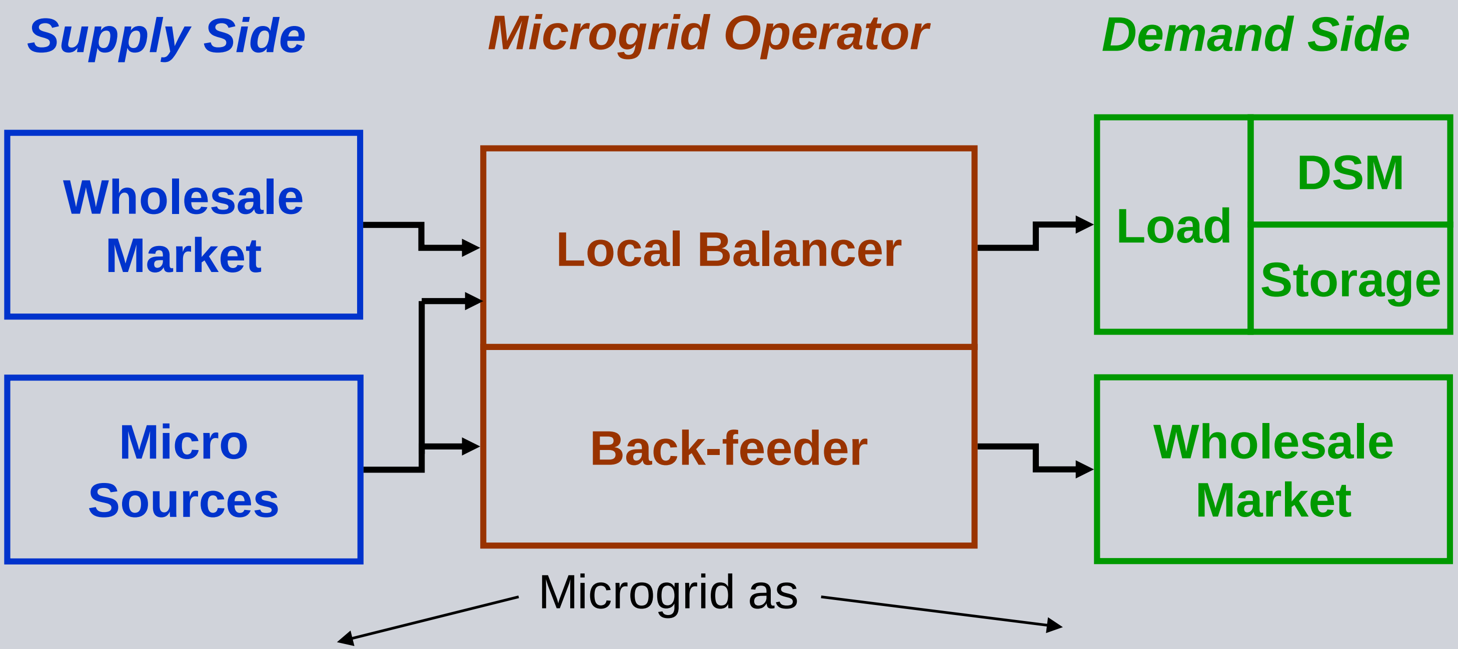
What is a Microgrid?
Microgrid on Different Scales



Summary of Microgrid Stakeholders



Why Microgrids? Microgrid as an Aggregator of Both Supply- and Demand-Side Players



Aggregator and Control Centre that optimises outputs of multiple units

Competitive Retailer that could provide lower tariff and better carbon footprints

Microgrid integrates **supply-side and demand-side** players
-> interest allocator to **minimise total social cost** summed from all involved entities

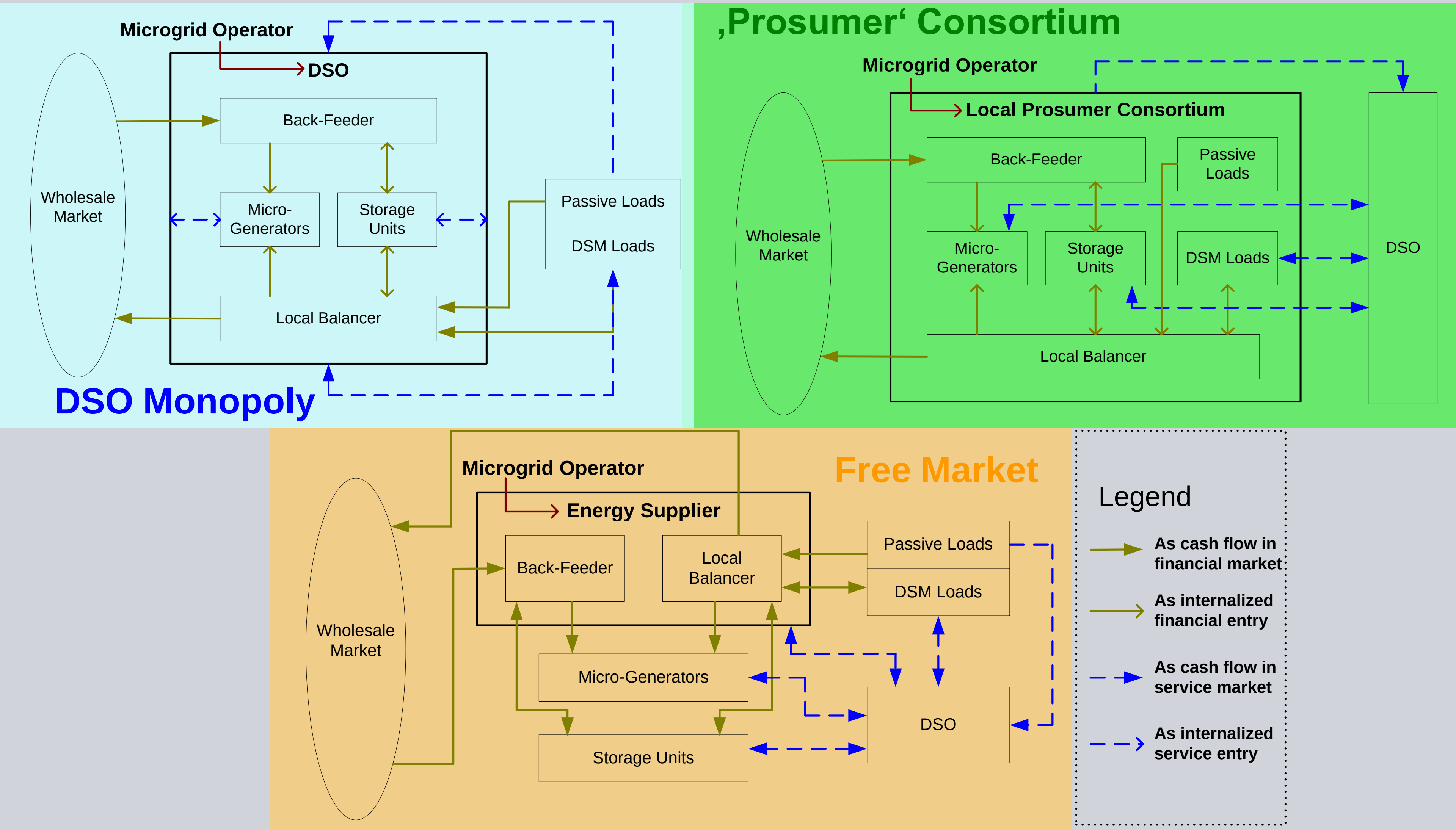
Who will develop a Microgrid?
Who will own or operate it?

- Investments in a Microgrid can be done in multiple phases by different interest groups: DSO, energy supplier, end consumer, IPP (individual power producer) all could take part in the process

- The operation right of Microgrid will be mainly decided by the ownership of Micro-Sources, thus four general conditions could happen:

    - DSO owns the MS units (DSO Monopoly)
    - End consumers own the MS units (Consumer Consortium)
    - IPP’s own the MS units (Free Market)
    - Energy supplier owns the MS units (traditional approach)

Typical Microgrid Ownership Models

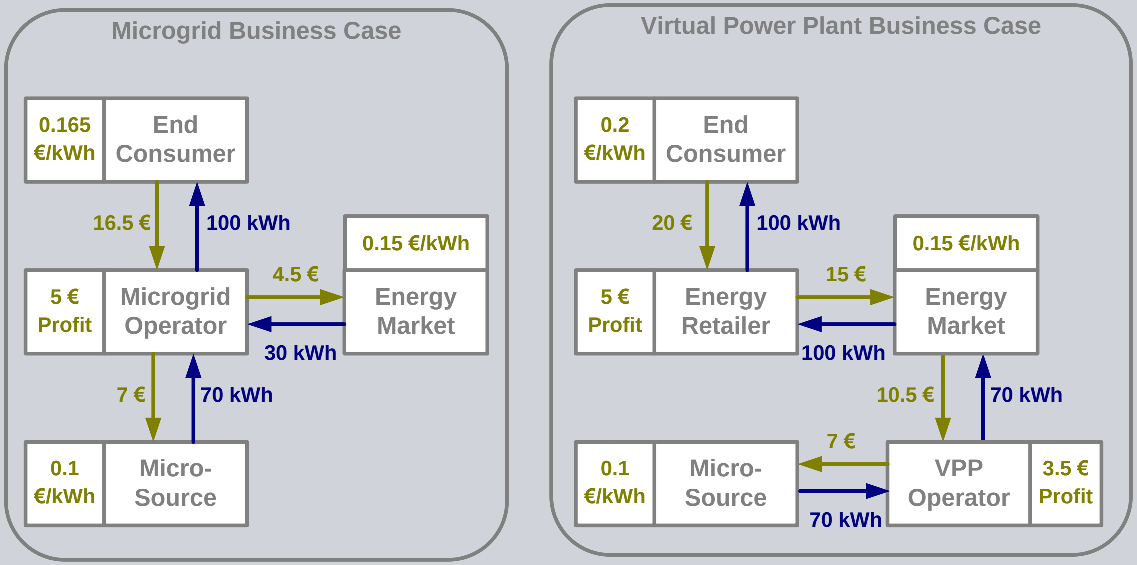


Comparison with VPP Concept

Three main differences between Microgrids and VPP concept :

- **Size** (small vs. anything from small to large)
- **Locality** (local concern vs. traditional power trading strategy)
- **Demand Interest**
  (end consumer interest expressed somehow vs. only DSI remuneration)

Microgrid Benefit Over VPP due to Intermediary Reduction



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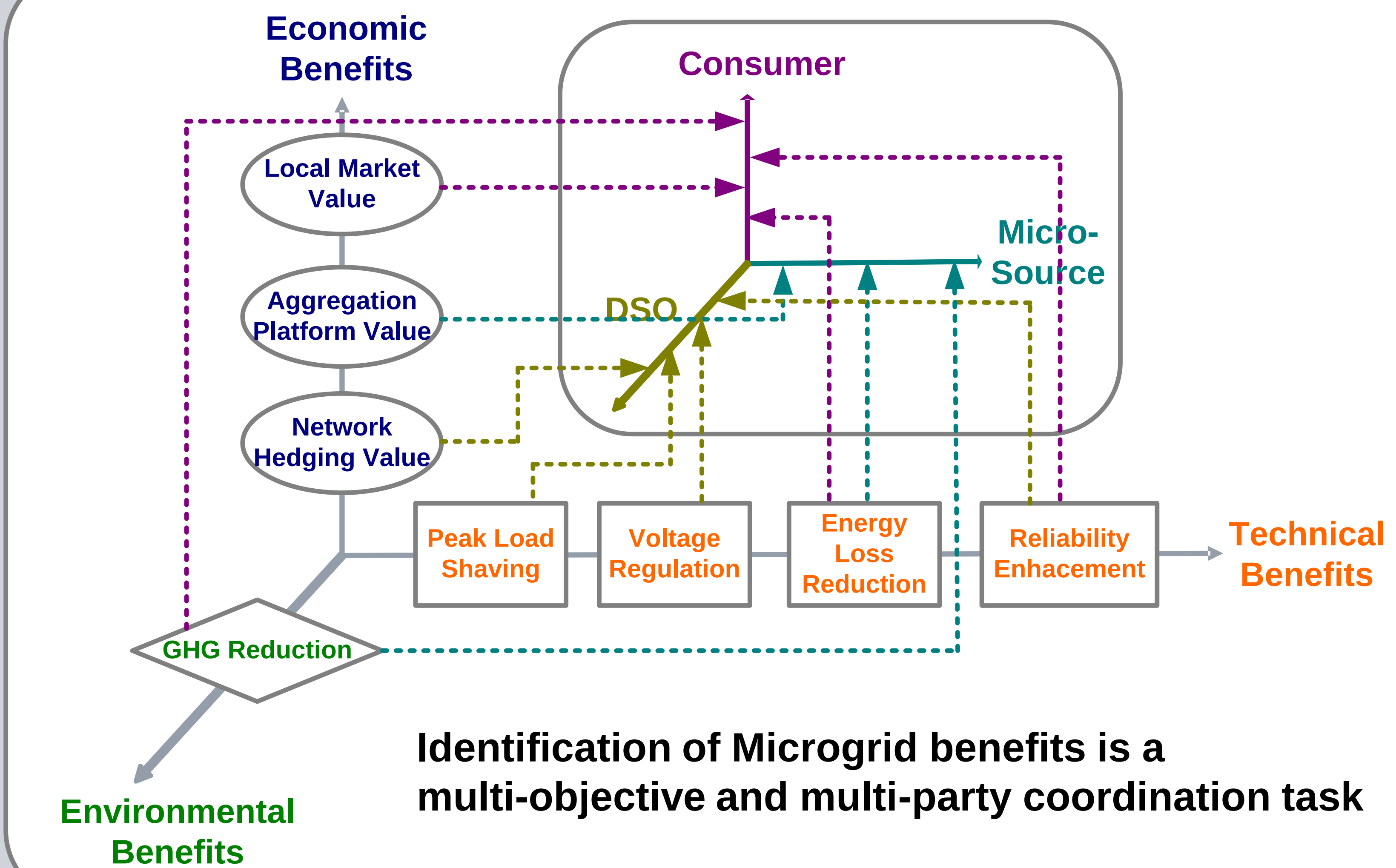
Potential Microgrid Benefits

Microgrid Benefits by Criteria and Recipient



Identification of Microgrid benefits is a multi-objective and multi-party coordination task

How to identify Microgrid benefits?

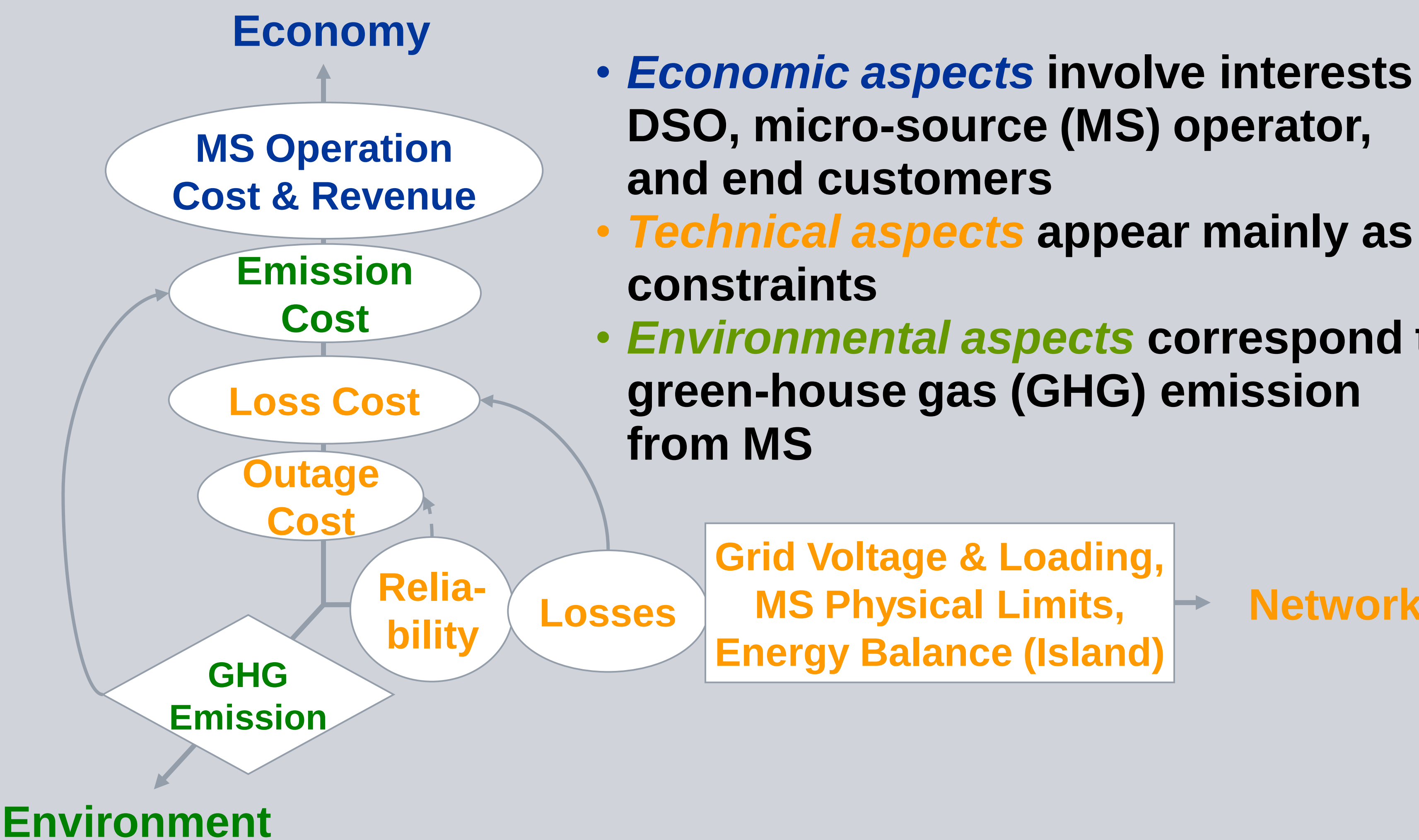
- Identification of Microgrid benefit is both a problem of Microgrid design (i.e. siting and sizing of micro-sources) and a problem of Microgrid scheduling (i.e. real-time operation).
  Network planning (design, with impact on reliability) and network operation (scheduling) are no longer decoupled procedures for a Microgrid.

- Additional investment in extra control, communication, and metering devices can be at least partially justified by the benefits evaluated from simulated grid operation conditions.

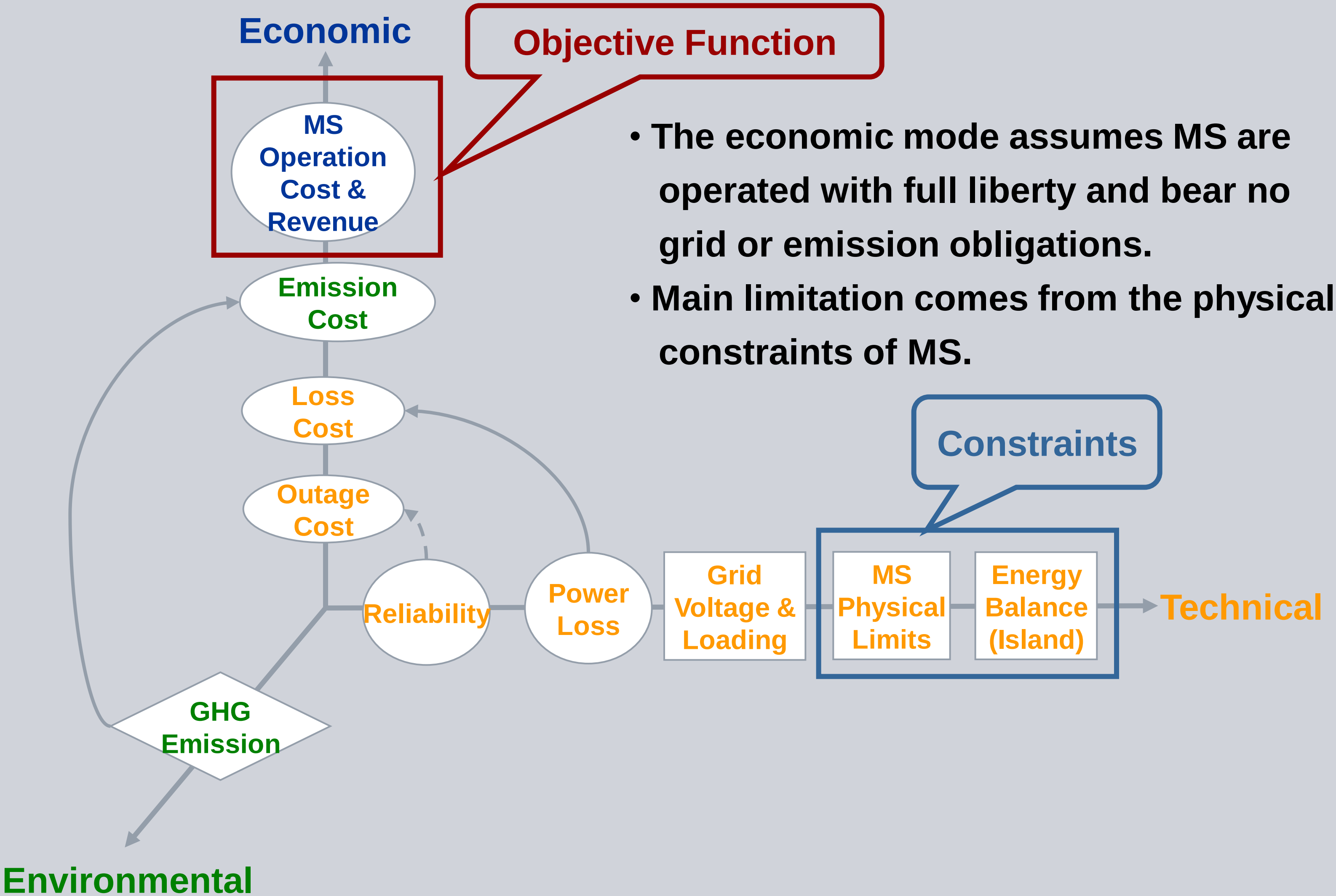
- Optimum Microgrid operation is a multi-objective task likely covering one or more of economic, technical and environmental objectives.

Microgrid Operation Strategies

- ***Economic aspects*** **involve interests of DSO, micro-source (MS) operator, and end customers**
- ***Technical aspects*** **appear mainly as constraints**
- ***Environmental aspects*** **correspond to green-house gas (GHG) emission from MS**

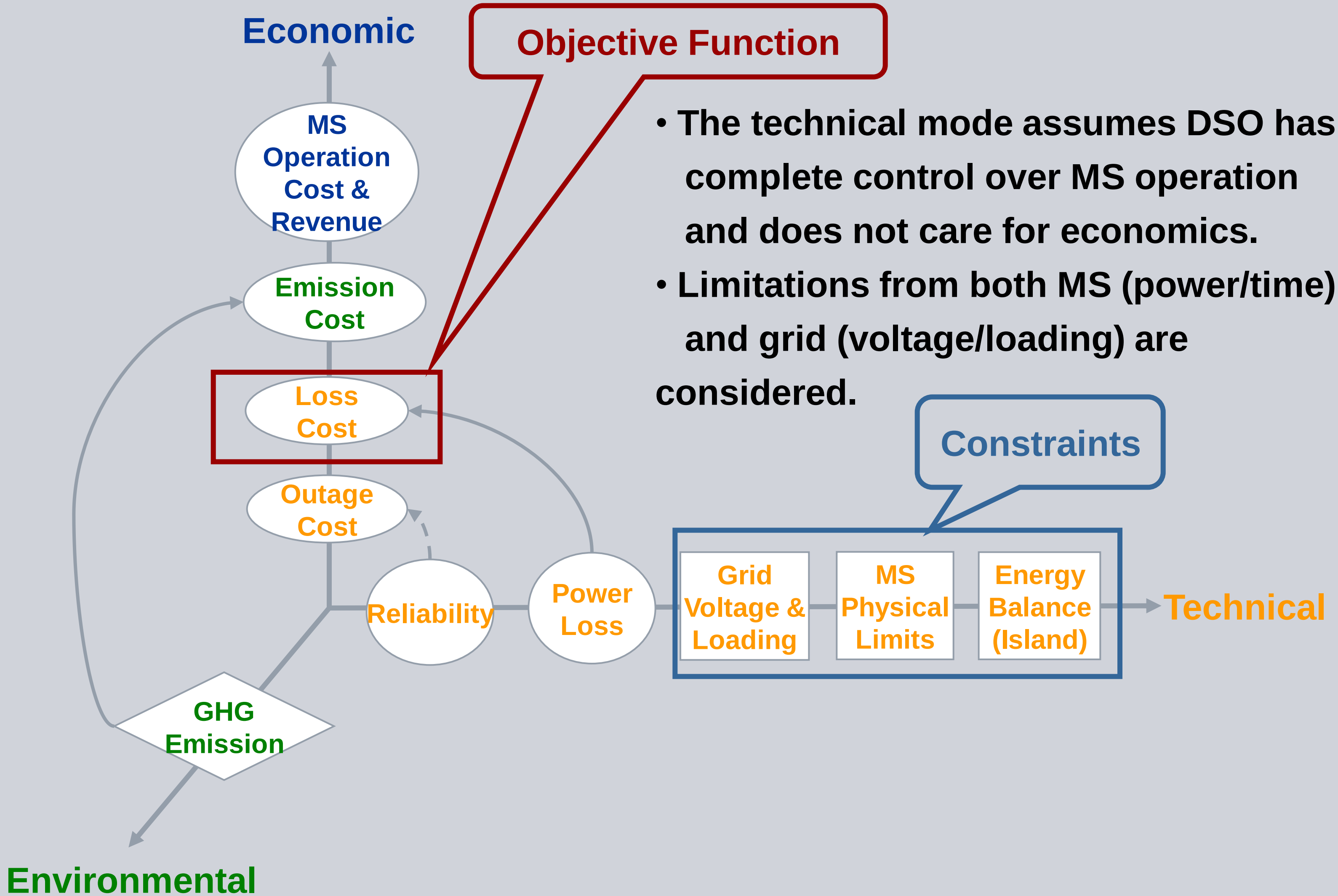


Economic Mode of Microgrid Scheduling



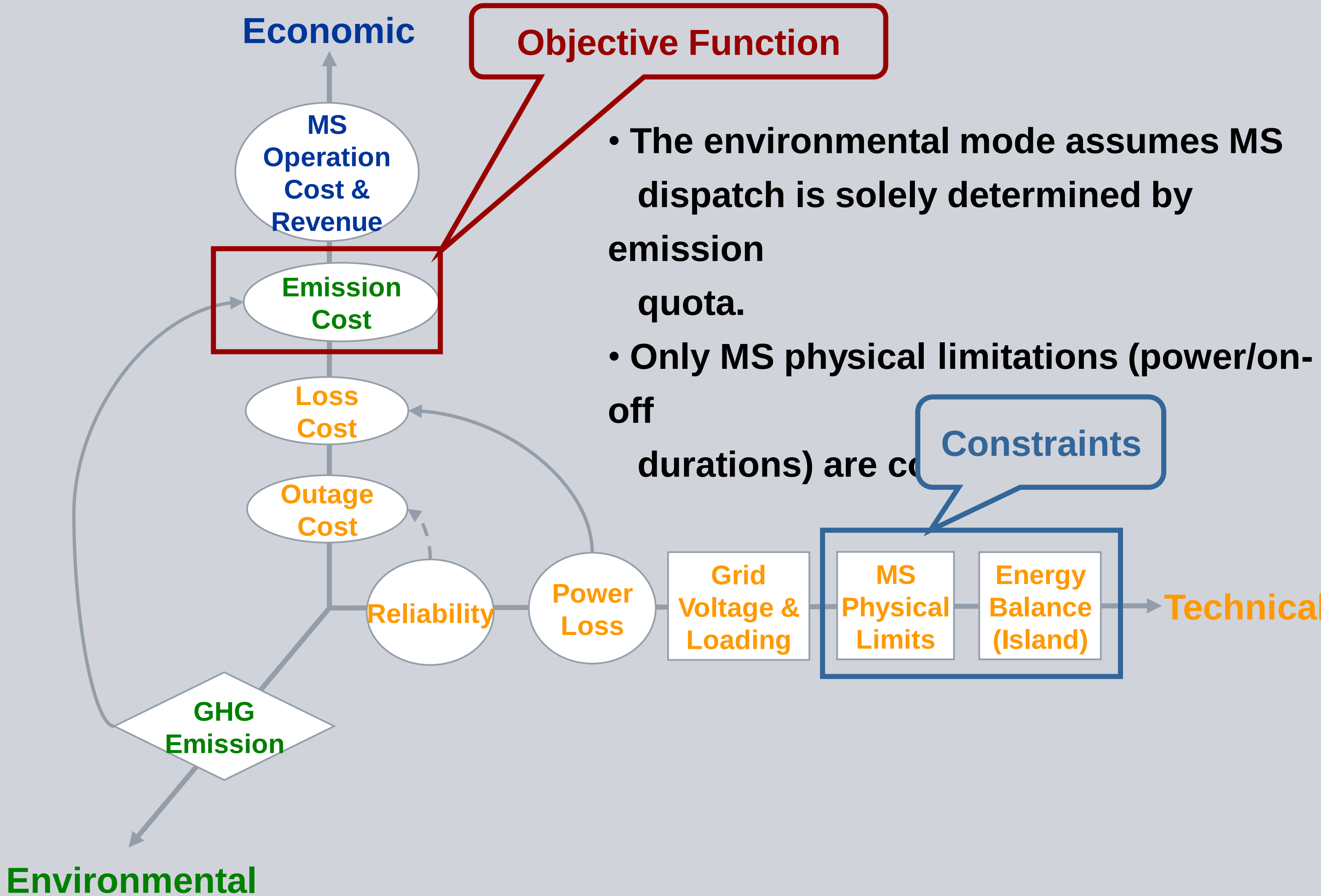
- The economic mode assumes MS are operated with full liberty and bear no grid or emission obligations.
- Main limitation comes from the physical constraints of MS.

Technical Mode of Microgrid Scheduling



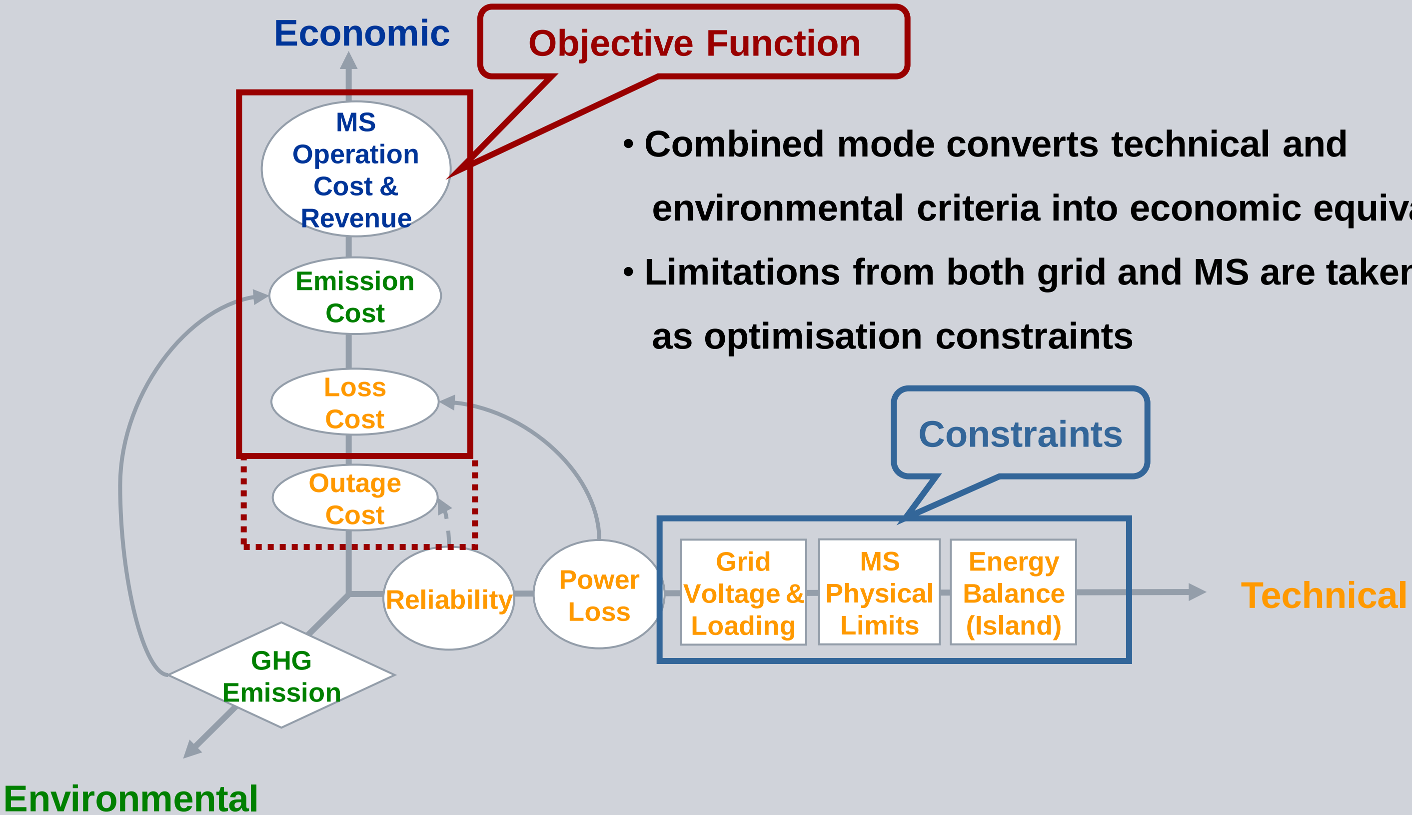
- The technical mode assumes DSO has complete control over MS operation and does not care for economics.
- Limitations from both MS (power/time) and grid (voltage/loading) are considered.

Environmental Mode of Microgrid Scheduling



- The environmental mode assumes MS dispatch is solely determined by emission quota.
- Only MS physical limitations (power/on-off durations) are c

Combined Mode of Microgrid Scheduling



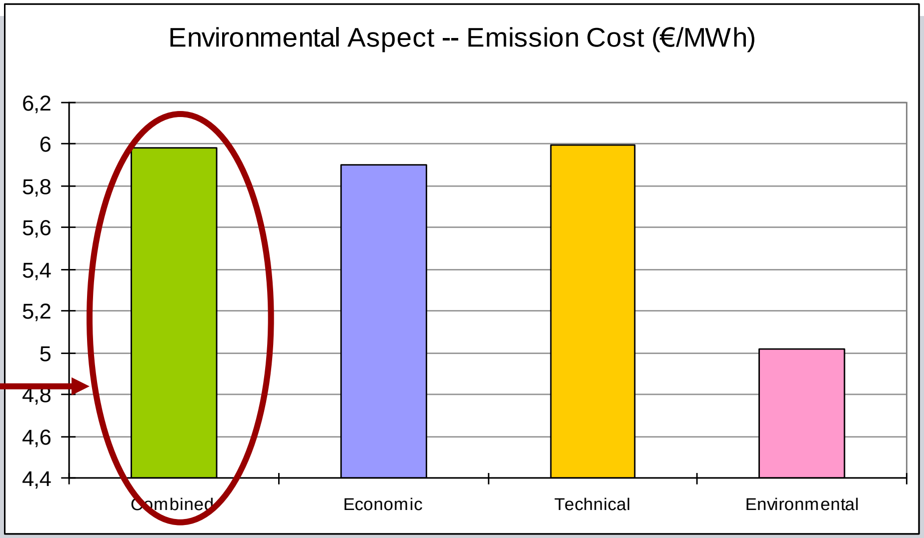
- Combined mode converts technical and environmental criteria into economic equivalents
- Limitations from both grid and MS are taken as optimisation constraints

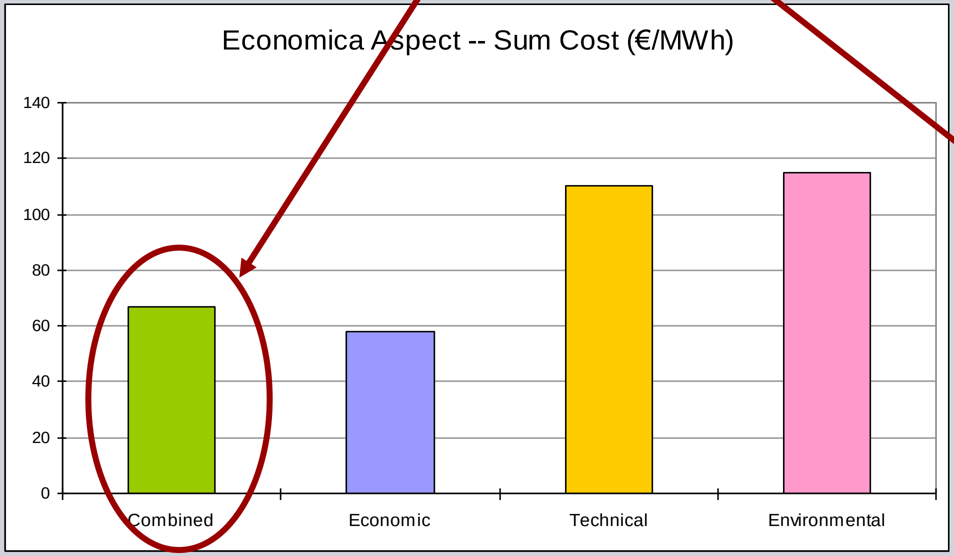
Combined Mode as a ***multi-objective optimization procedure*** attempts to achieve a best available solution that satisfies all economic, technical and environmental requirements

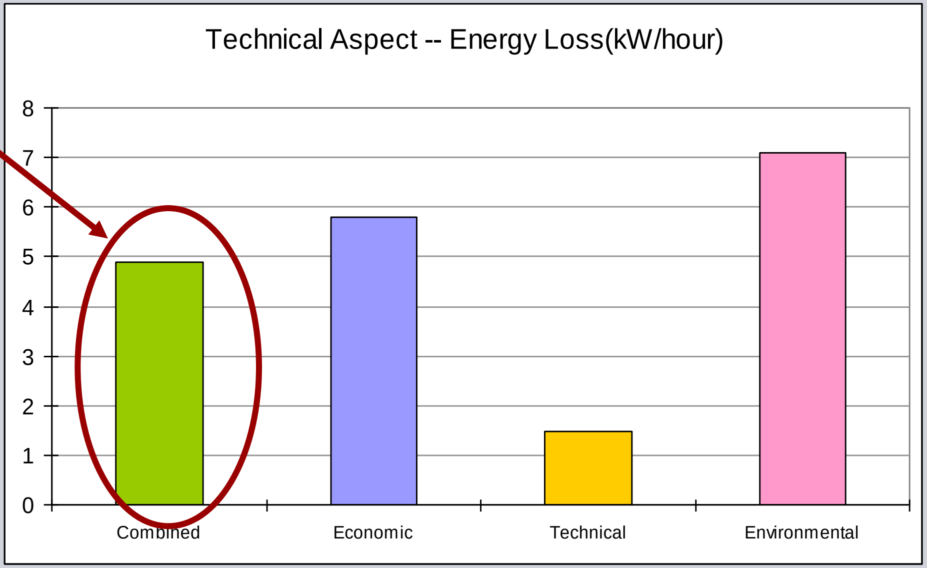
Impact of Microgrid Control Strategy

Example Economic, Technical, and Environmental Benefits

Combined mode as best compromise







What makes Microgrid scheduling task unique and difficult?

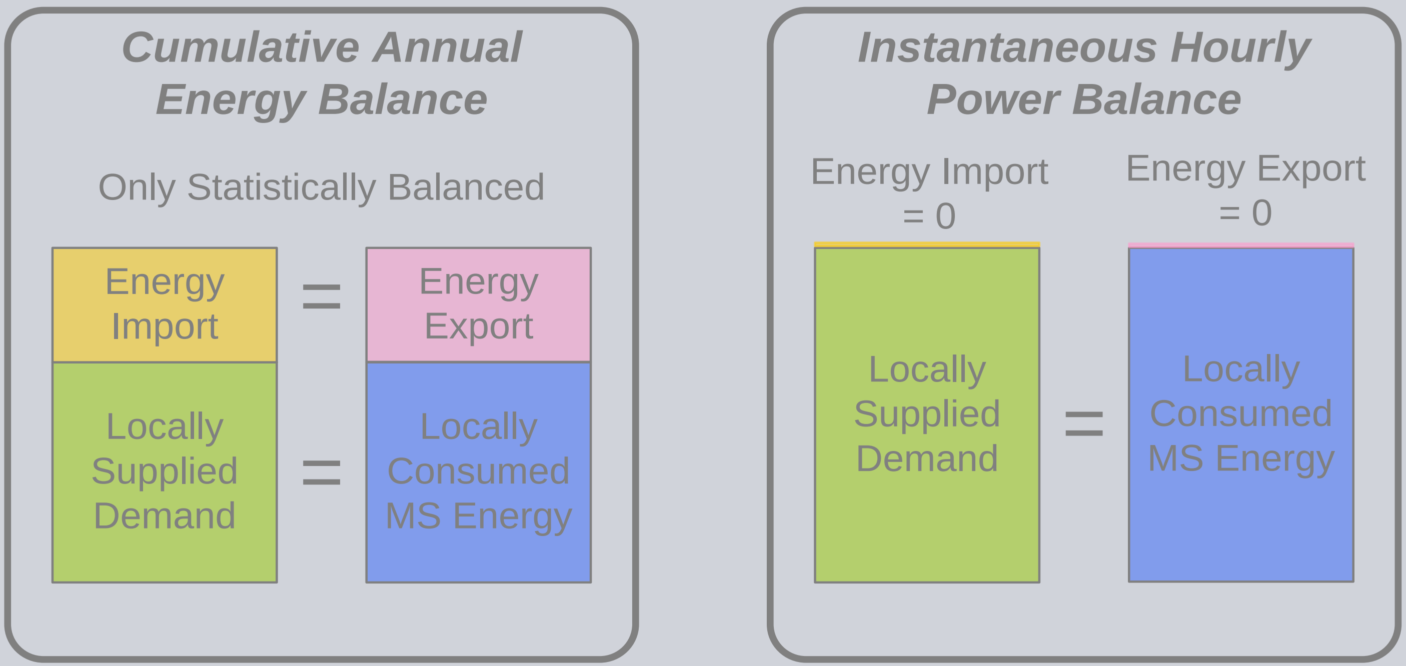
- Intertwined/Conflicting interests from different entities: DSO, DER operator, regulator, consumer etc.
  New tools have been developed in Microgrids Project!

- Different forms of network components (mainly belong to DER) to be monitored and controlled: dispatchable DG, intermittent RES, micro CHP, storage units (electrical and thermal), DSM-capable loads etc.

- Complications due to simultaneous application of varied operation objectives and constraints (e.g. time-domain consideration vs multi-unit dimension)

Is local balancing (quasi-islanding) a preferable option for Microgrids?

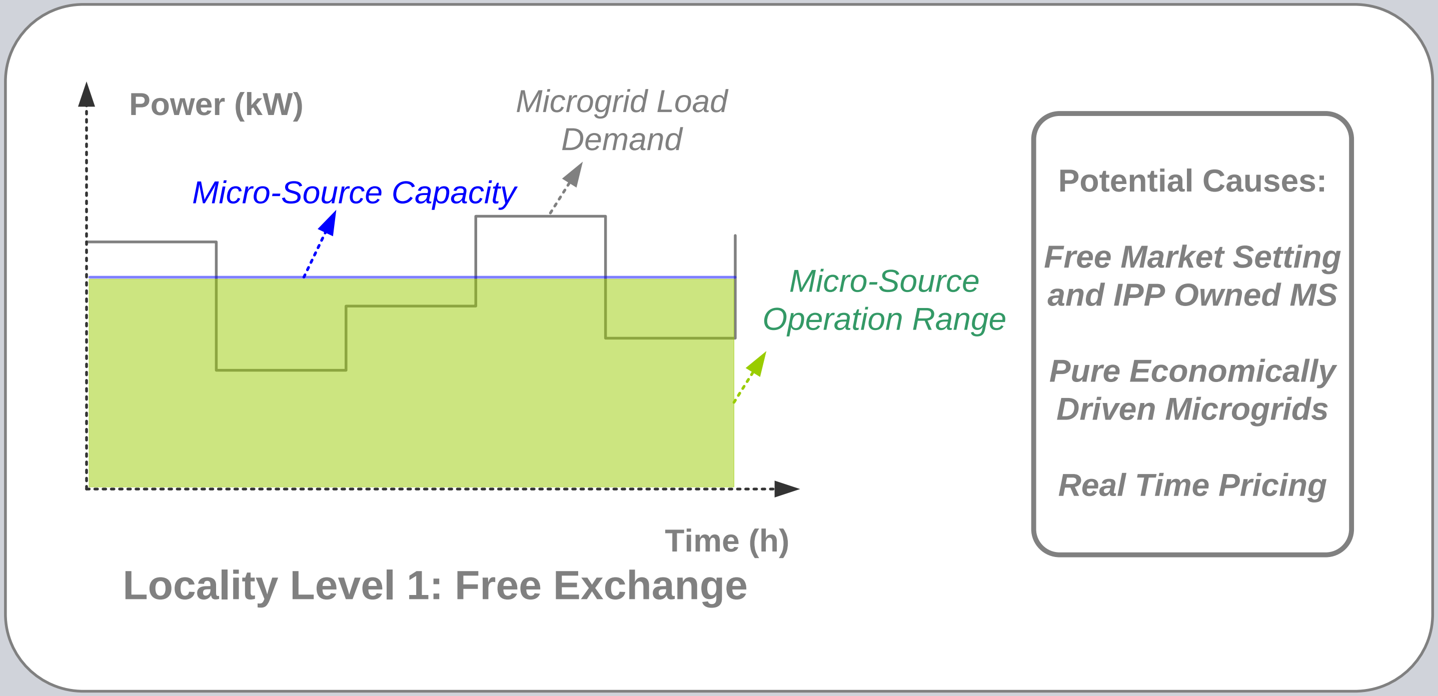
Different types of local balancing



Only instantaneous balance requires real time balancing of load and generation within a Microgrid

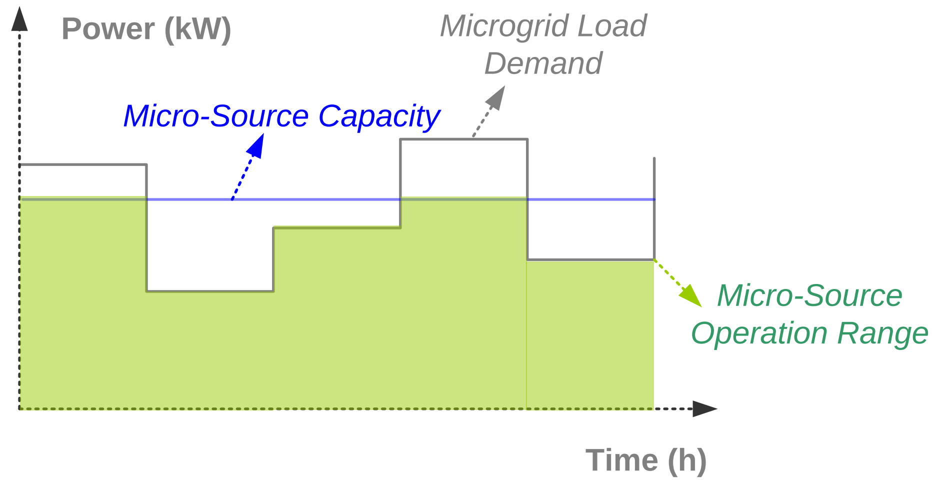
Is local balancing (quasi-islanding) a preferable option for Microgrids?

- Three levels of self-sufficiency can be found with a Microgrid:
  - Level 1: Free Exchange



Is local balancing (quasi-islanding) a preferable option for Microgrids?

- Three levels of self-sufficiency can be found with a Microgrid:
  - Level 1: Free Exchange
  - Level 2: Strict Generator or Strict Consumer



Locality Level 2: Strict Consumer

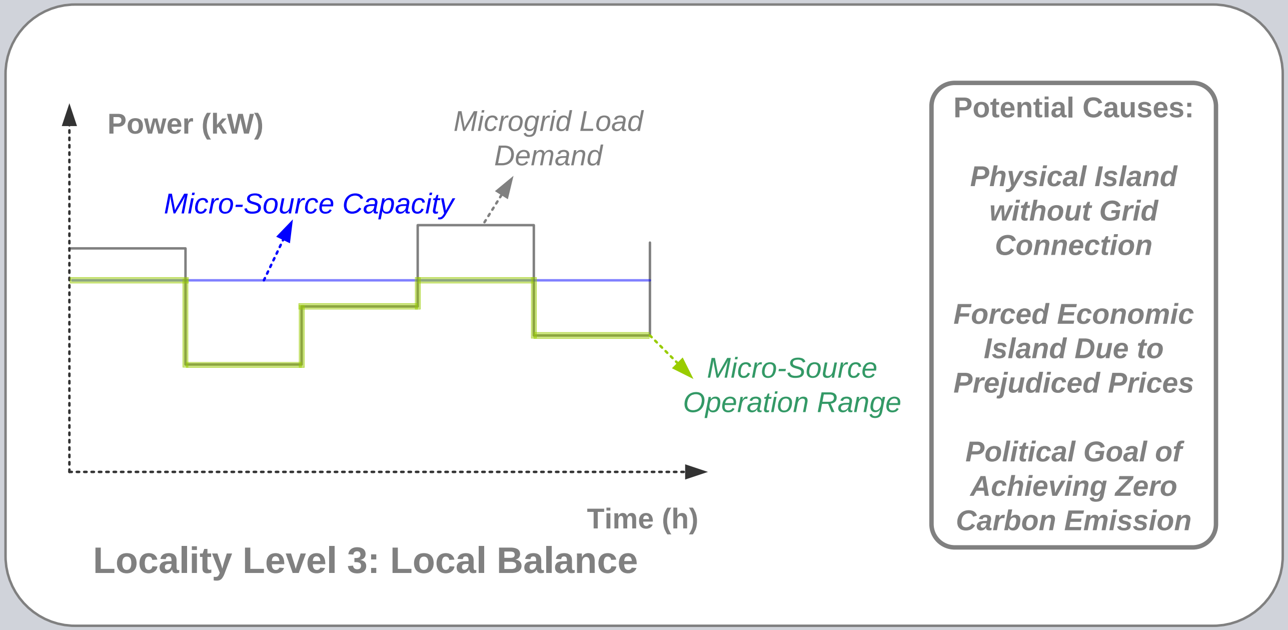
Potential Causes:

Banned Energy Export from Microgrid

Long Term Low to Medium Import Price (Real Time)

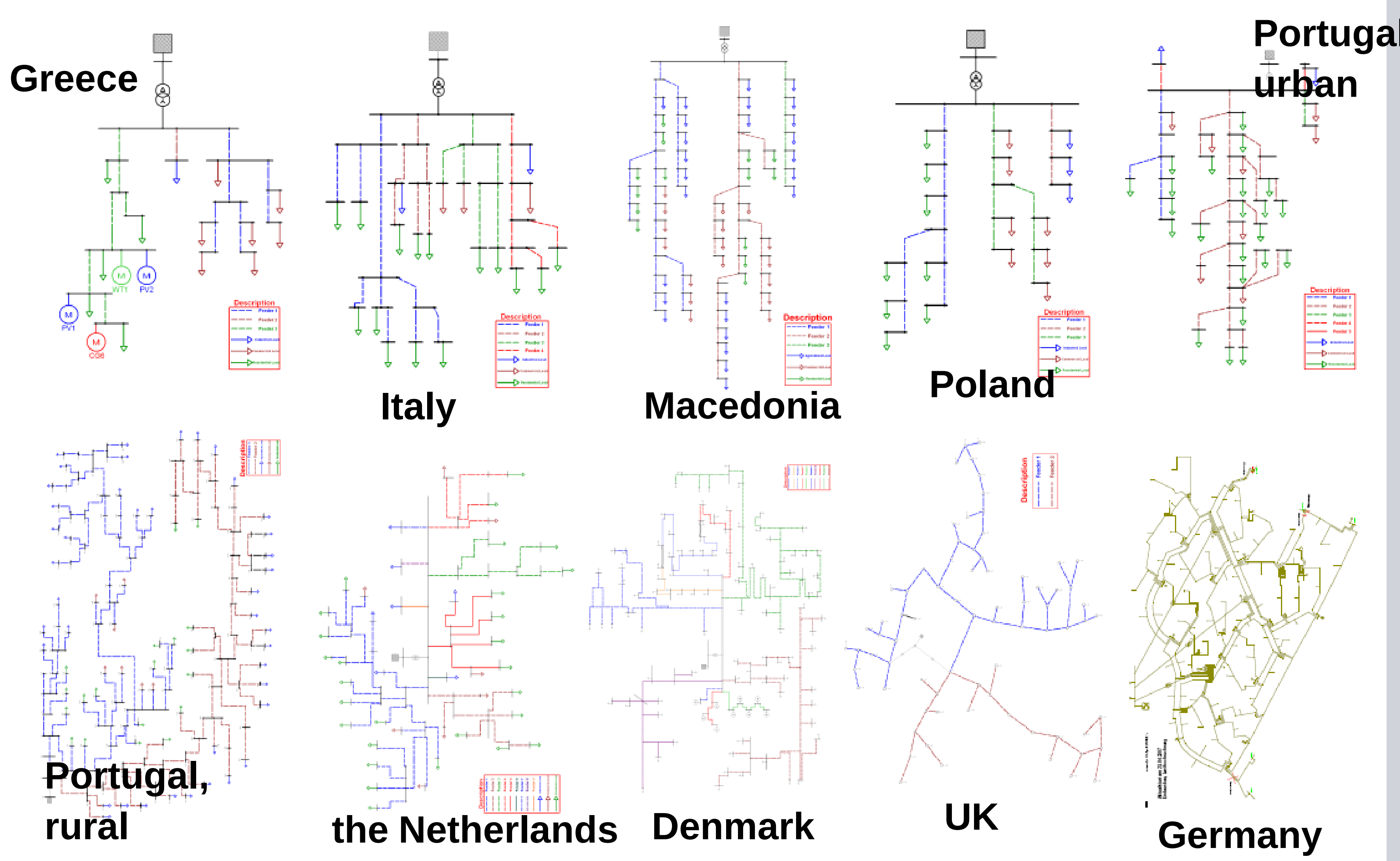
Is local balancing (quasi-islanding) a preferable option for Microgrids?

- Three levels of self-sufficiency can be found with a Microgrid:
  - Level 1: Free Exchange
  - Level 2: Strict Generator or Strict Consumer
  - Level 3: Local Balance (minimizes both import and export)



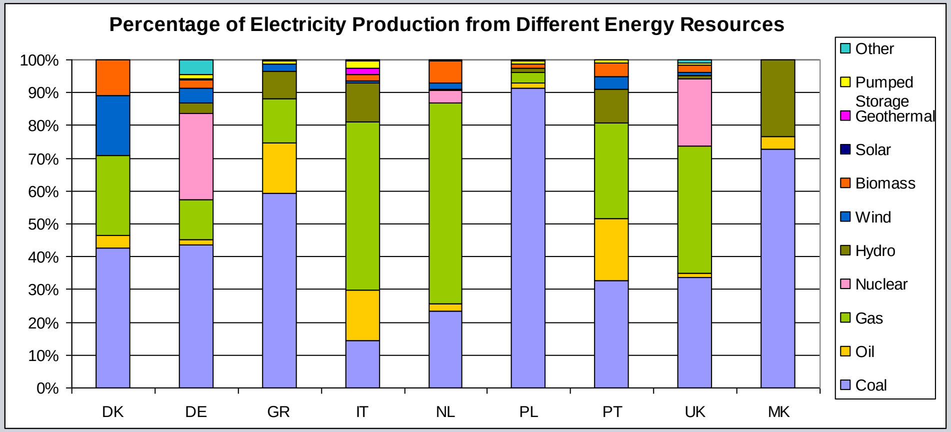
Setup of the European Microgrid Study Framework

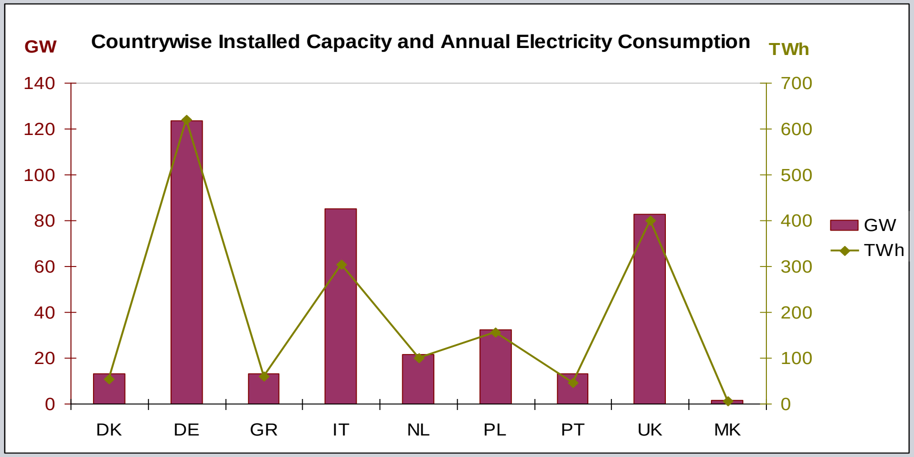
European Network Data Collection
Topology Information

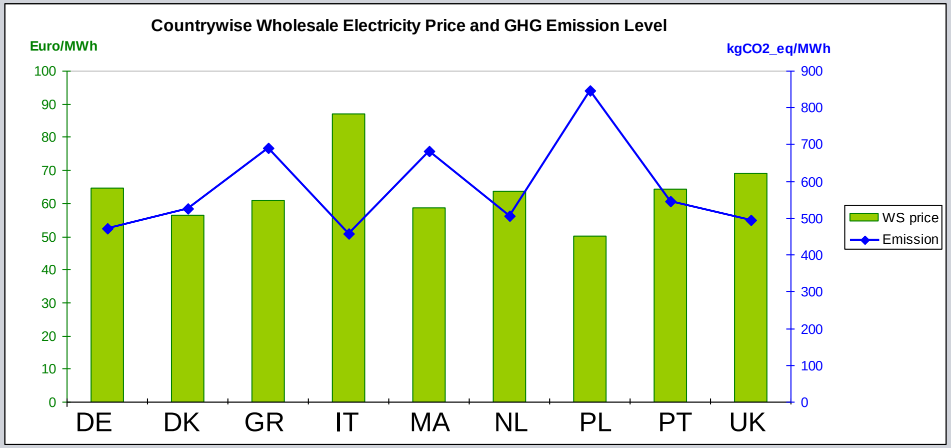


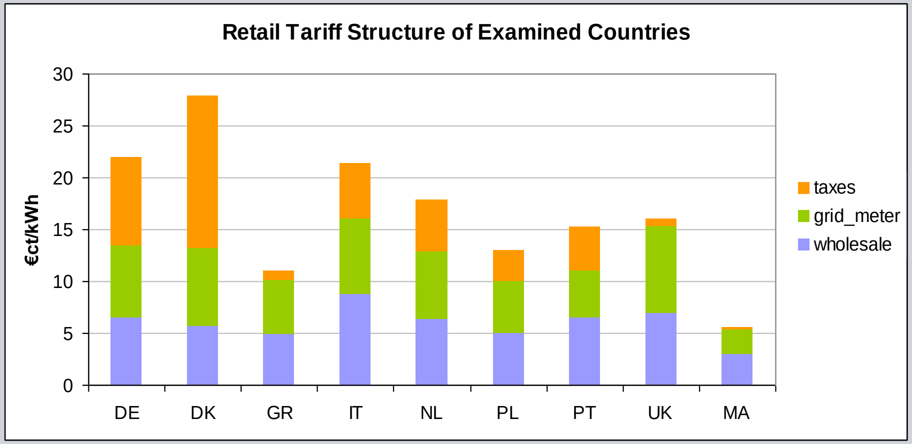
National energetical, economical, and emission data

DK	Denmark	IT	Italy	PT	Portugal
DE	Germany	NL	Netherlands	UK	United Kingdom
GR	Greece	PL	Poland	MA	Macedonia

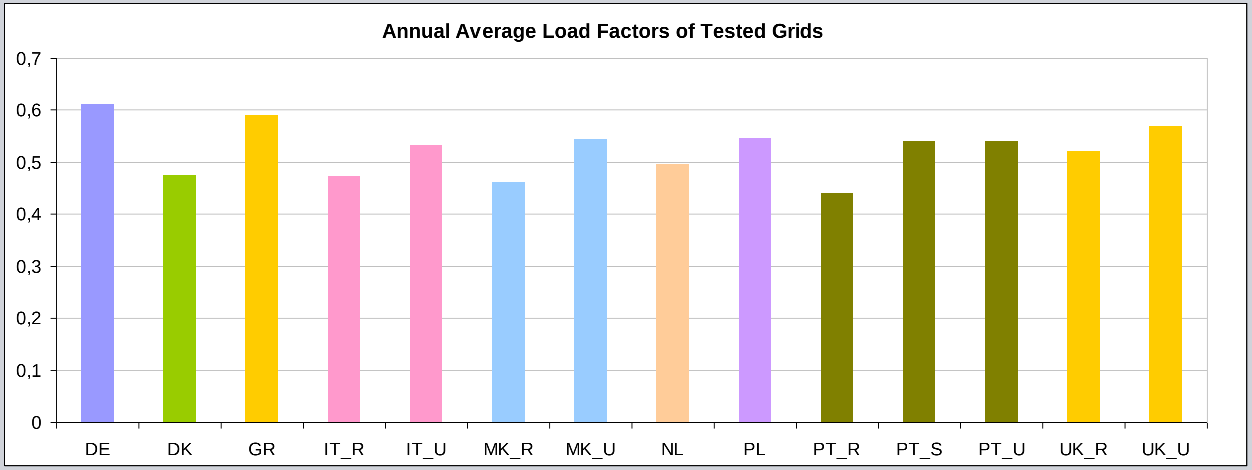


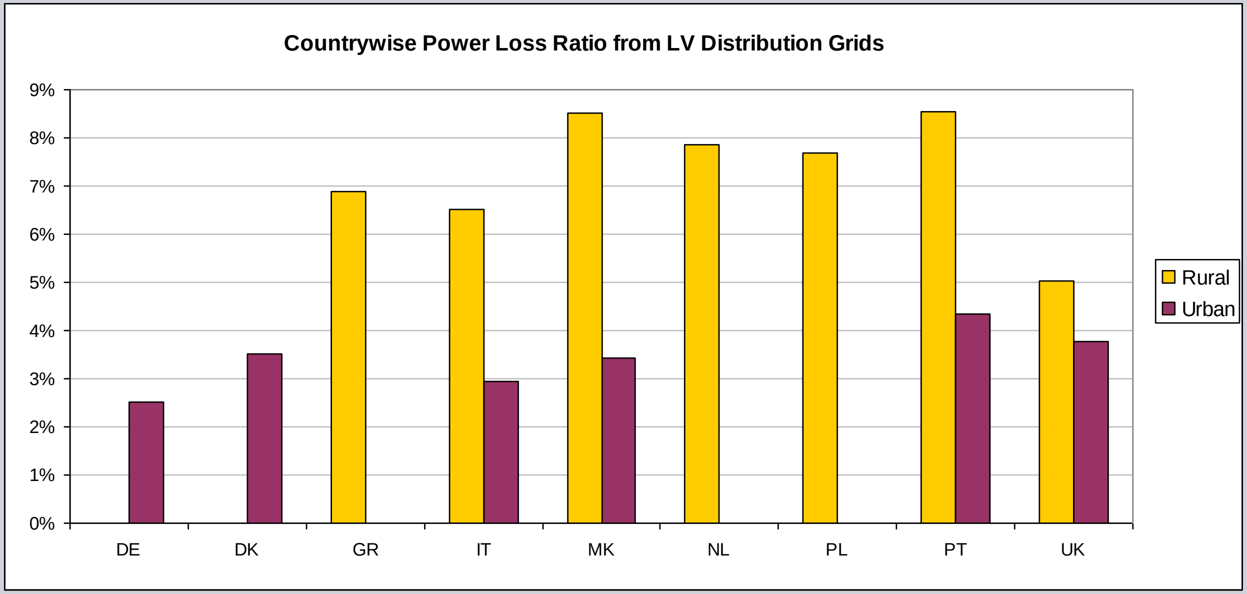




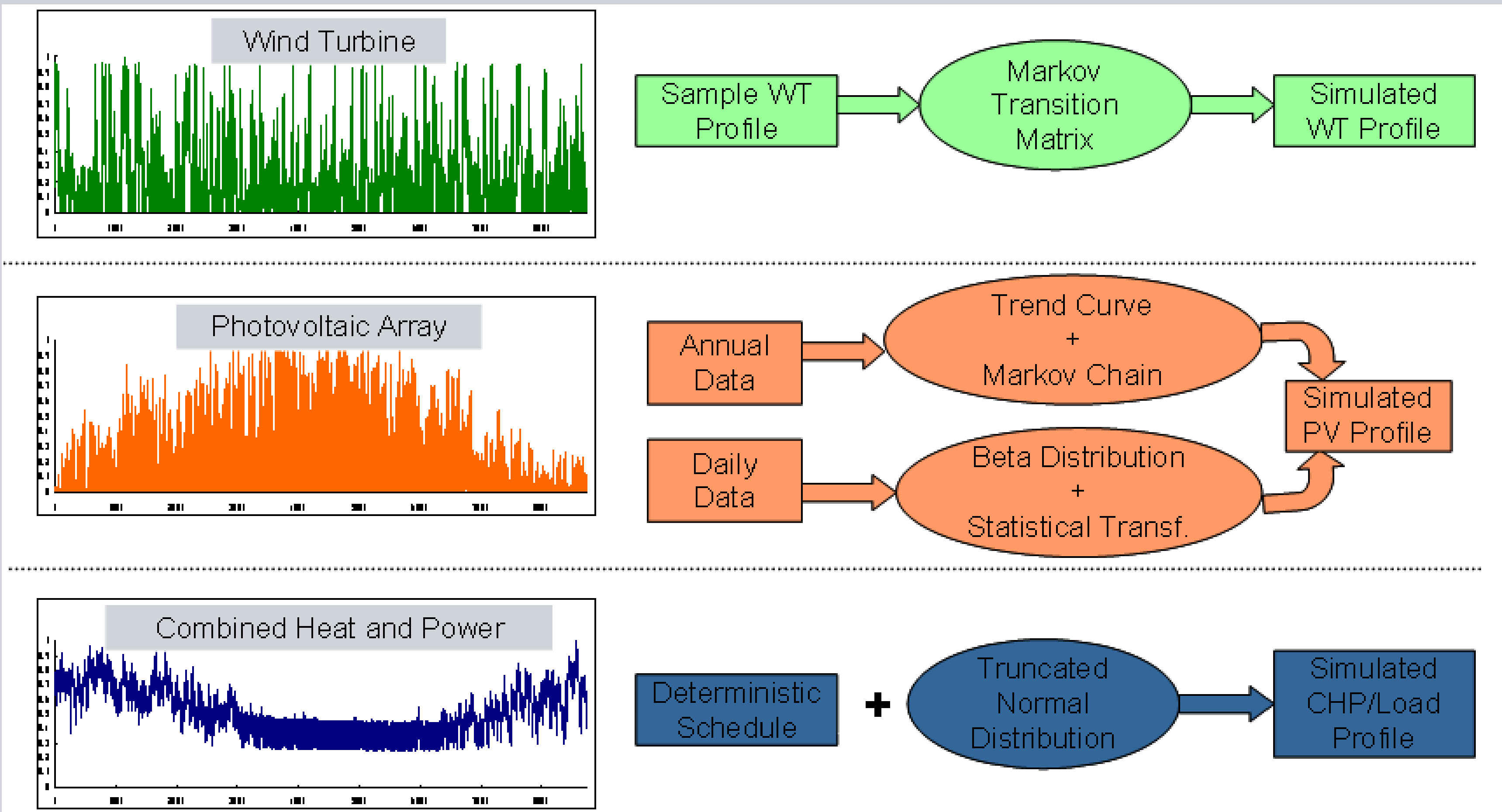


Case Study Network Data

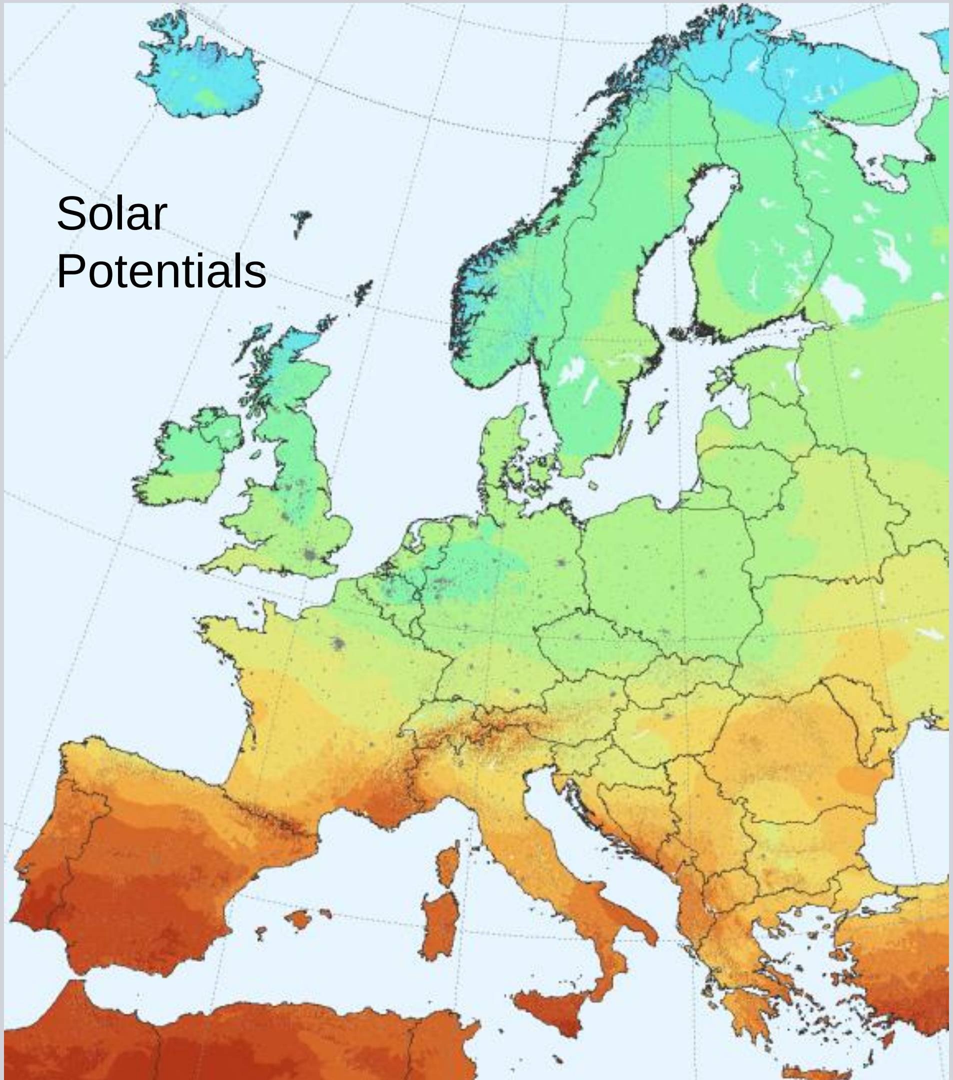


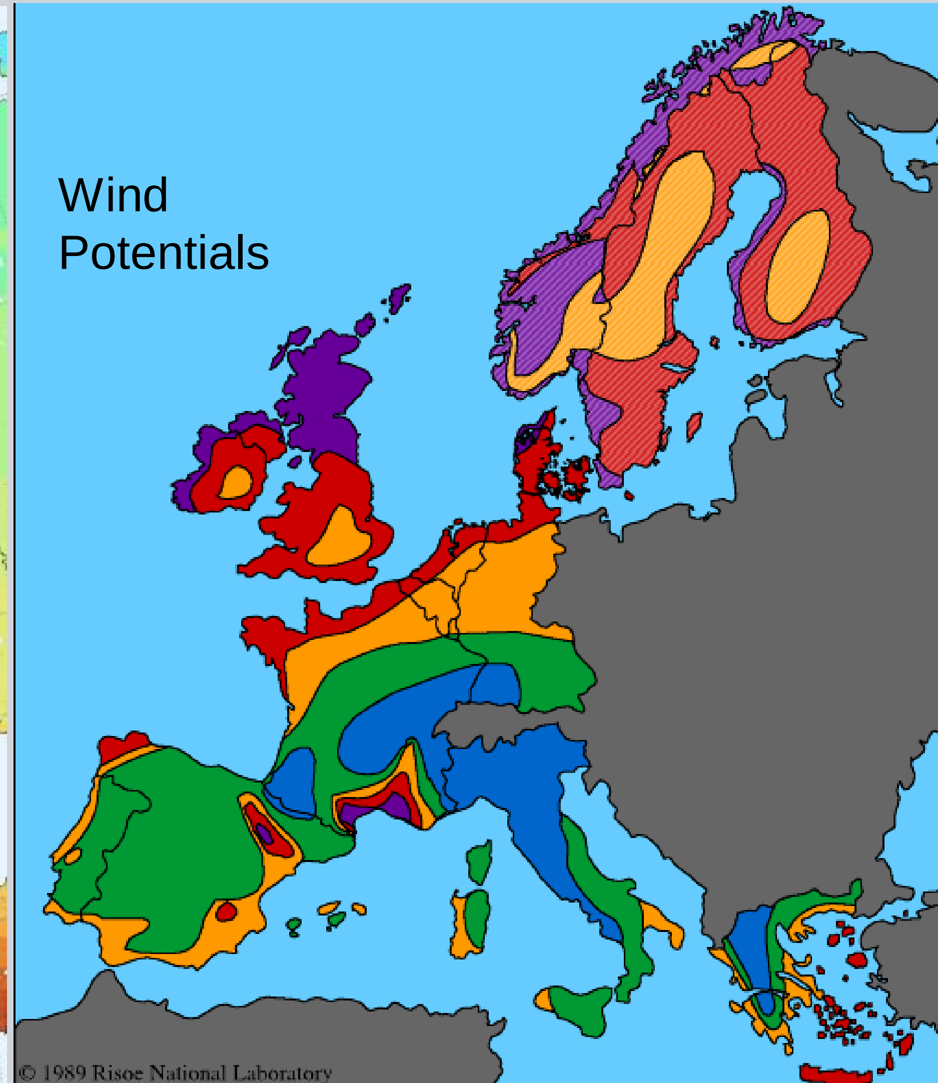


Stochastic Modelling of RES, CHP, and Electricity Markets



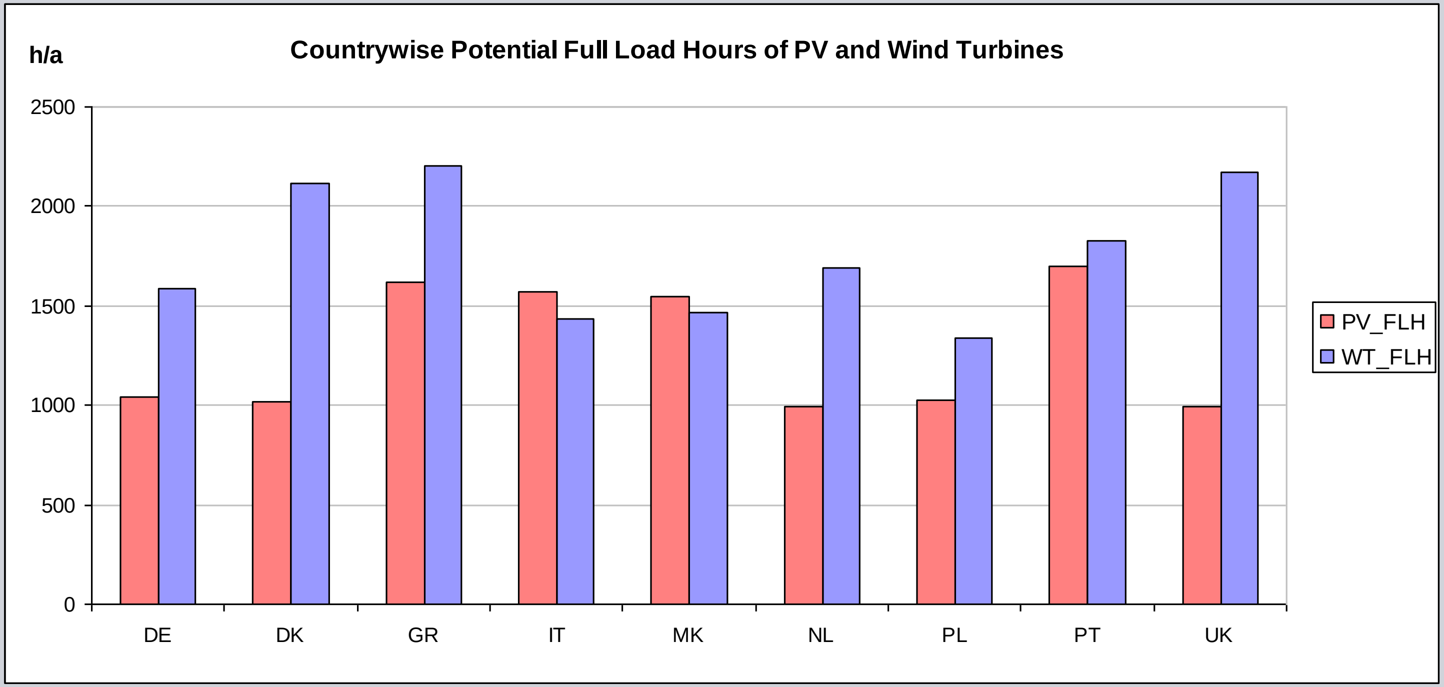
Mapping of European RES Resources





Stochastic Modelling of RES and CHP Output

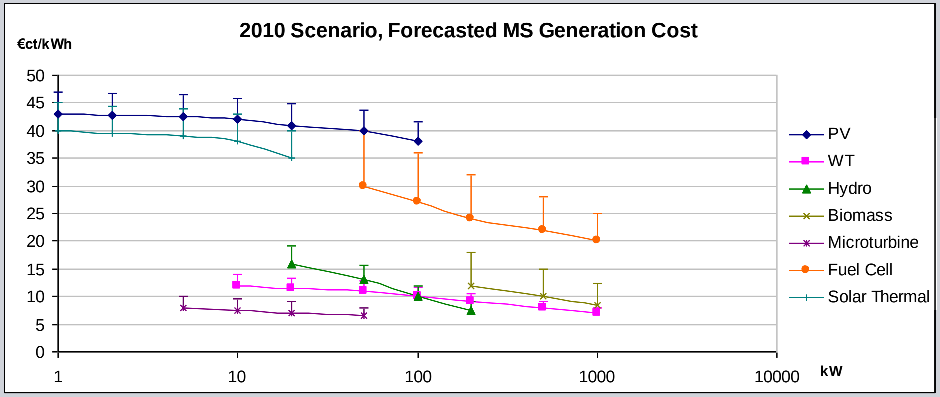
National differences in potential full load hours of PV and WT

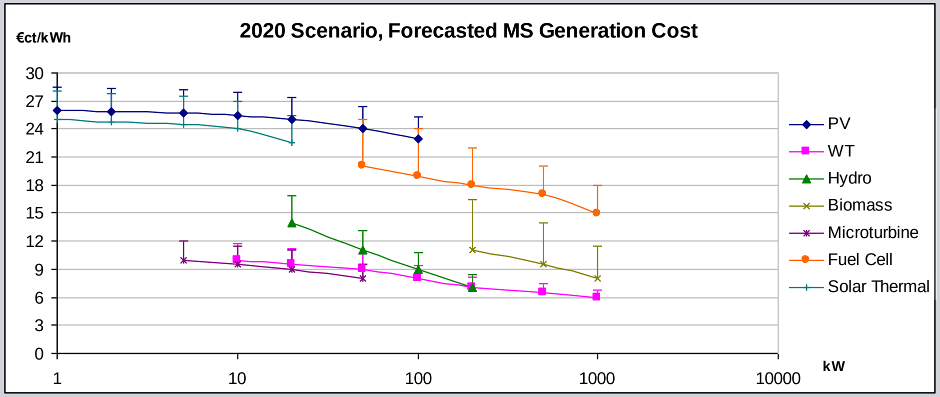


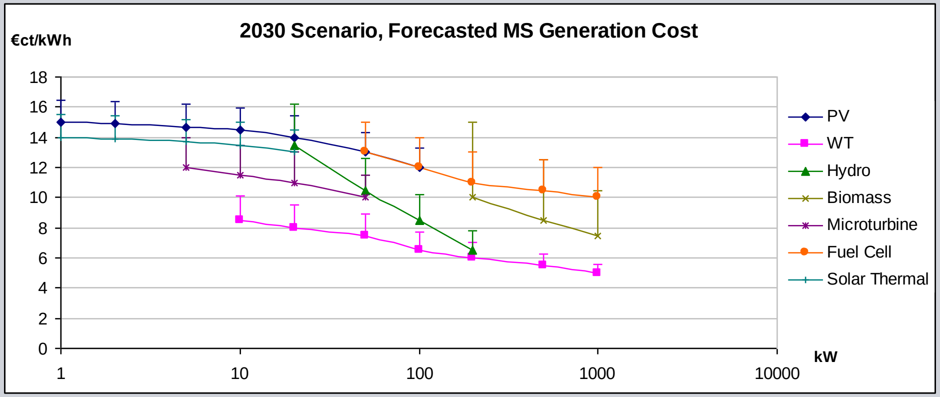
each with a maximum of 50 % performance variation

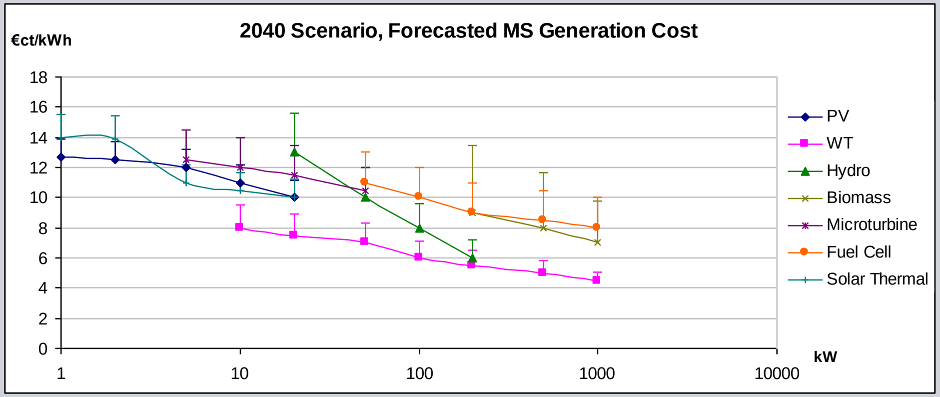
Projected MS Generation Costs

A general convergence of generation costs from different MS technologies has been assumed for the period 2010-2040



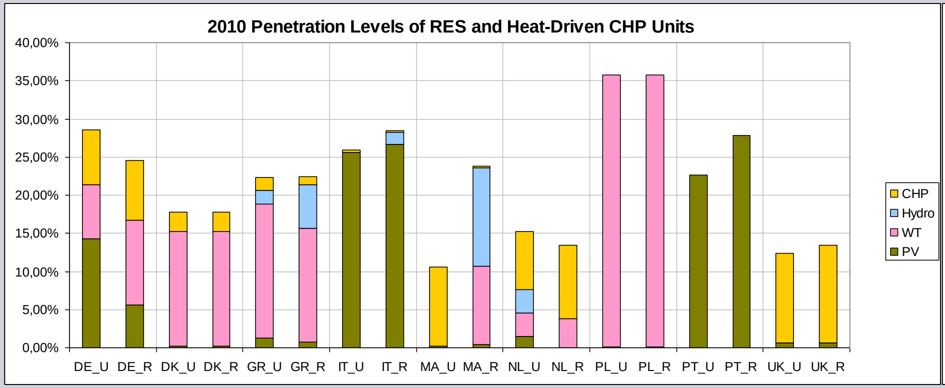


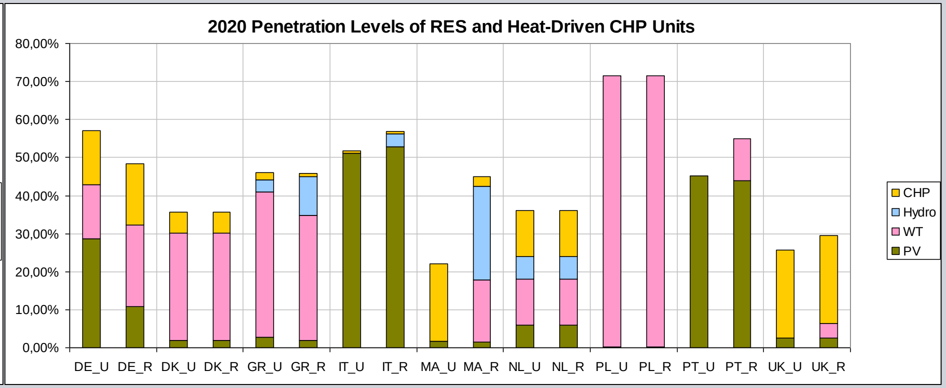


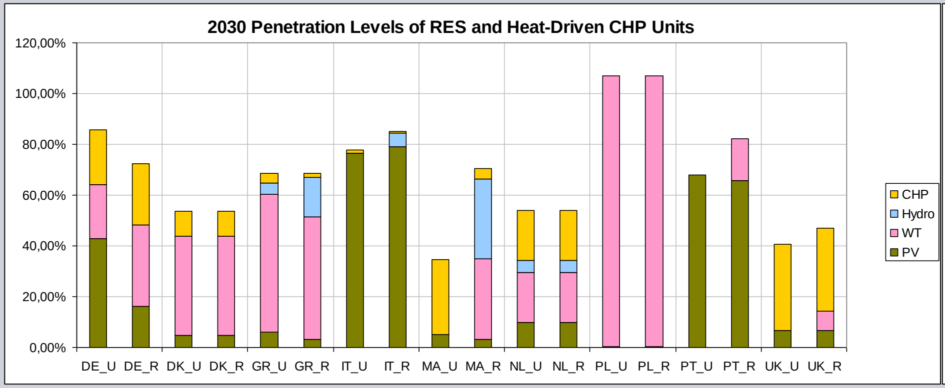


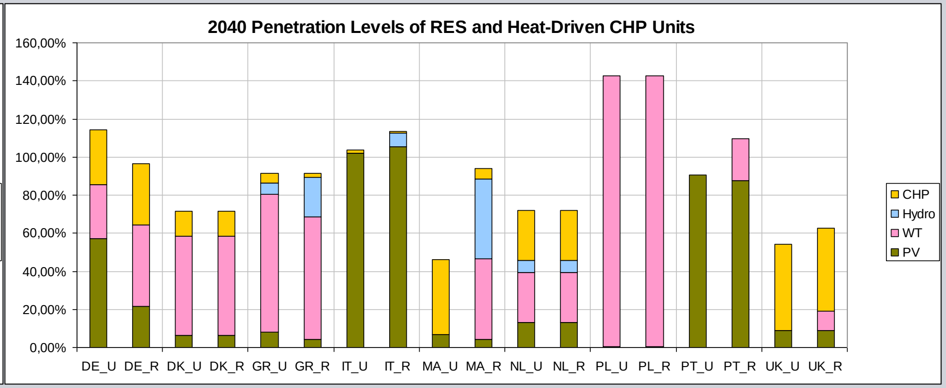
Typical Microgrid Buildups for 2010, 2020, 2030, and 2040 Scenarios

Penetration levels of different MS technologies in examined Microgrids grids (per questionnaire data)



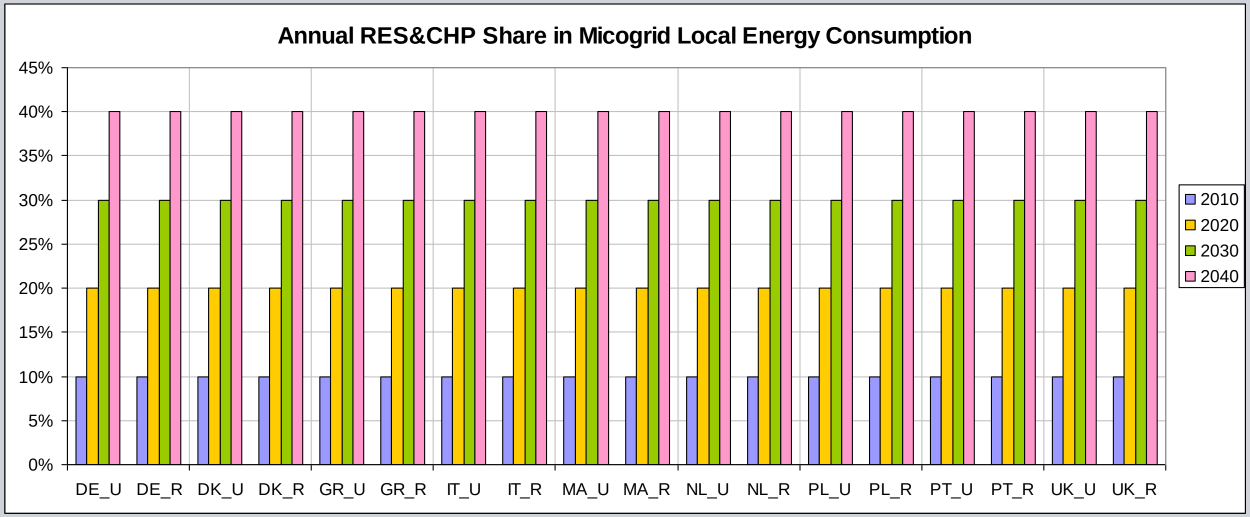




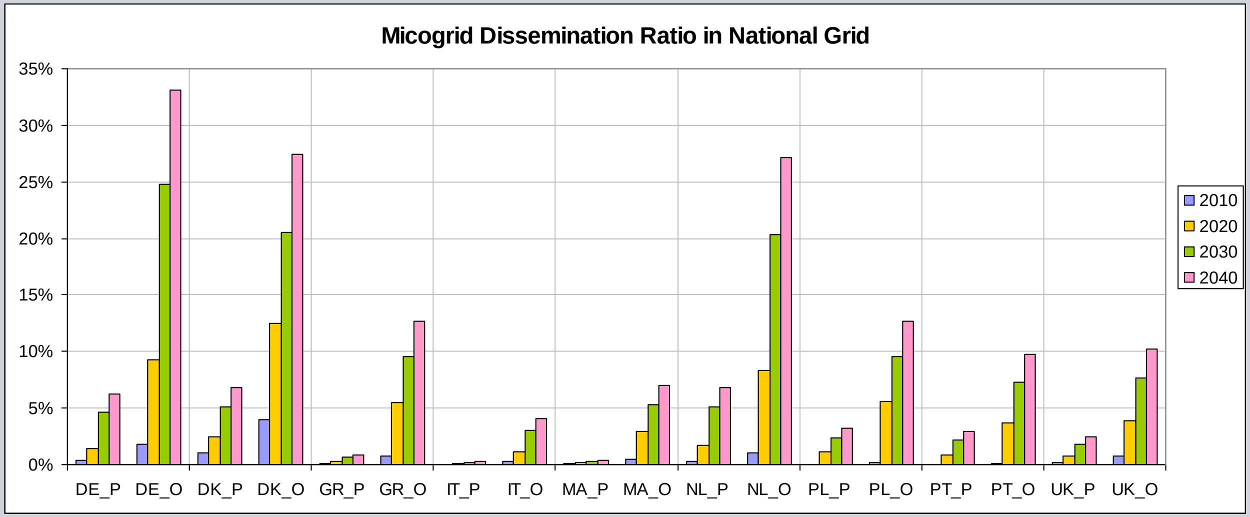


Typical Microgrid Buildups for 2010, 2020, 2030, and 2040 Scenarios

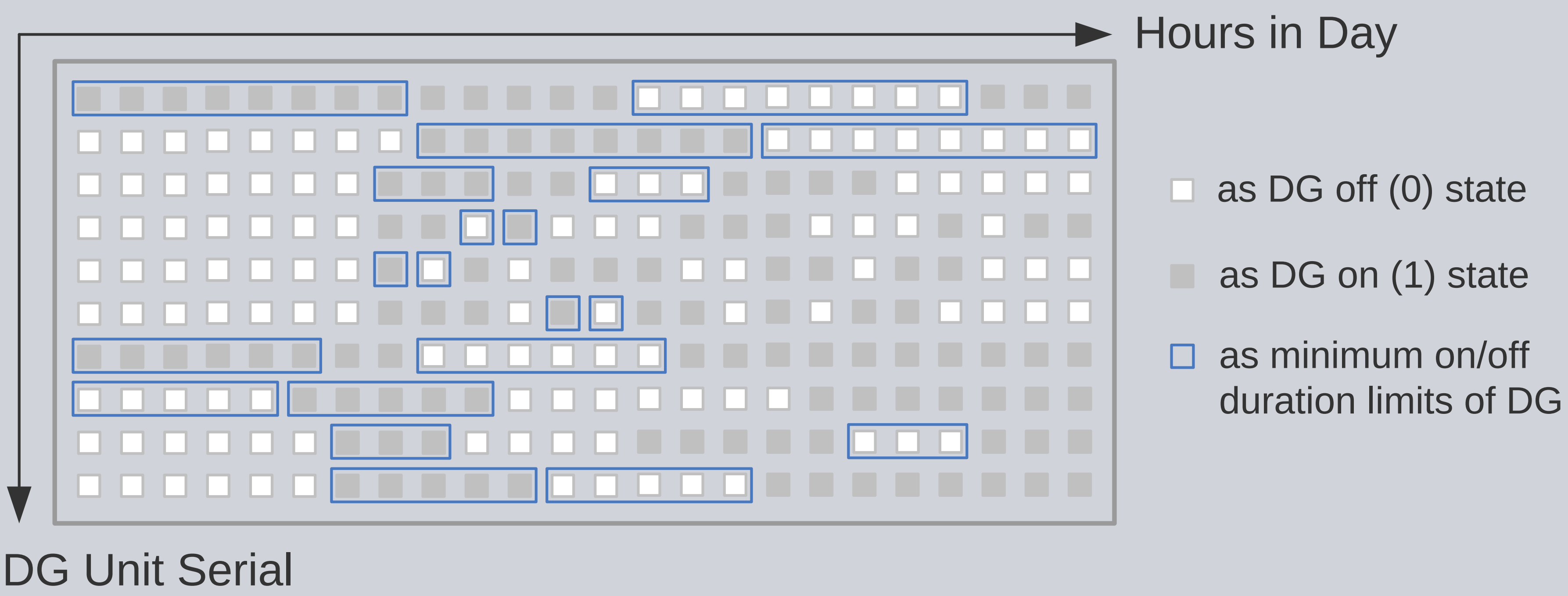
RES and CHP Energy in Annual Local Microgrid Demand



Microgrid Dissemination Ratio in National Grids



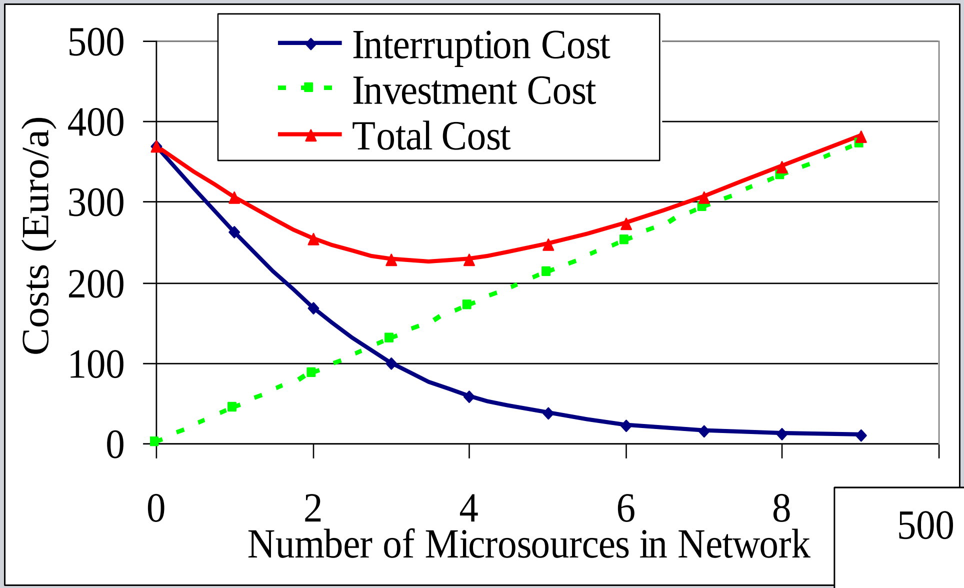
Microgrid Scheduling via Genetic Algorithm and Heuristic Search



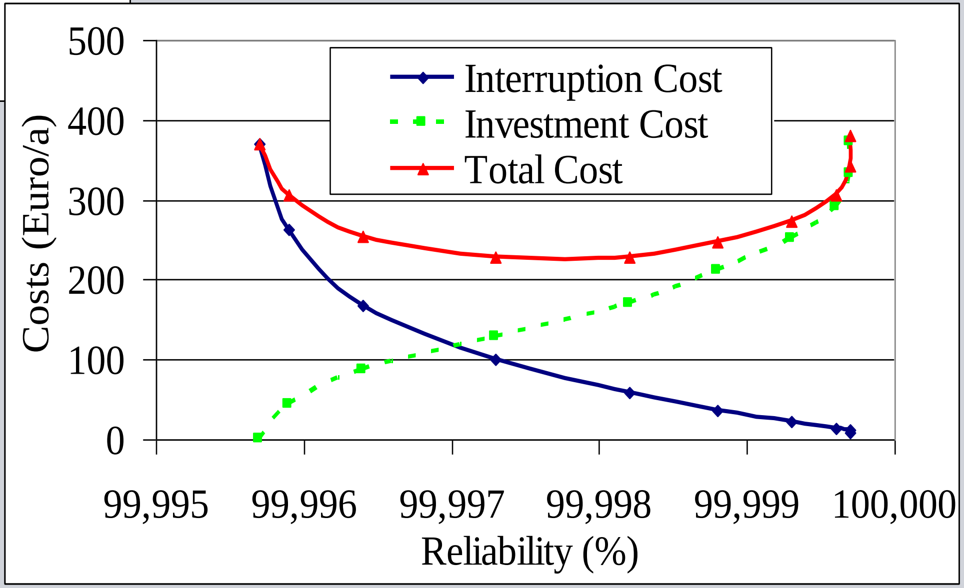
Simulation Results

- Reliability
- Technical, environmental, economic benefits
- Social benefits

Evaluation of Costs for Microgrid Reliability Improvement



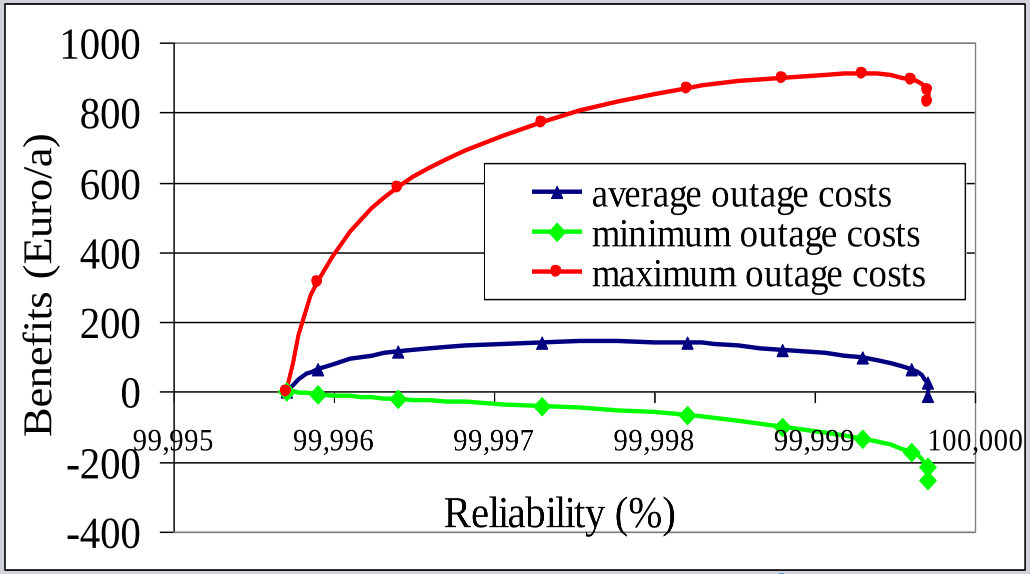
Assumption:
DG availability = 100 %



- Minimum total reliability cost when interruption cost and investment cost arrive at an optimized reliability index!

Economic Benefits from Reliability Improvement under Microgrid operation

Specific interruption costs of customer segments

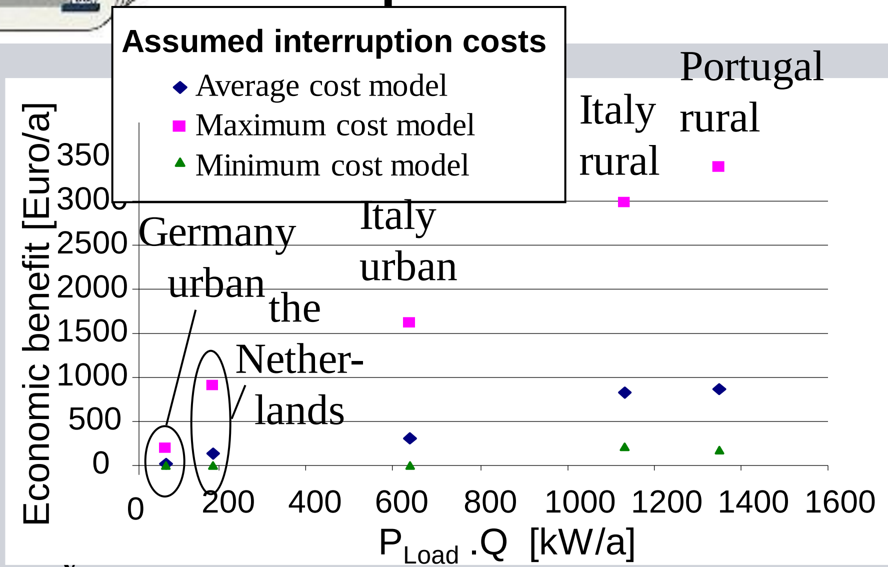


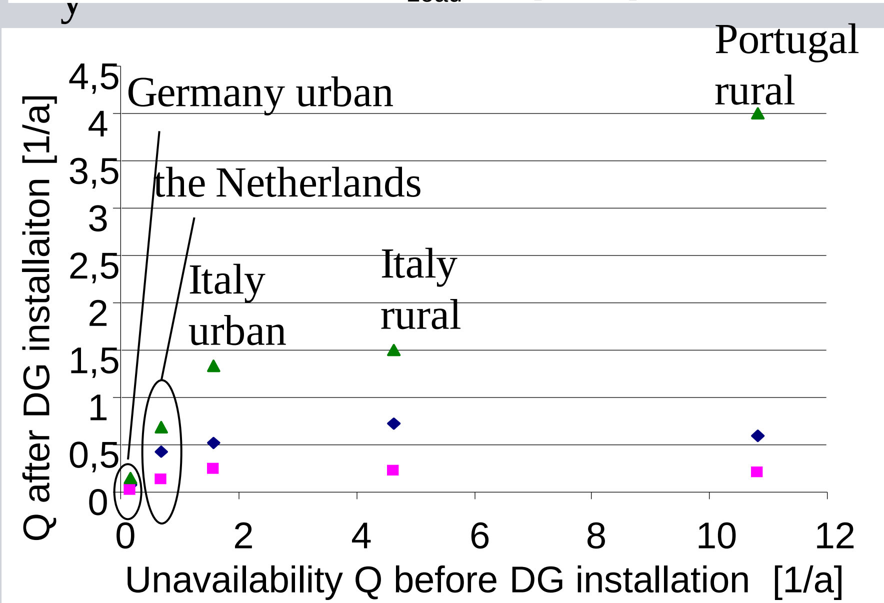
	€/kW	Min €/kWh	Average €/kWh	Max €/kWh
Residential	0	0.5	1.5	5
Agriculture	0.5	2	5	10
Industry	3	5	10	25
Commercial	2	5	10	30

Assumption:
DG availability = 100 %

- Economic benefits due to Microgrid operation concerning reliability strongly increase with increasing customer outage costs; especially for commercial and industrial customer segments

Economic benefits comparison of European countries concerning reliability





- Economic benefit depends on total demand and system unavailability, higher economic benefit is achieved with higher specific interruption cost
- System unavailability in different countries decreases with installed DG penetration, especially when system availability is low
- Optimum DG penetration level increases with raising interruption cost

Simulation Results to evaluate technical, environmental and economic benefits

Variety of impacts needs to be considered for benefits evalution

Standard Test Conditions (STC)

1. *Real-time and directional (flexible) price setting scheme*

2. Mid-level wholesale market price

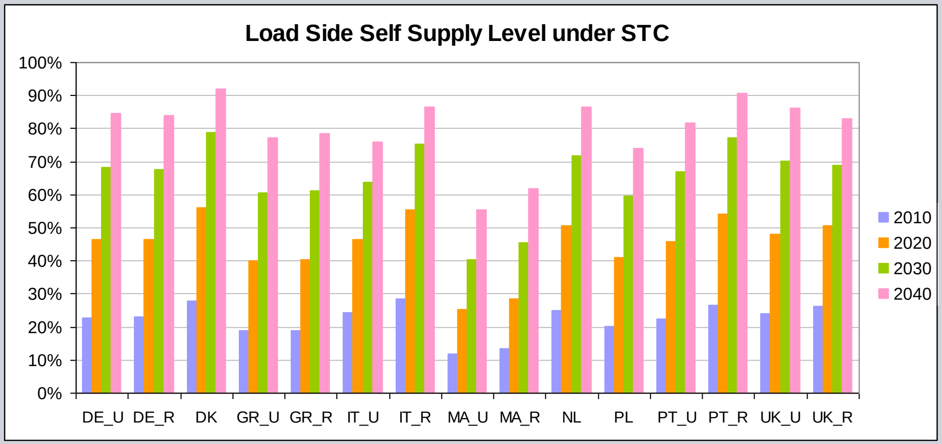
3. Dispatchable MS and Storage/DSM units available

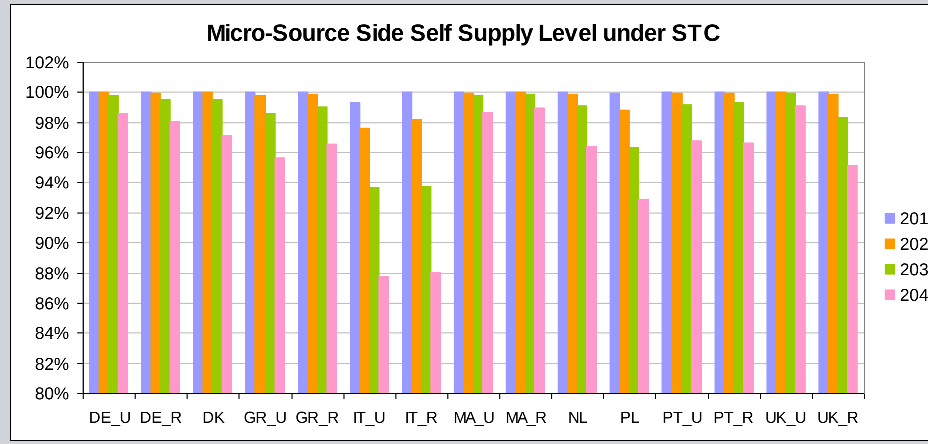
4. Optimal MS unit allocation

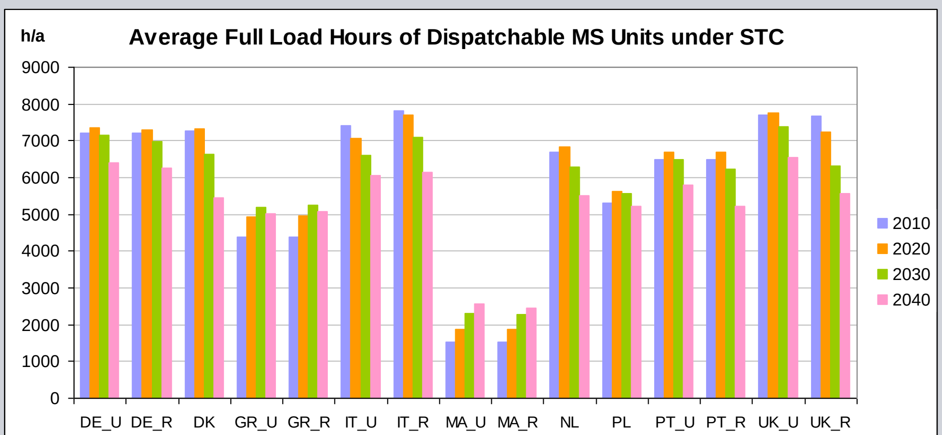
5. Combined operation mode

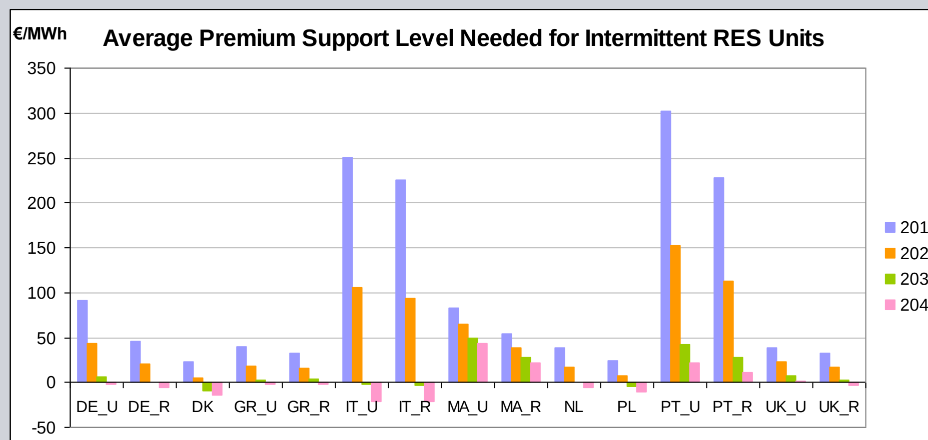
Standard Test Conditions Results: Balancing and Energy Results

- Majority of examined Microgrids are able to supply up to 80%-90% of their own needs by 2040;
- Full load hours of dispatchable MS units are closely linked to national electricity price levels;
- Most countries are able to withdraw from RES financial support schemes by 2030 or 2040;





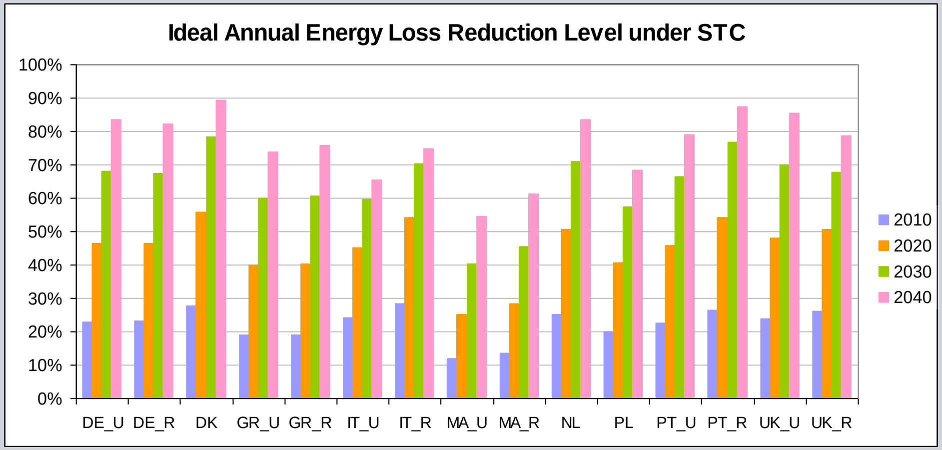


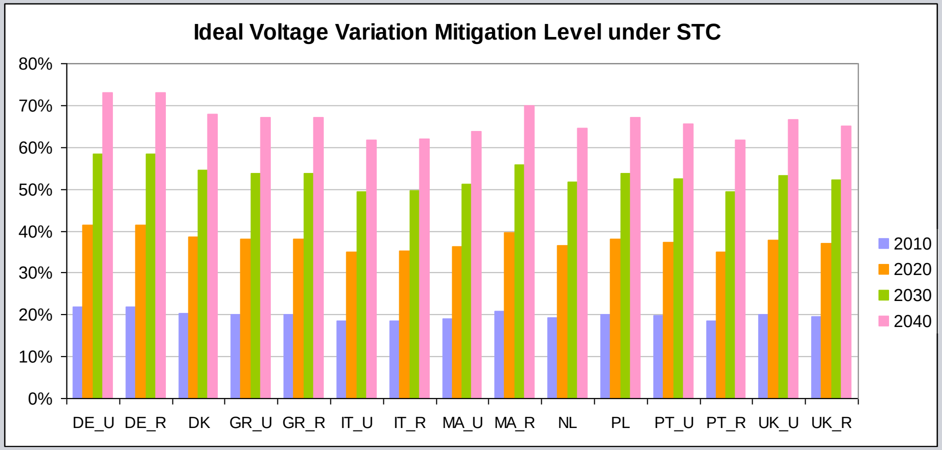


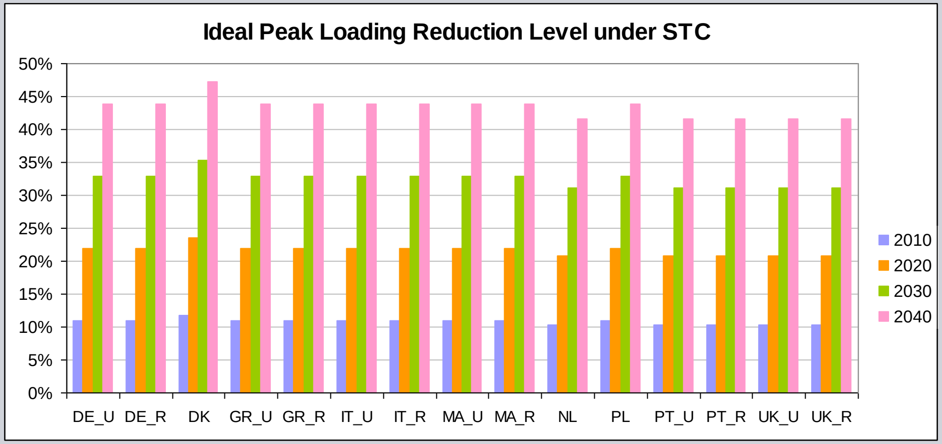
Standard Test Conditions Results: Technical Benefits

• The potentially extractable technical benefits (i.e. optimal MS allocation) from Microgrids seem to be highest for loss reduction, followed by voltage regulation, and peak load support ranks last.

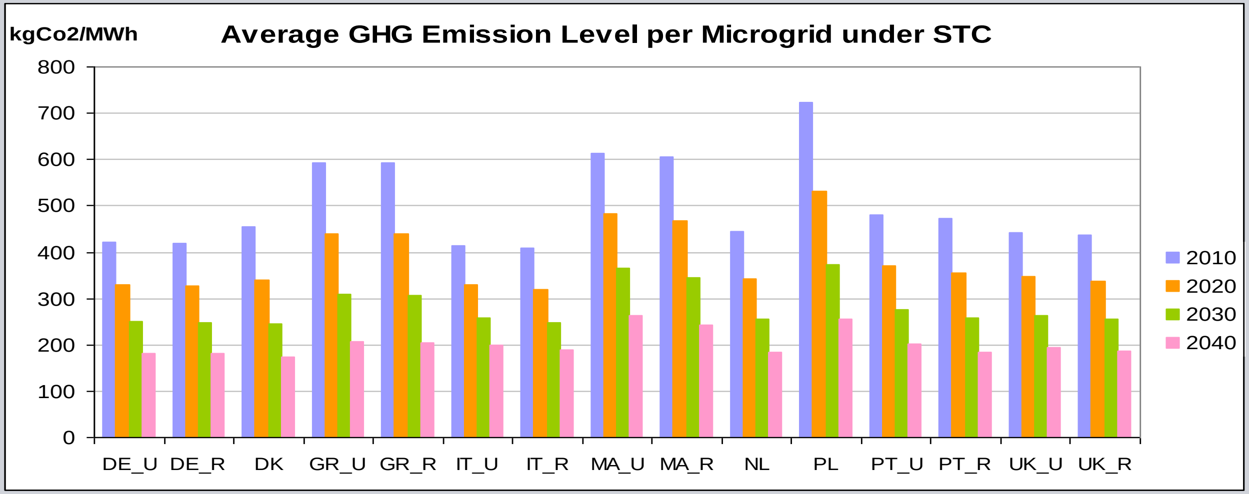
• This is due to assumed large intermittent RES shares compared to dispatchable MS units.

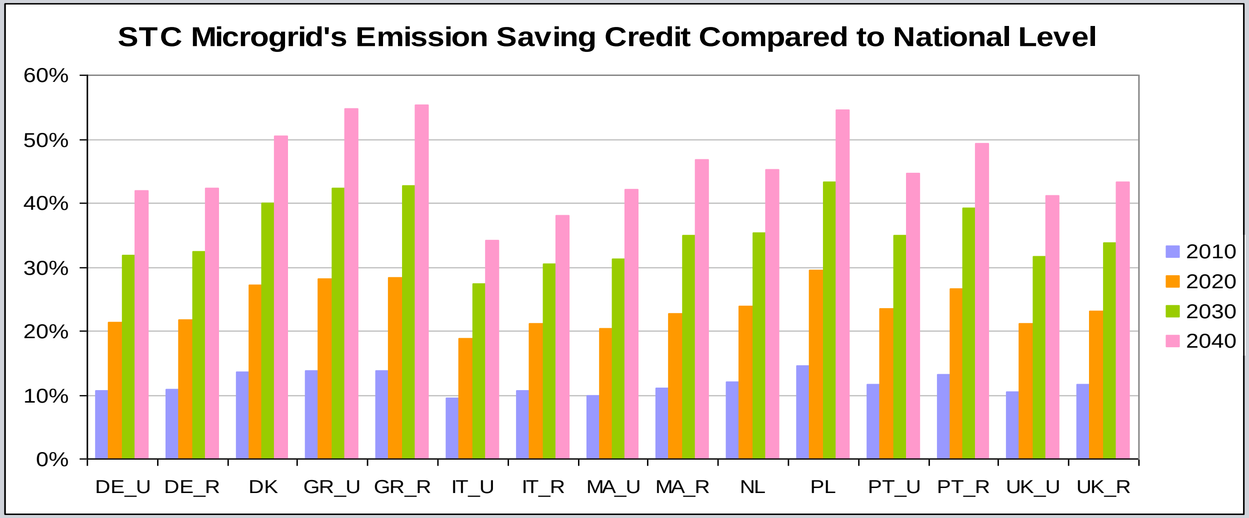






Standard Test Conditions Results: Environmental Benefits





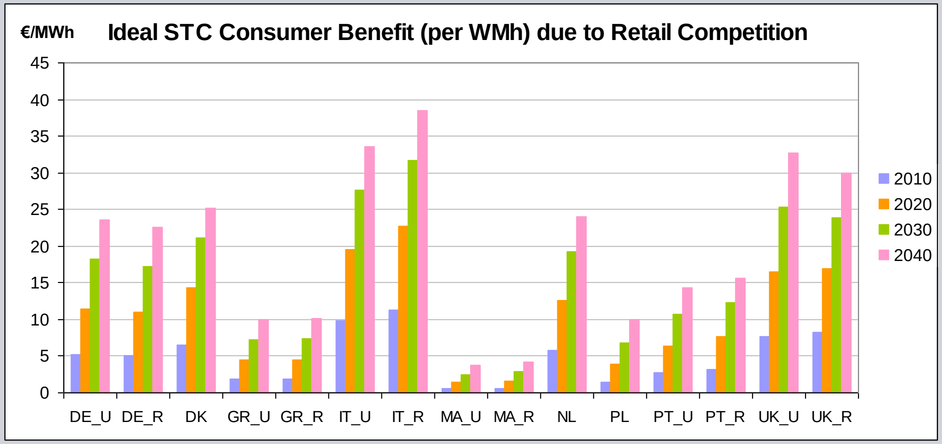
- A general convergence of Microgrid GHG emission level to around 200 kg (CO_2 eq)/MWh by 2040 despite very different starting points in 2010

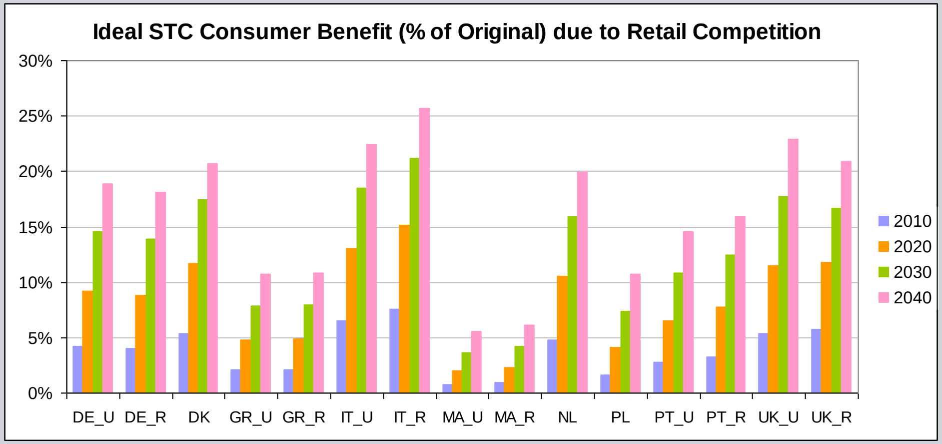
- Countries started with high emission levels could expect reduction credits as high as over 50%, while countries with lower initial figures find comparatively smaller credits by 2040.

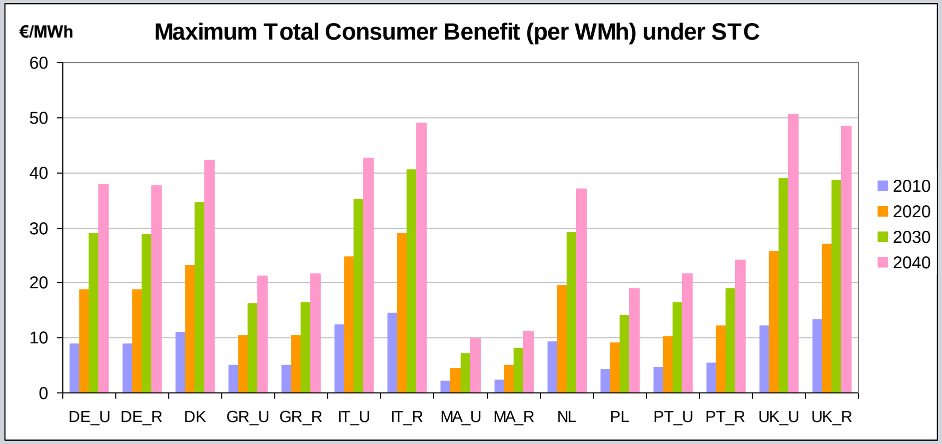
Standard Test Conditions Results: Economic Benefit on Consumer Side

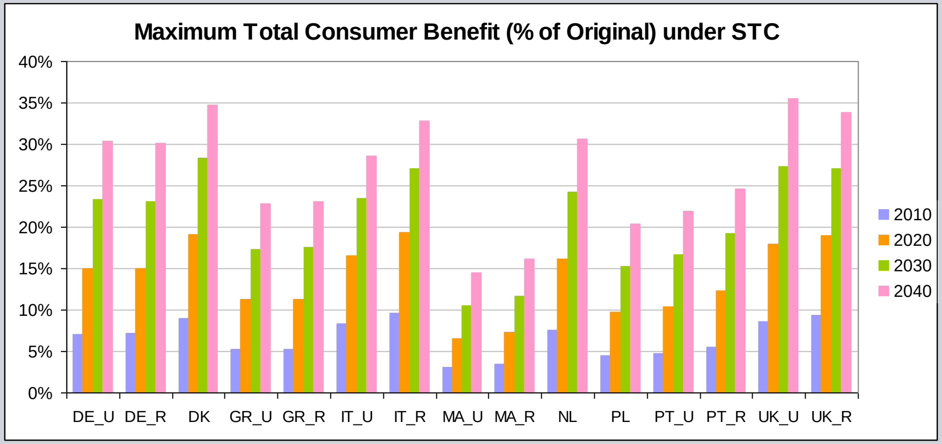
• Load side selectivity benefit level can be seen as extremely sensitive to national electricity prices

• The majority of maximum total consumer benefit results points to a potential cost saving range from 7% ± 5% in 2010 to 25% ± 10% in 2040 (assuming zero MS profit)



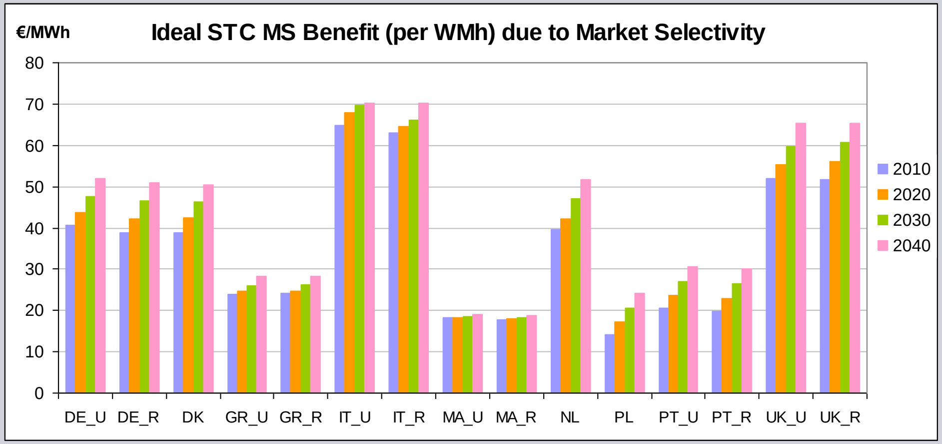


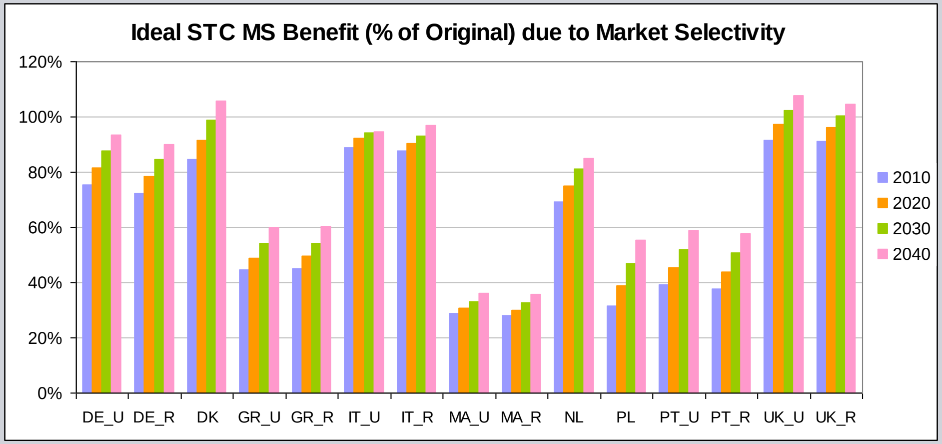


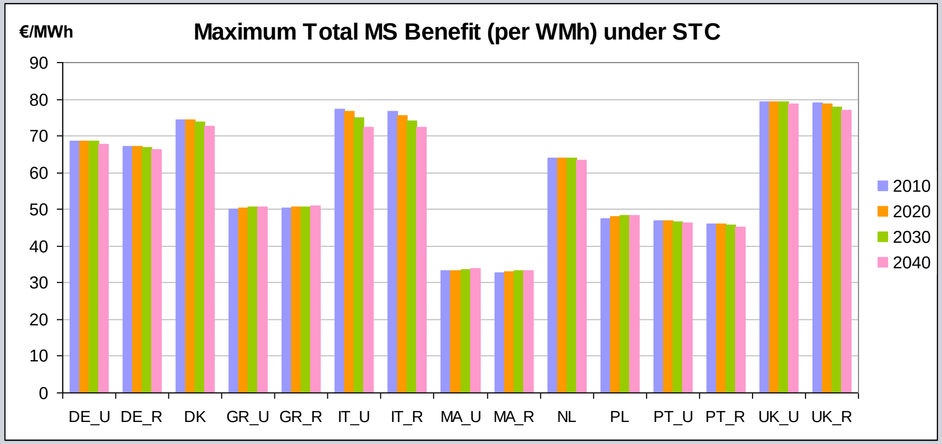


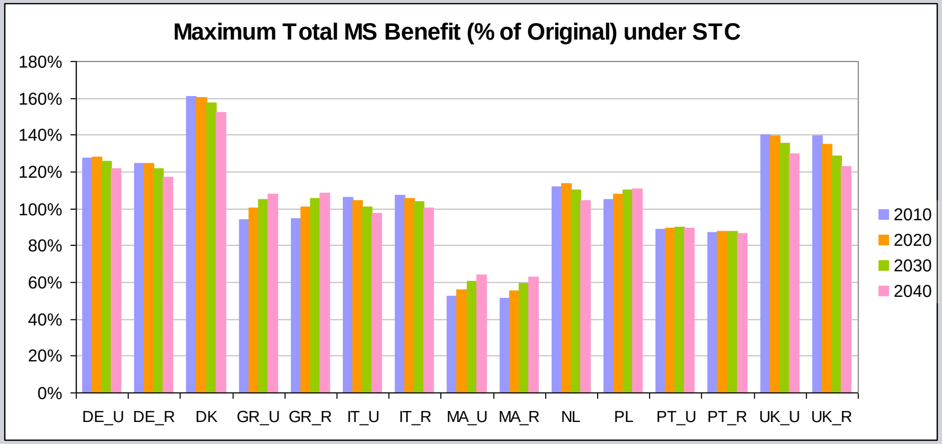
Standard Test Conditions Results: Economic Benefit on MS Side

- Maximum MS profit is closely linked to retail market price level, which yields high profits at 60-70 €/MWh for high-price countries and much lower results around 20 €/MWh for low-price countries
- Maximum total MS benefit stays largely constant despite scenario variations



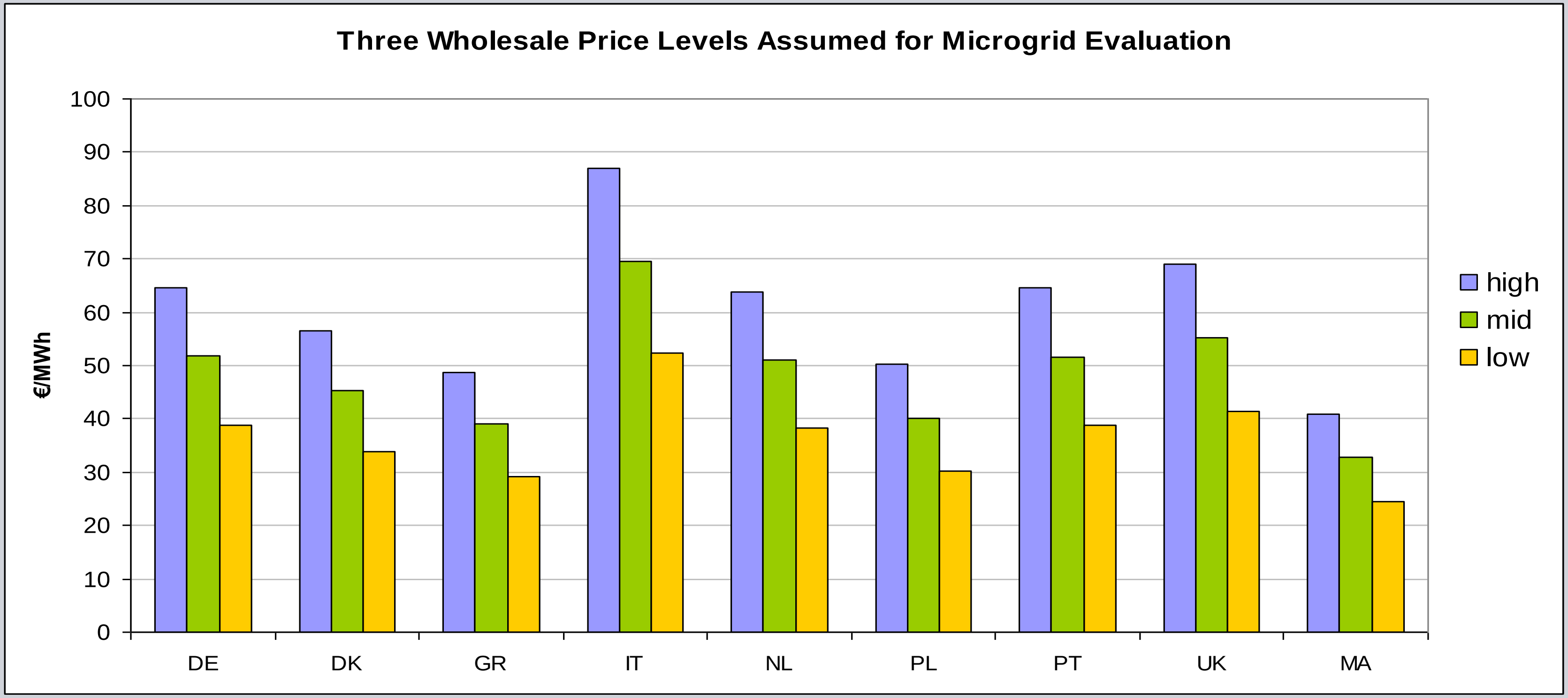




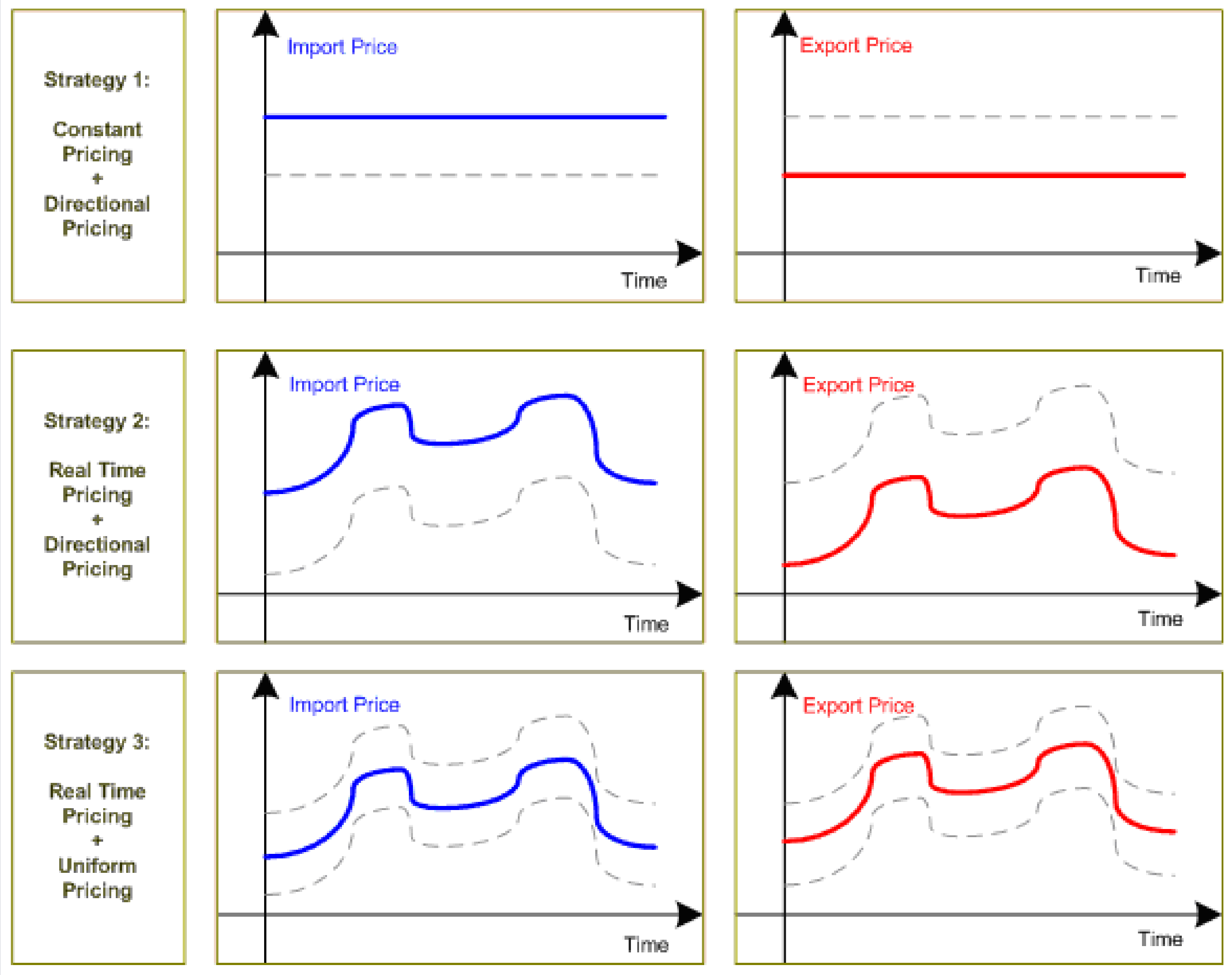


Simulation Results to evaluate technical, environmental and economic benefits

Sensitivity Analysis 1: Wholesale Market Price Level

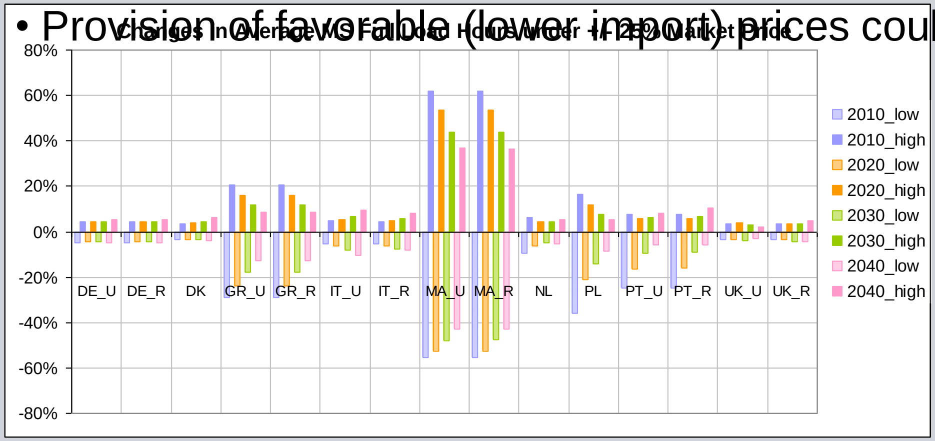


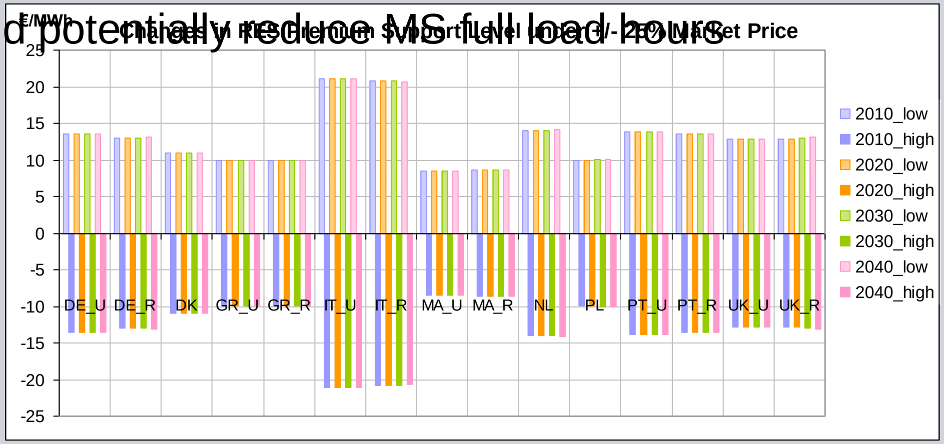
Sensitivity Analysis 2: Wholesale Market Price Level

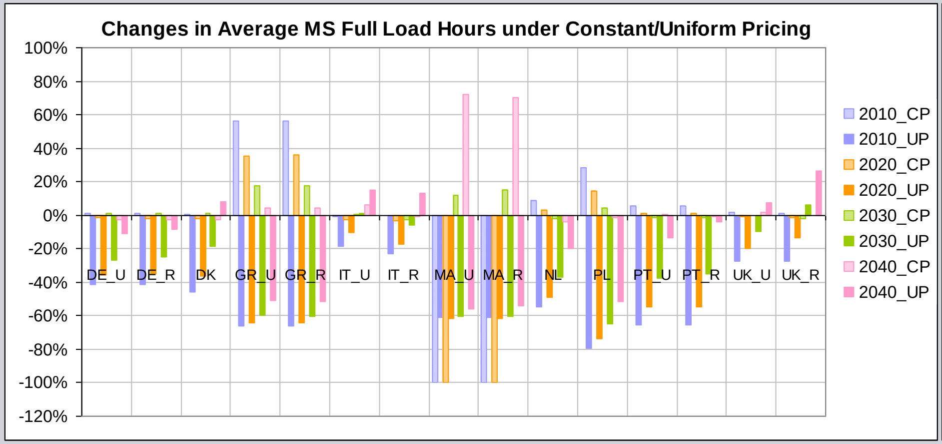


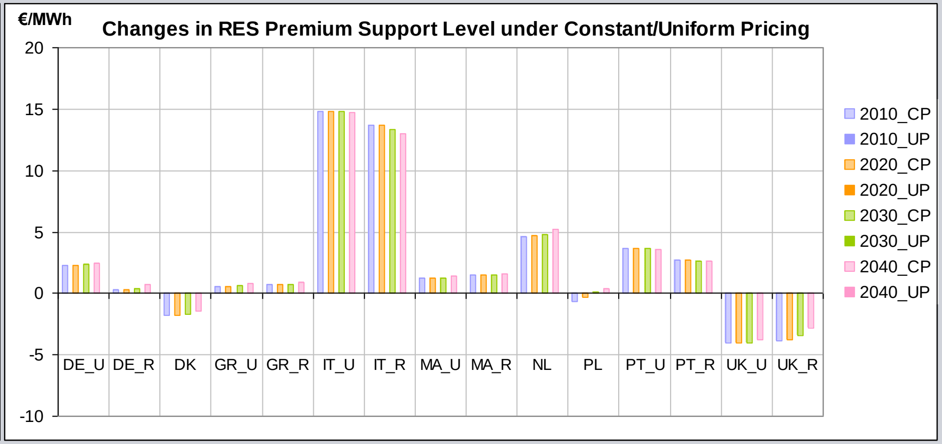
Sensitivity Analysis: Balancing and Energy Results

- Market price reduction always reduces MS full load hours, low-price countries are more sensitive
- Constant pricing could potentially increase MS full load hours but can also lead to zero MS usage
- Provision of favorable (lower import) prices could potentially reduce MS full load hours





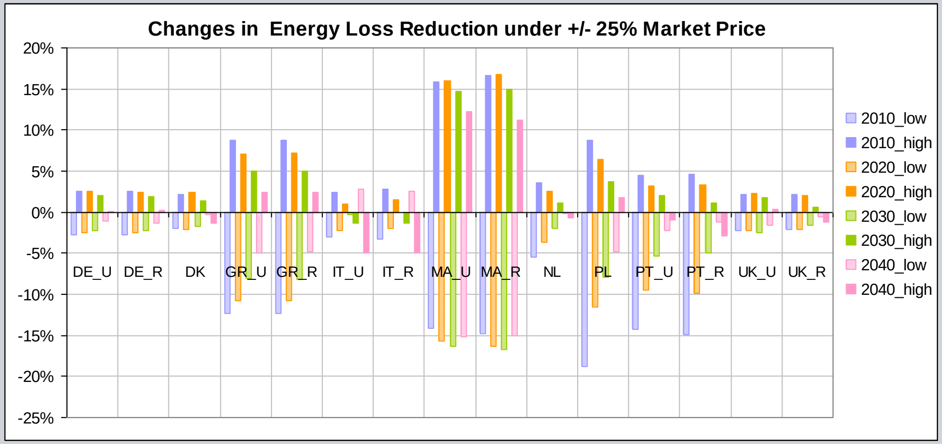


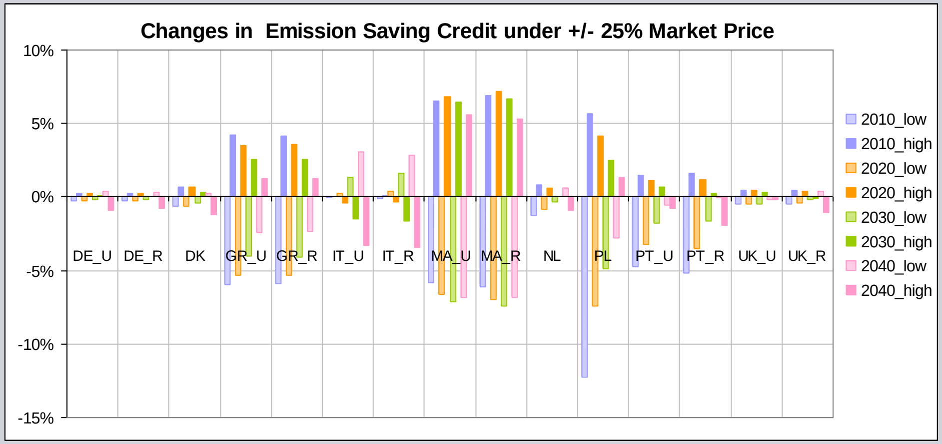


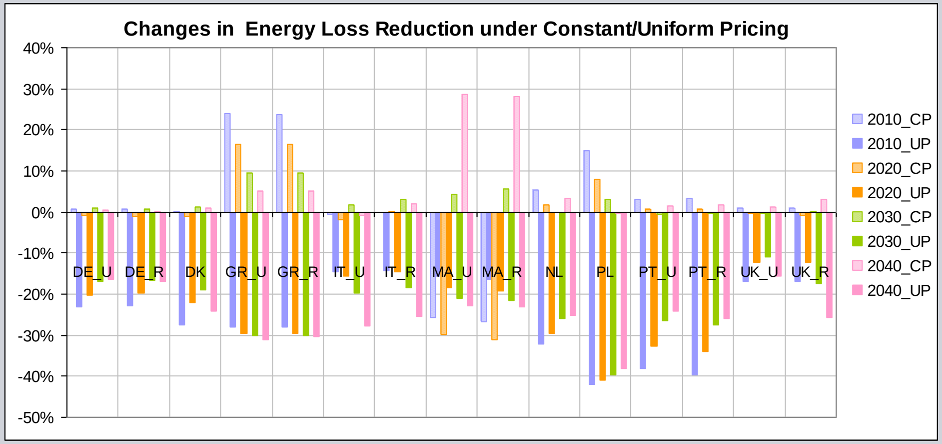
Sensitivity Analysis : Technical and Environmental Benefits

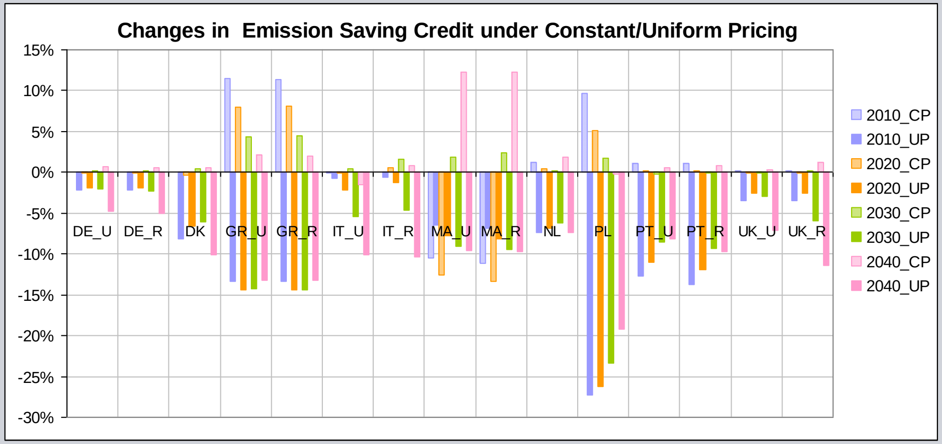
• Voltage and loading related technical performance criteria are instantaneous in nature and thus not affected by pricing levels or scheme, loss reduction credit is closely linked to self supply level

• Both pricing level and pricing scheme have small (< ±10%) impacts on emission reduction credit



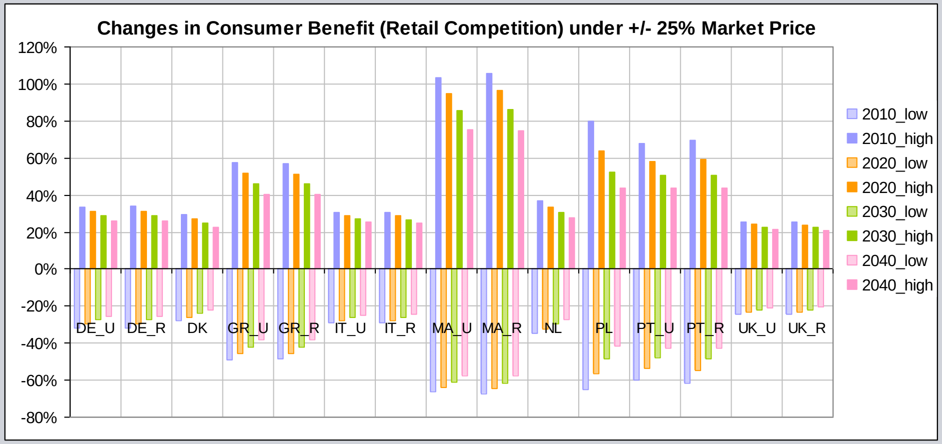


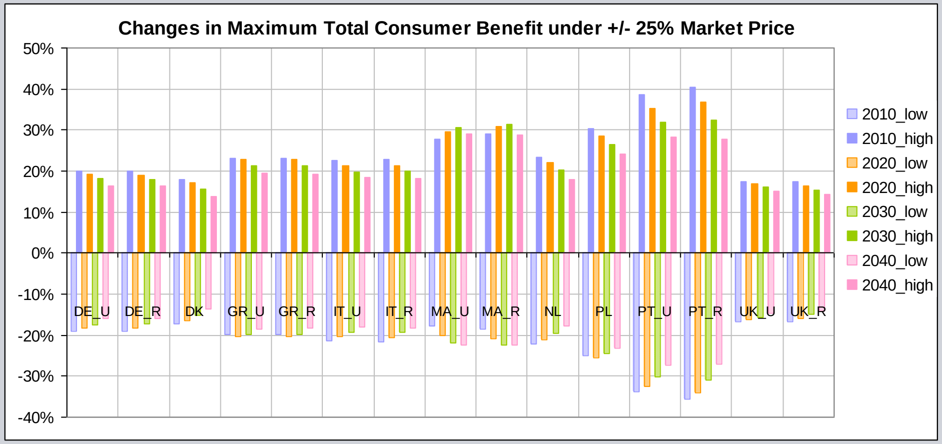


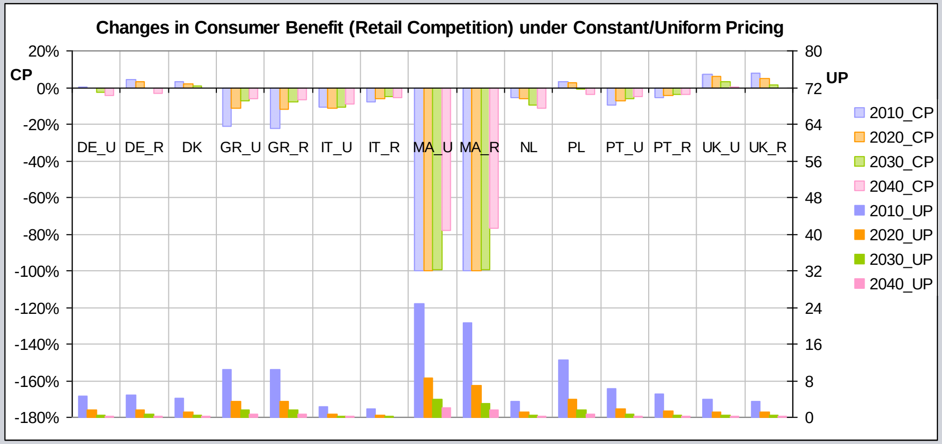


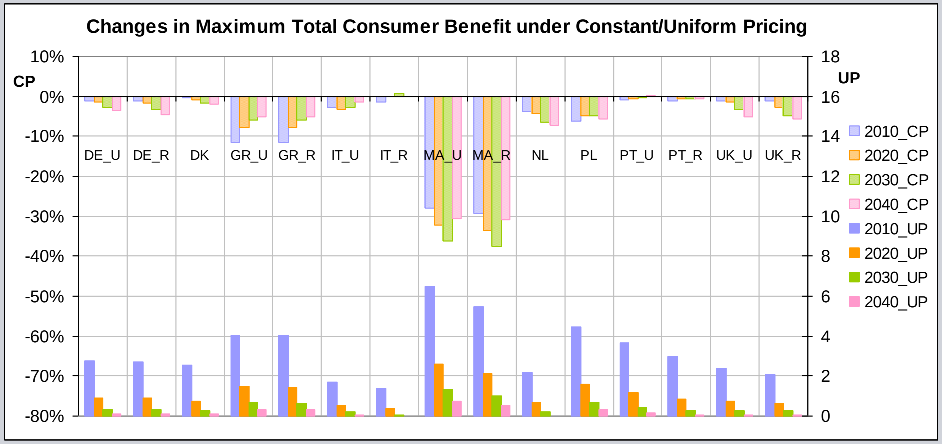
Sensitivity Analysis :
Economic Benefit on Consumer Side

- Introduction of favorable prices (import and export) could drastically improve selectivity benefit on consumer side under low-MS scenarios, such effects are much weaker as MS share goes up
- Wholesale price level has a moderate impact (20%-40%) on maximum total consumer benefit



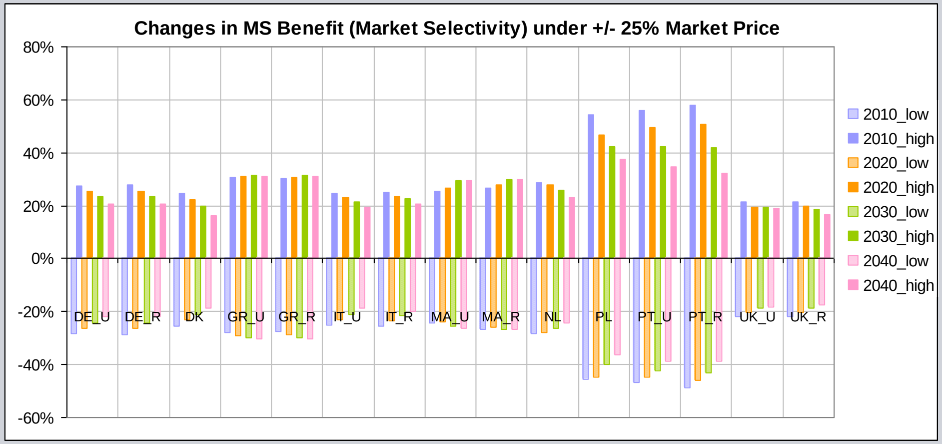


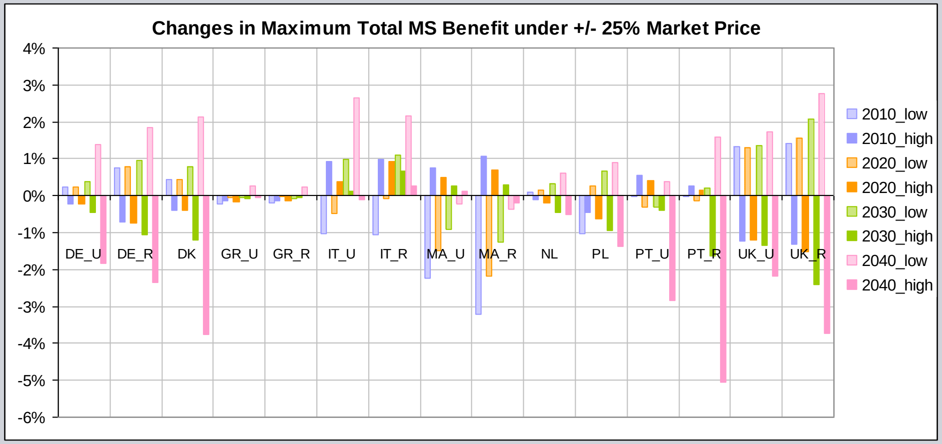


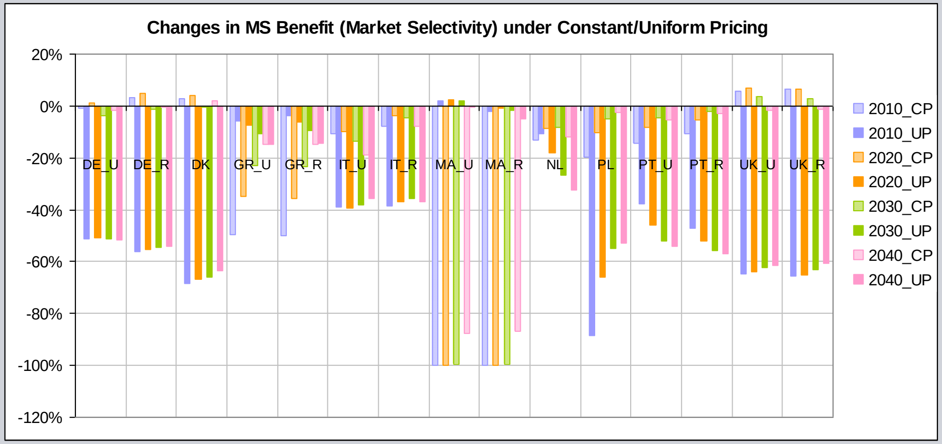


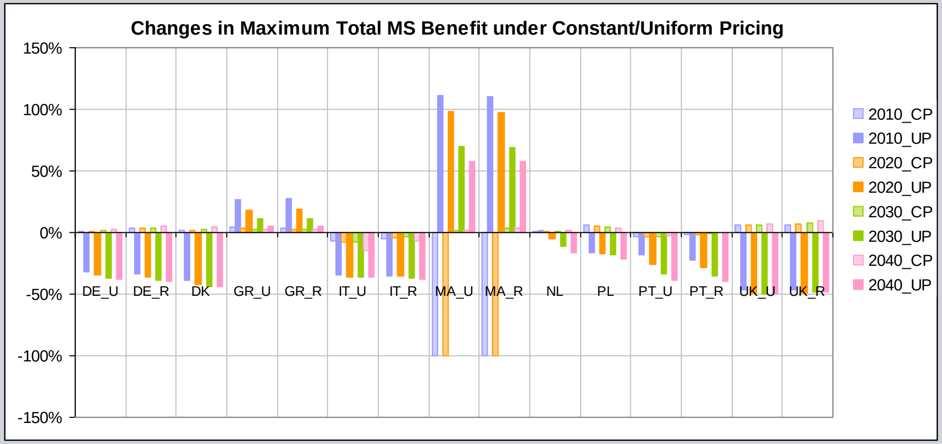
Sensitivity Analysis : Economic Benefit on MS Side

- Wholesale price level has been revealed to hold a moderate impact (20%-60%) on maximum MS profit margin
- Both constant and favorable pricing schemes undercut maximum MS profit margin at most times





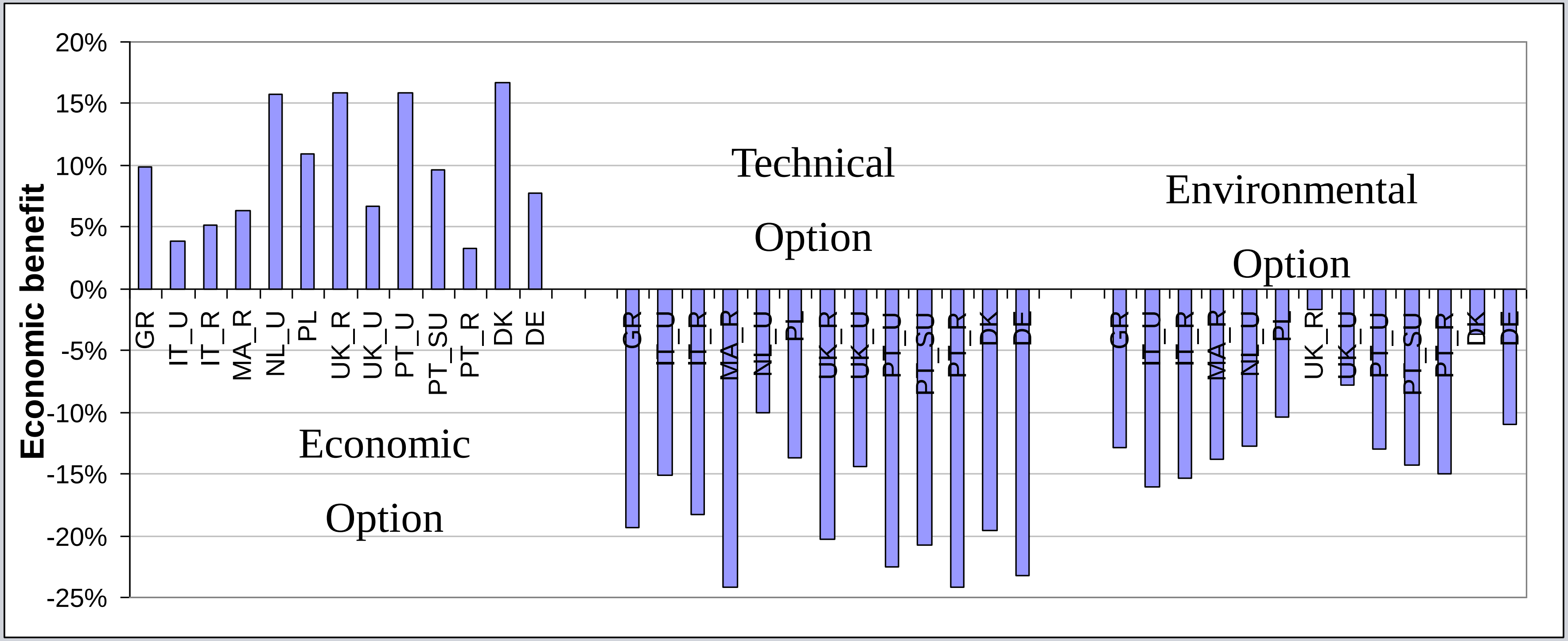




Impact of Microgrid Operation Strategy

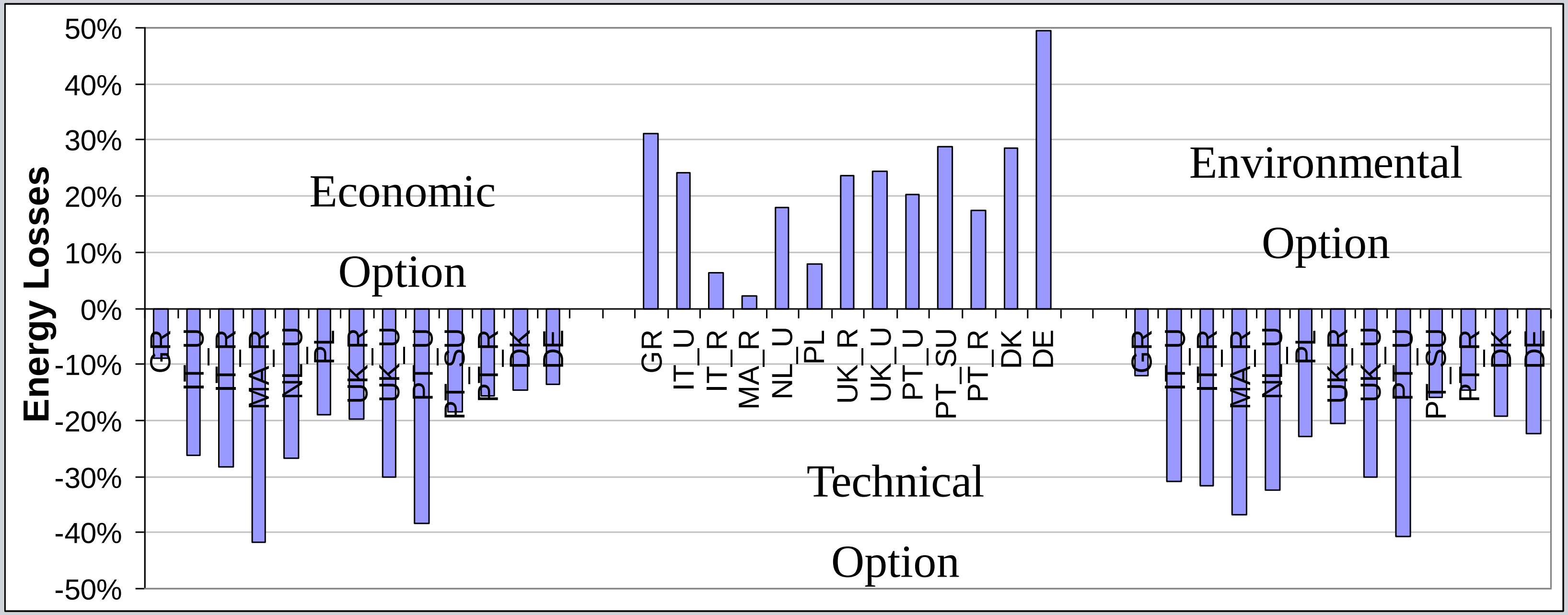
GR	Greece
IT	Italy
MA	Macedonia
NL	Netherlands
PL	Poland
PT	Portugal
DK	Denmark
DE	Germany
_U	urban
_R	rural

Impact on Maximum Economic Benefits



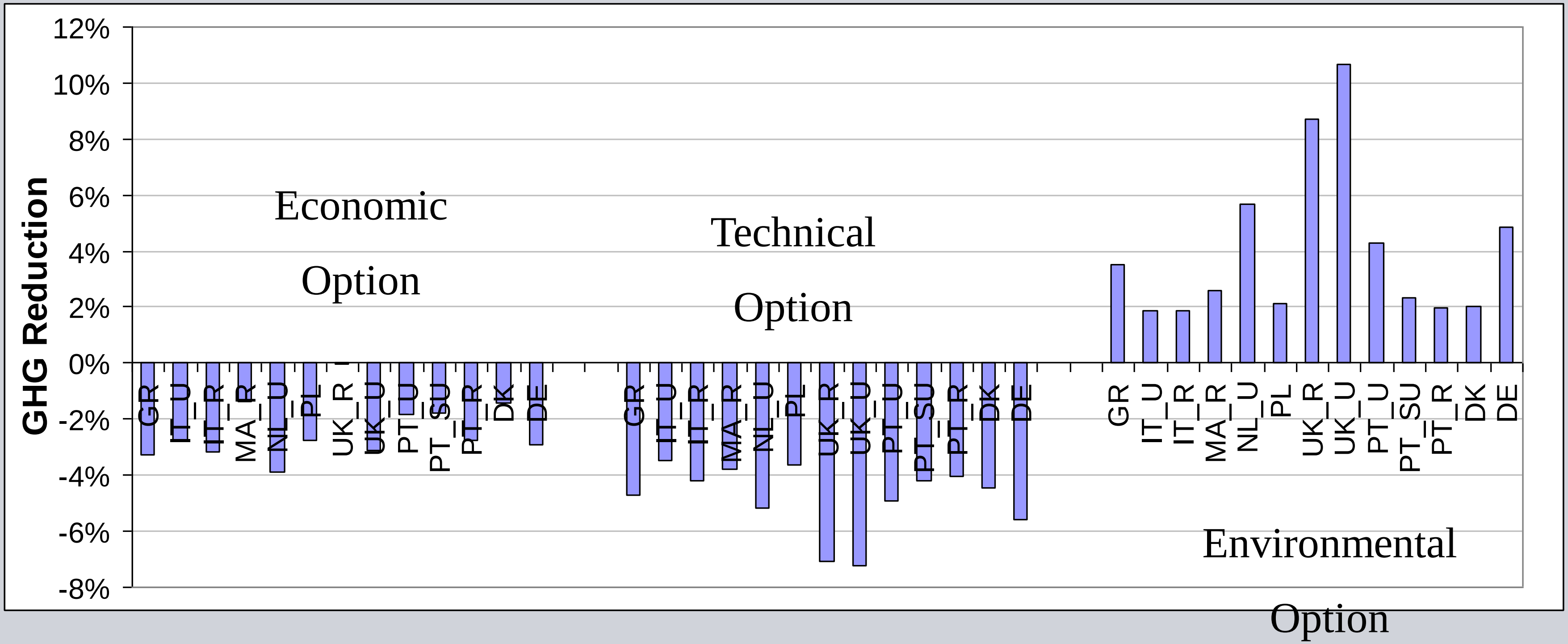
Impact of Microgrid Operation Strategy

Potential Energy Loss Reduction



Impact of Microgrid Operation Strategy

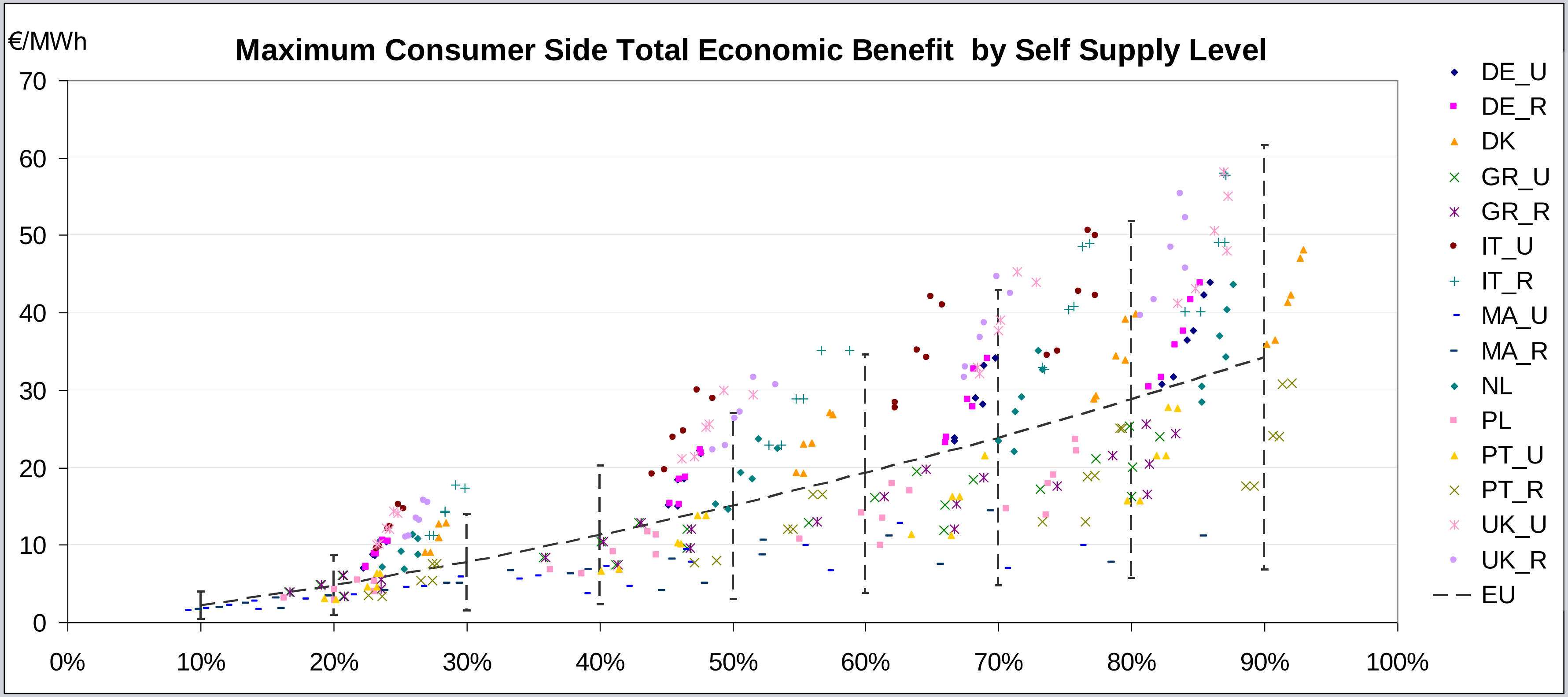
GHG Reduction Credits



Microgrids Workshop - Paris, January 2010

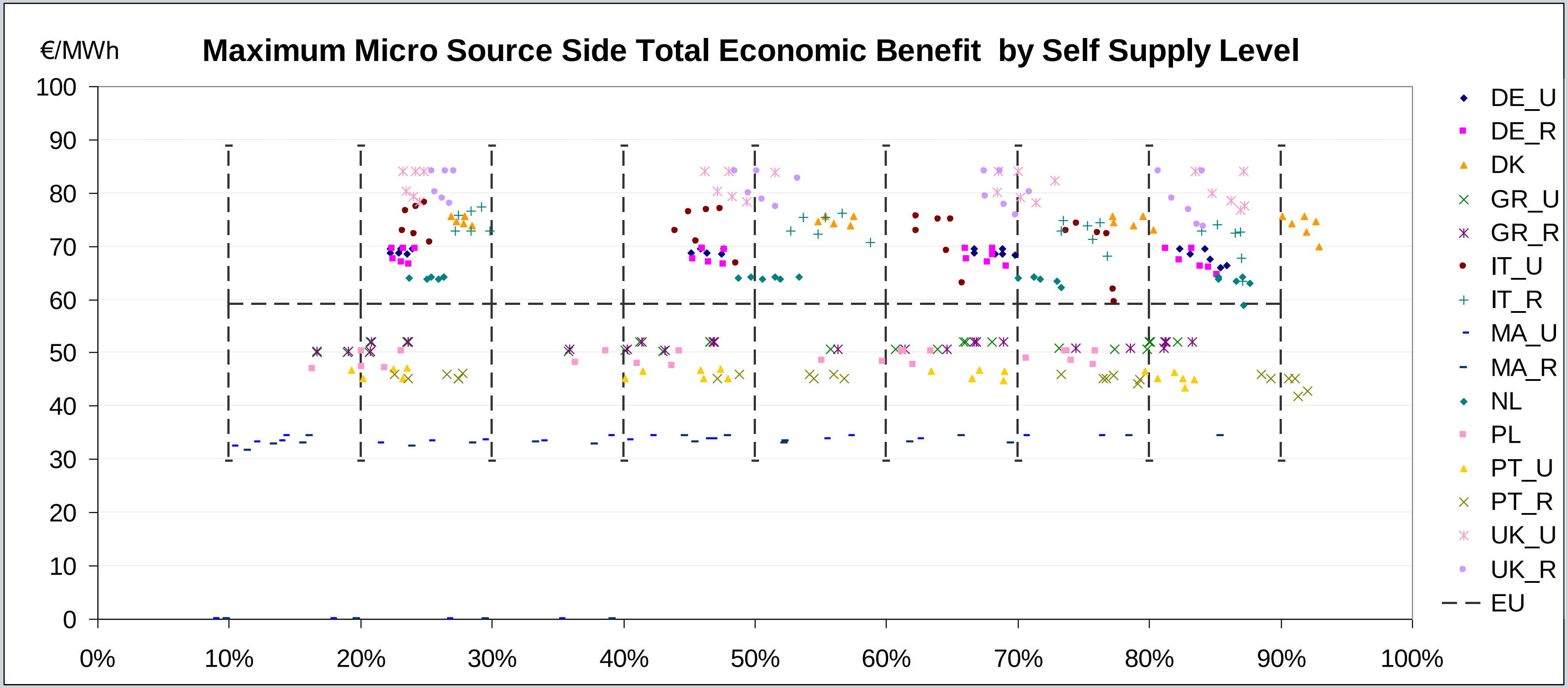
European Level Results: Maximum Total Consumer Benefit

Around 35 ± 25 €/MWh maximum total consumer benefit can be expected at 90% (load side) self supply level



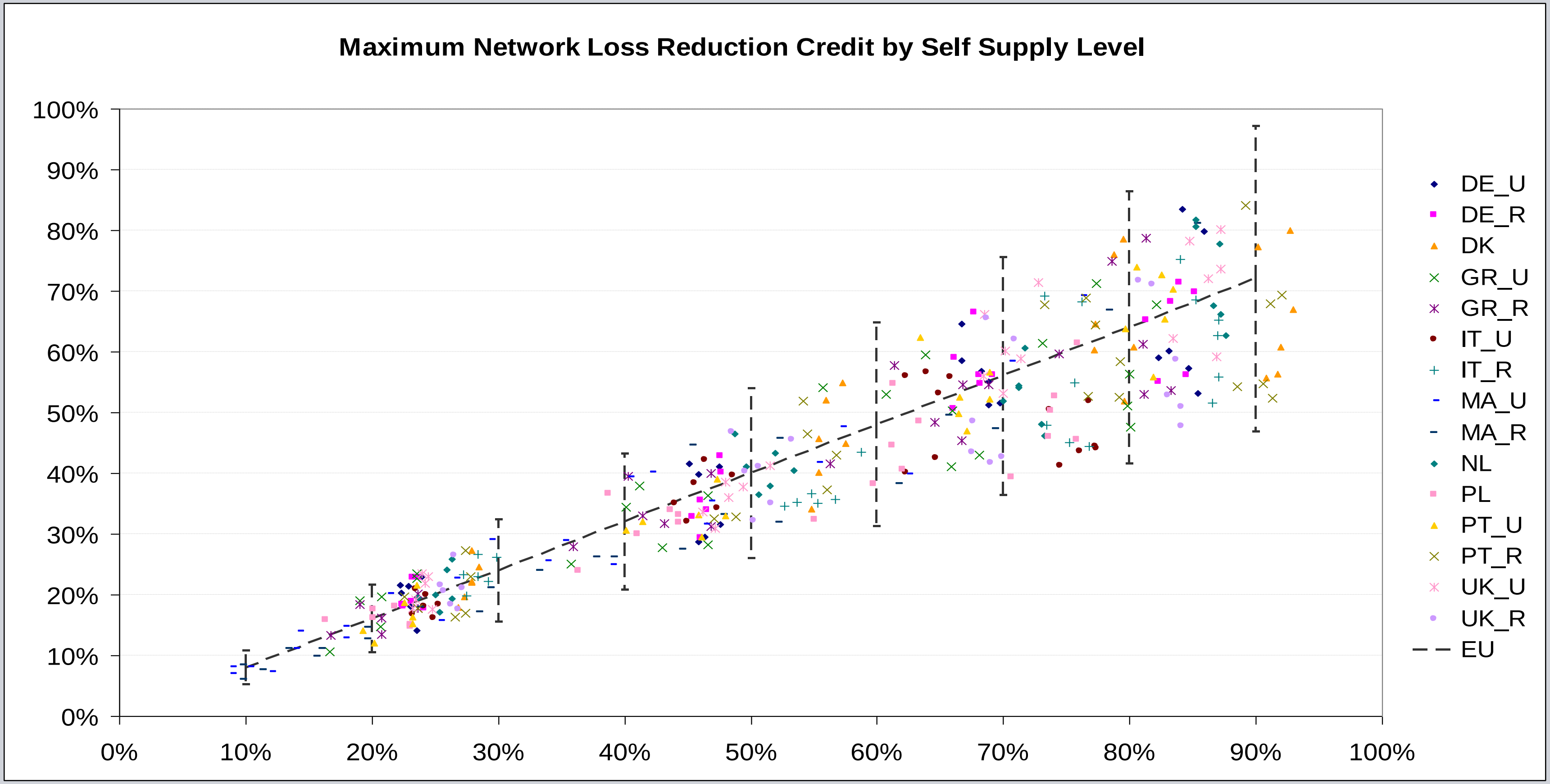
European Level Results: Maximum Total MS Benefit

Around 60 ± 30 €/MWh maximum total MS benefit can be expected under all conditions



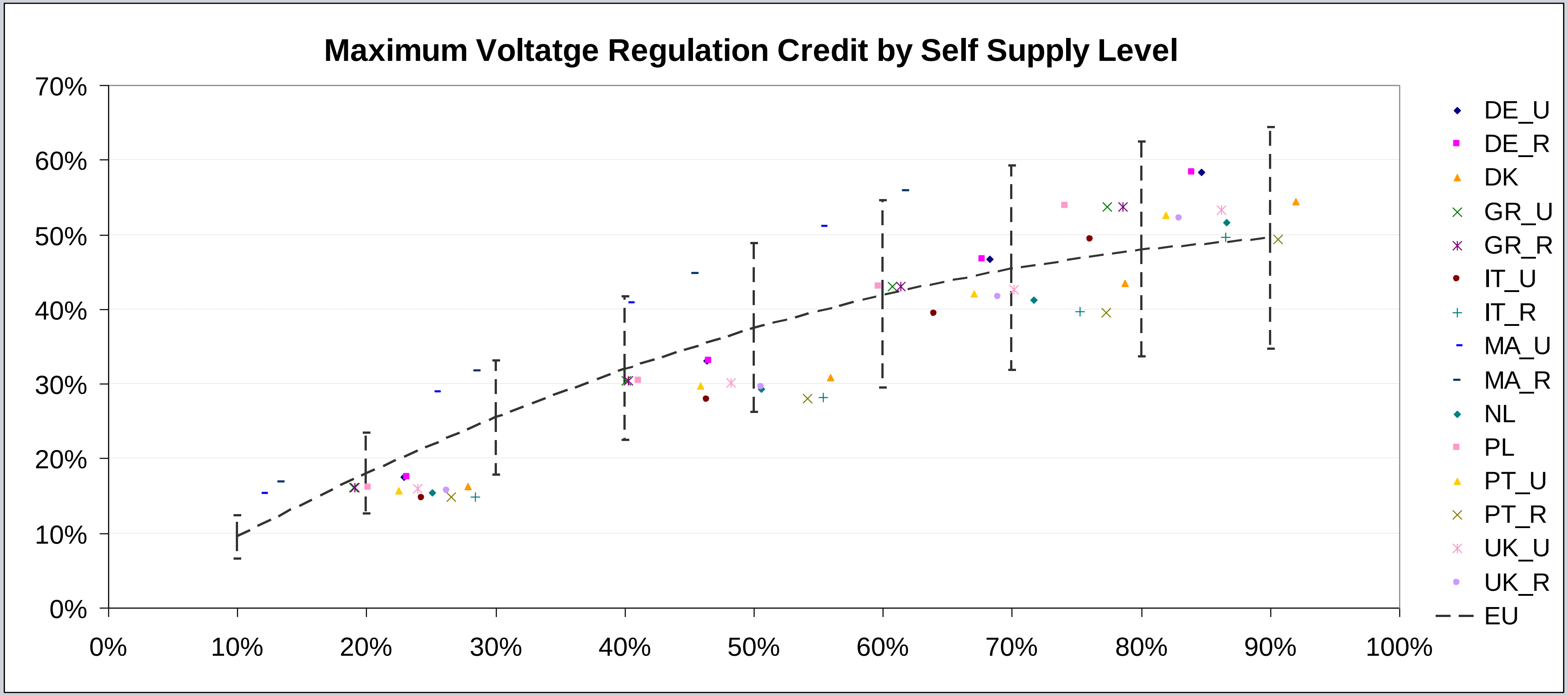
European Level Results:
Maximum Network Loss Reduction Credit

Around 70% ± 20% loss reduction credit can be expected at 90% self supply level
→ Actual value may be much lower under non-ideal MS allocation results



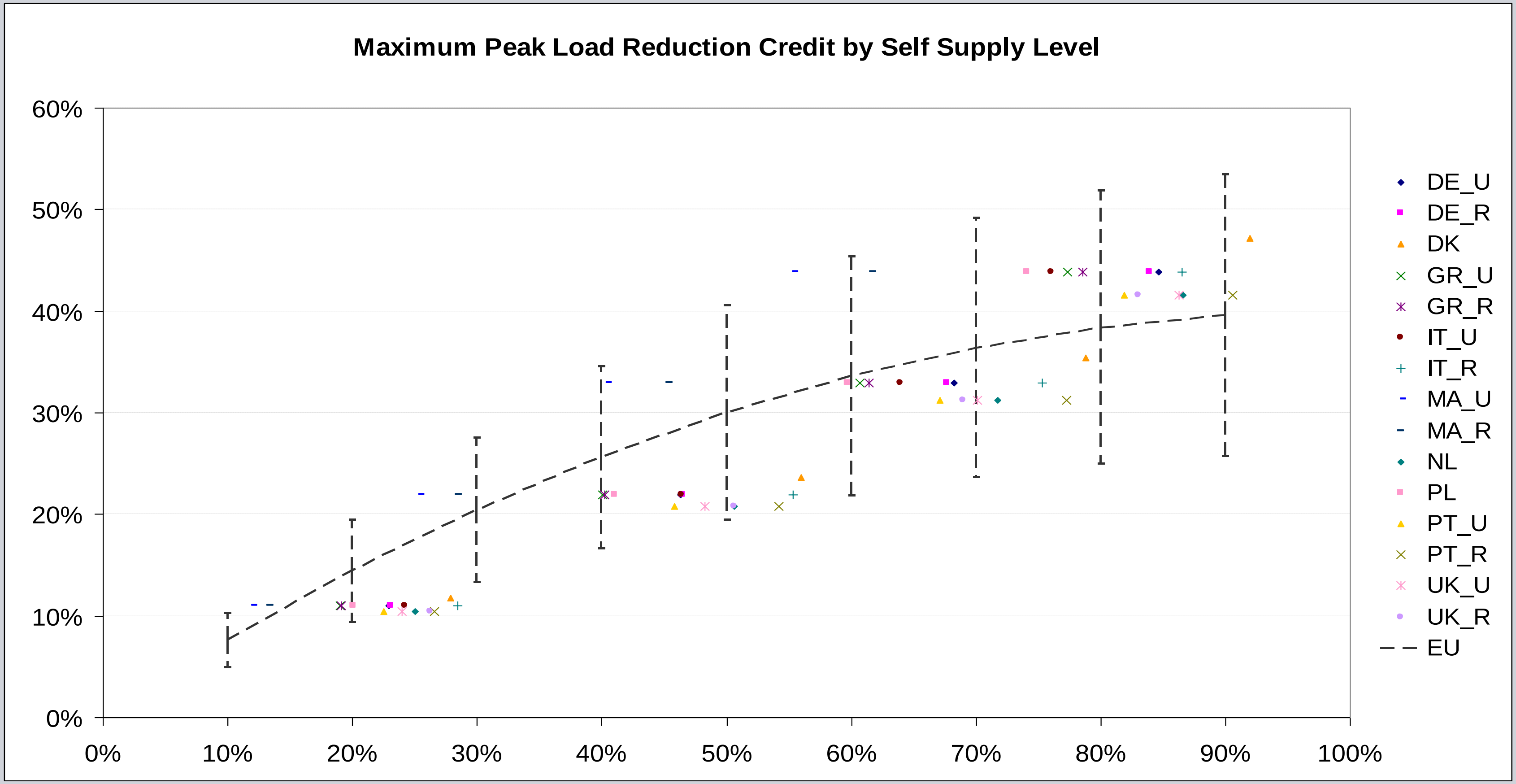
European Level Results: Maximum Voltage Regulation Credit

Around 50% ± 15% voltage regulation credit can be expected at 90% self supply level
→ Actual value may be much lower under non-ideal MS allocation results



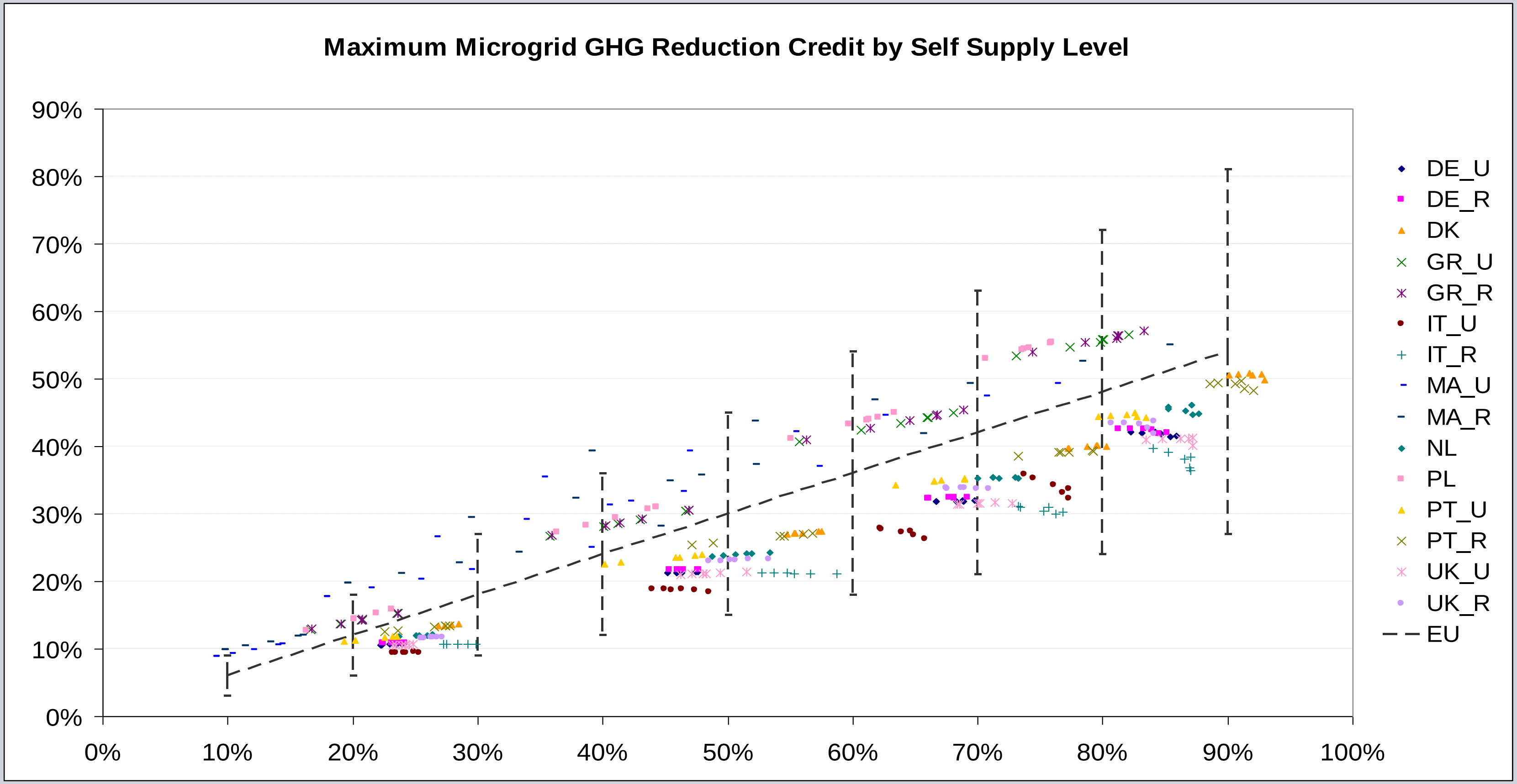
European Level Results:
Maximum Peak Load Reduction Credit

Around 40% ± 12% peak reduction credit can be expected at 90% self supply level
→ Actual value may be much lower under non-ideal MS allocation results



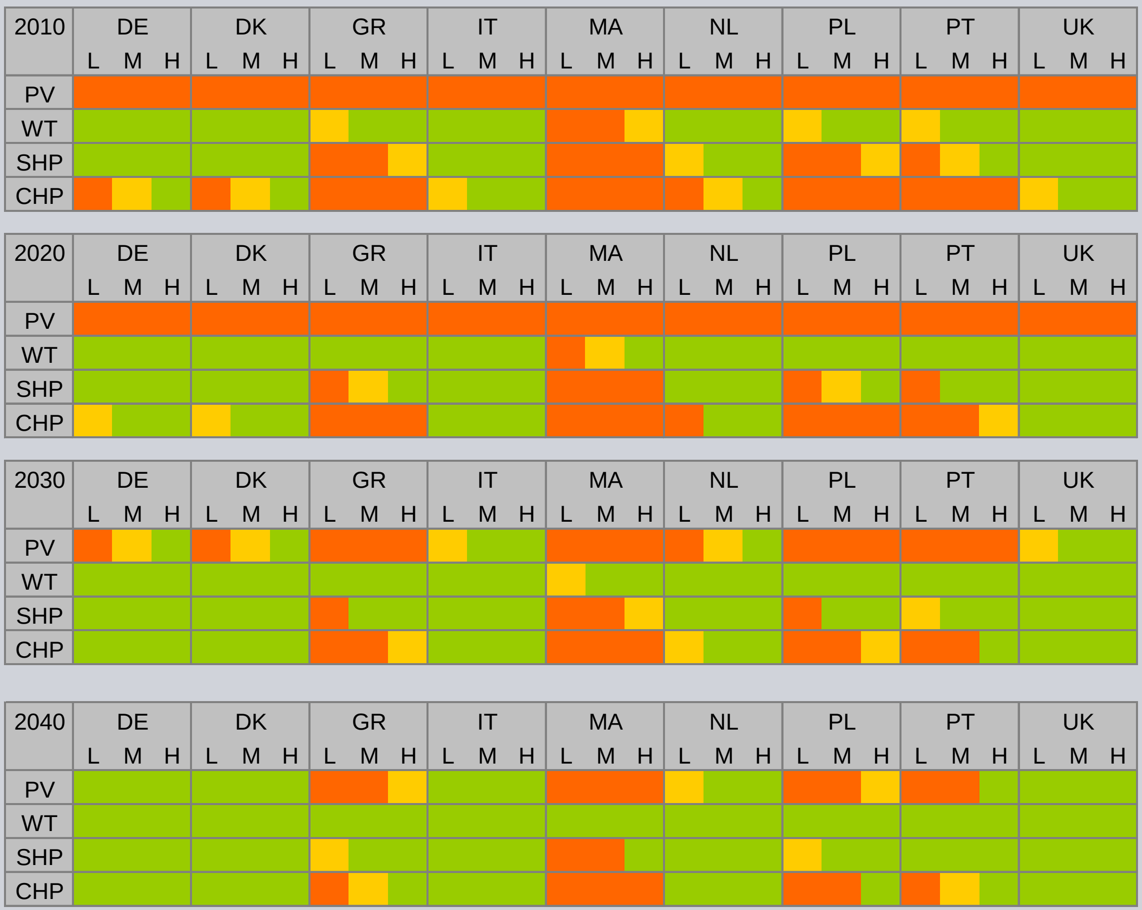
European Level Results:
Maximum GHG Reduction Credit

Around 55% ± 25% emission reduction credit can be expected at 90% self supply level
→ Actual value may be much lower under non-ideal MS allocation results



Projection of Required RES Support Levels

Most high-price countries will be able to withdraw financial supports for almost all RES options except for PV by 2030; by 2040 even the PV support can be retracted.



Red color refers definitive need of financial support;

Yellow color refers to marginal condition where need for external support is very small;

Green color refers to complete RES entry into free market within Microgrids;

Social benefits of Microgrids

Investigation on general social issues (addressed in the Lisbon Strategy) and identifying the ways by which Microgrids influence these issues

- More job opportunities in research, industry and SMEs
- Remote areas electrification
- Social cohesion and sustainable regional development

Investigation on social aspects of Microgrids based on the experiences from the test locations – done with specially developed questionnaire

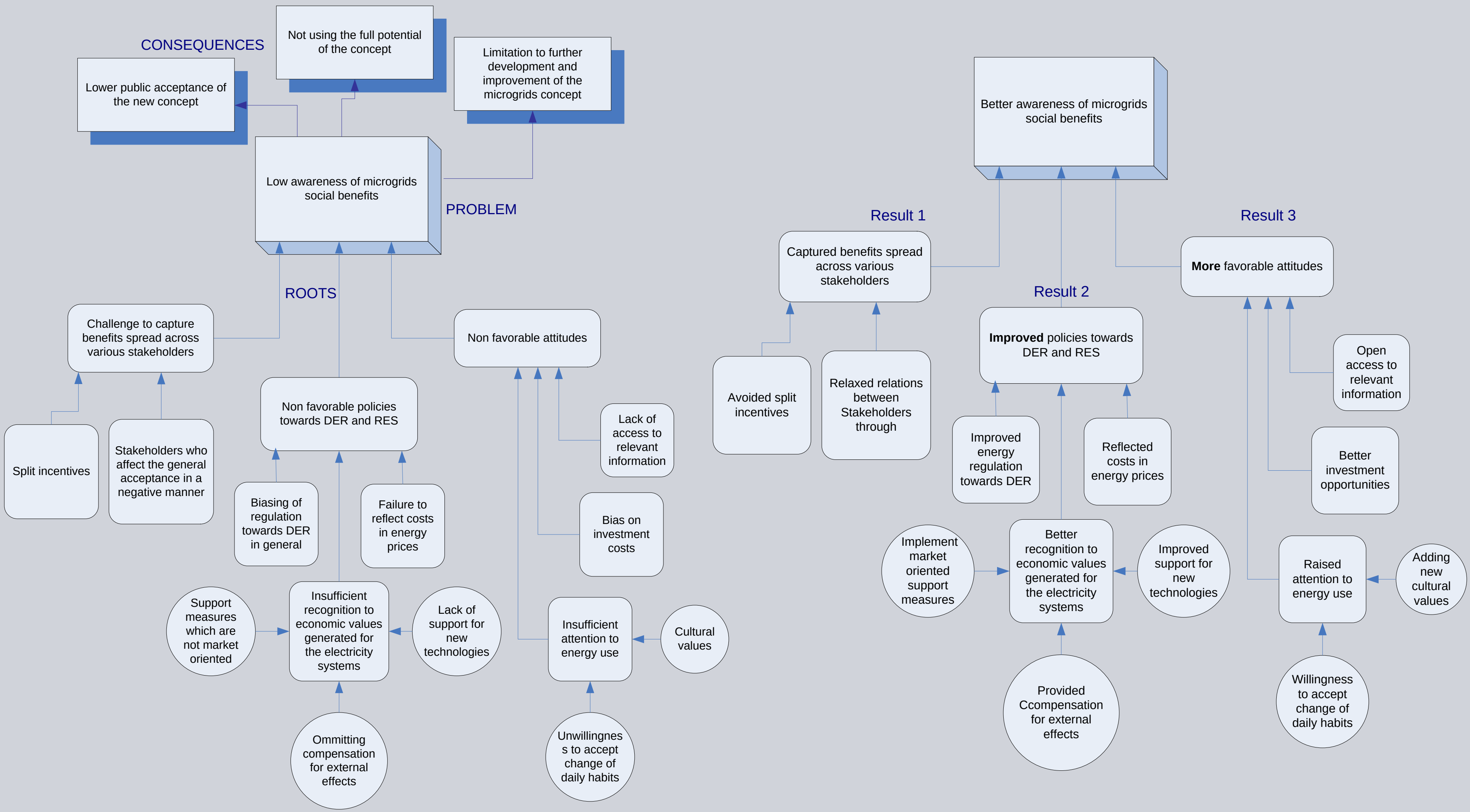
- The companies are interested in further research on Microgirds and further field testing - more job openings, R&D projects The chances are higher if environmental benefits are described in a qualitative manner
- The awareness of the Microgrids concept at the locations prior the field tests was low – different events were organized by project partners to increase the awareness
- The customers are interested in applying energy efficiency measures and emissions reductions measures – increased possibility to apply Microgrids concept

Social benefits of Microgrids

Conclusion: how to increase the social benefits of Microgrids?

- Social benefits of the Microgrids concept exist,
  but it is not always easy to recognize them and value them appropriately.
- The low awareness might result in:
  - Not using the full potential of the concept
  - Lower public acceptance
  - Limitation to further development and improvement of the concept

Social benefits of Microgrids



General Conclusions

- Microgrid is capable of overcoming conflicting interests of different stakeholder and achieving a global socio-economic optimum in operation of distributed energy sources, however necessity for proper market, regulatory, and design settings

- Economic, technical, and environmental impacts of a Microgrid are intertwined together as simultaneous outcomes of DG, storage, and DSM operation decisions; thus extensive communications are needed among these individual entities so as to maximize the potential benefits from a Microgrid.

- Proper planning of a Microgrid requires knowledge and simulation of its actual operating conditions; while in the mean time different planning decisions (especially referring to DG/RES penetration level) will lead to different levels of potential benefits that the Microgrid could bring about.

Summary of Economic Benefits from Microgrid

A Microgrid could potentially offer (single or multiple from list):

- Price reduction for end consumers
- Revenue increment for Micro Sources
- Investment deferral for Distribution System Operators

Suggestions to achieve expected economic benefits:

- Recognition of local (‘over-the-grid’) energy trading within a Microgrid
- Application of real-time import and export prices for Microgrids
- RES support scheme and favorable tariffs (optional)

Summary of Technical Benefits from Microgrid

A Microgrid could potentially offer:

- Energy loss reduction
- Mitigation of voltage variation
- Peak loading (congestion) relief
- Reliability improvement

Technical benefits can be either traded in a local service market between MS and DSO or implemented as price signals

Needs to achieve expected technical benefits:

- Optimum dimensioning and allocation of Micro Sources
- Coordinated multi-unit MS dispatch based on real time grid condition

Summary of Environmental and Social Benefits from Microgrid

Main environmental benefits:

- Shift toward renewable or low-emission fuels used by internal MS
- Adoption of more energy efficient technologies such as CHP

Main social benefits:

- Raise public awareness and foster incentive for energy saving and GHG emission reduction
- Creation of new research and job opportunities
- Electrification of remote or underdeveloped areas

Main Findings from WPG

1. Microgrid can be **profitable** to invest and operate if proper policy and financial supports are available, given current situation in EU

2. Microgrid offers a **local market** opportunity for ‘over-the-grid’ energy trading between Micro Sources and end consumers

3. Microgrid can **maximize total system efficiency** as it represents the interests of Micro Sources, end consumers, and local LV grid as a whole

4. Microgrid allows for real time, **multi-objective dispatch** optimization to achieve economic, technical, and environmental aims in the same time

5. Microgrid can accommodate different ownership models and provide **end consumer motivation** where other concepts fail to do so

6. Microgrid can **accelerate commercialization** of RES units such as PV

Thank you for your attention !