UMONS
Université de Mons

Enhanced Representation of Flow-Based Market Coupling in European Resource Adequacy Assessments

Workshop on Reliability and Resilience of the Grid

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University of Mons
14 May 2024

POLYTECH MONS

PSMR

EPEU
Electrical Power Engineering Unit

University of Mons

UMONS, IN SOME KEY POINTS

1500

Teachers, Scientists, researchers and technical and administrative staff

About us →

10.000

Students

7 Faculty and 3 Schools →

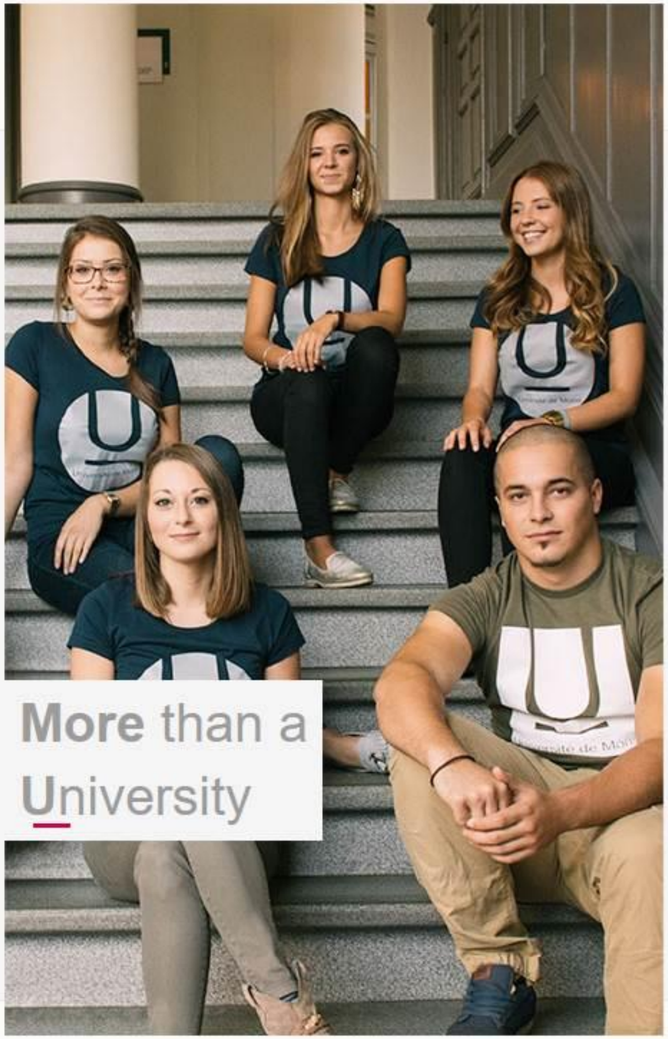
1000

Researchers

10 Research Institutes →

> 150

University course programmes from Bachelor to Doctorate



UMONS: 7 Faculties – 3 Schools

- Faculty of **Science**
- **Faculty of Engineering**
- Faculty of **Medicine and Pharmacy**
- Faculty of **Architecture and Urban Planning**
- Warocqué School of **Business and Economics**
- Faculty of **Psychology and Education**
- Faculty of **Translation and Interpretation**
- School of **Human and Social Sciences**
- **Teacher Training** School
- **Law** School

Faculty of Engineering

POLYTECH MONS

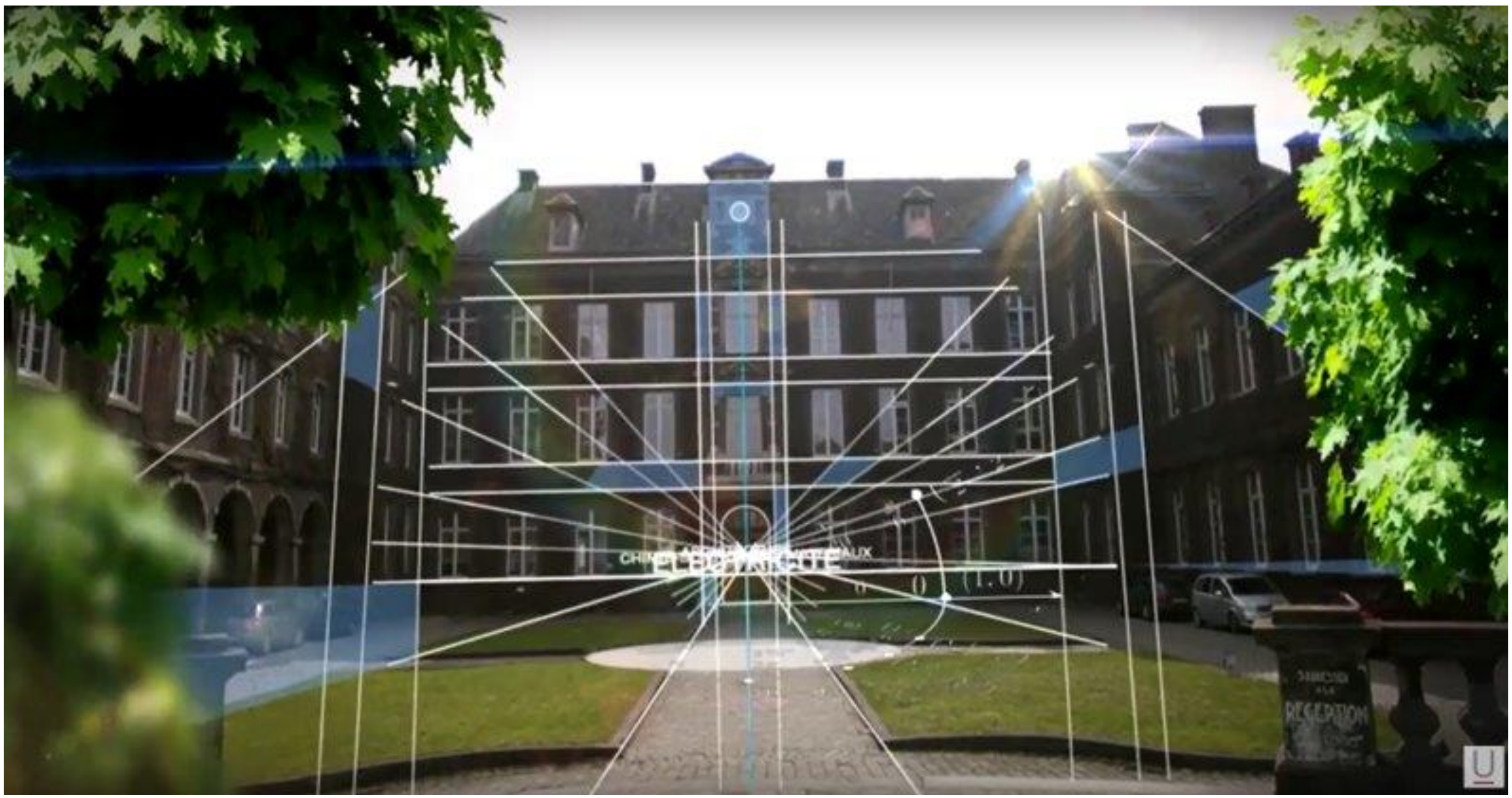
- **Founded** in **1837** as a School of Mines.
- One of the oldest engineering schools in Belgium.
- One of the four faculties of engineering in the Wallonia-Brussels Federation.

2008 - creation of UMONS
by **merging** the University of Mons-Hainaut (**UMH**) &
the Faculty of Engineering of Mons (**FPMs**)

Faculty of Engineering

POLYTECH MONS

- Around **1000 students** in engineering sciences (BSc, MSc, PhD, etc.)
- More than **250 staff** (academic, researchers, technicians)



Who are we?

UMONS
Université de Mons

… 7 Faculties …

… 10 Research institutes …

energy

POLYTECH MONS

… 6 Departments …

Electrical Engineering Department

…

… 6 Units …

Electrical Power Engineering Unit

EPEU
Electrical Power Engineering Unit

2 research groups

UMONS Université de Mons ALSTOM
Academic chair in Energy Electronics

Power and Energy Conversion Research

Power & Energy Conversion Research

Energy Conversion:
Electrical Machines, Energy Electronics, Computational Electromagnetics

Power Systems and Markets **Research** Group

PSMR

Power Systems:
Electric Power Networks, Energy Economics, Multi-Energy systems

EPEU — Team

Electrical Power Engineering Unit

~20 people:

- **2 Professors**: **François Vallée** (head of PSMR), Olivier Deblecker (head of EPEU)
- **2 Associate Professors**: **Zacharie De Grève** (SMACCs coordinator), Bashir Bakhshideh Zad (Alstom Chair holder)
- **2 Senior Researchers**: Ahmad Hosseini, Jean-François Toubeau
- **14 PhD students**

PSMR

Main studied applications

- **Power System Adequacy** (renewable generation and flexible technologies modeling in Monte Carlo simulations) and **Security of Supply** (e.g. Reactive Power Planning, etc.)
- **Modeling and understanding wholesale and emerging local** (e.g. Energy Communities) **market mechanisms**
- **Cross-sector coupling** (electricity/heat/gaz/mobility)
- **Voltage control and congestion management in** electric **distribution** systems

Methods and models

- **Data Analytics applied to energy systems** (Machine Learning, Monte-Carlo sampling)
- **Operations Research for the optimal sizing and operation of energy systems** (exact optimization, game theory, optimization under uncertainty)
- A strong effort in **linking both areas of research** (e.g. neural-network informed optimization)

EPEU — Team

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Power & Energy Conversion Research

UMONS Université de Mons ALSTOM Academic chair in Energy Electronics

- **Design** of **power electronic converters** for **power grid applications:** BESS, HVDC, renewables, Electrolyzers, etc.
- **Control of Inverter-Based Resources:** grid forming, control loop interactions, interoperability, etc.
- **AI-assisted modeling, design and control** of power converters
- Power electronics for **electric mobility & transport**: electric traction & auxiliary applications)
- Power electronics in **other energy-related domains**: space, aeronautics, **electrification** of energy-intensive industries, etc.

EPEU — Main International Collaborations

Electrical Power Engineering Unit

DTU

SAPIENTIA · ET · VIRTUS

CITY
UNIVERSITY OF LONDON
EST 1894

THE UNIVERSITY OF EDINBURGH

Federation University

centralelille
ENSCL

Imperial College London

JOHNS HOPKINS UNIVERSITY

TU Delft

UNIVERSITÉ D'ARTOIS

EPEU — Fundings & projects

Electrical Power Engineering Unit

International Funds

- **WBI-MOST with the University of Hong-Kong (Prof. Yi Wang) -** Low-carbon operation of green buildings and urban energy systems in joint energy and carbon markets
- **Interreg VI-F-W,** partners UMONS, UGENT & Université du Littoral et de la Côte d'Opale **-** ageing-informed provision of ancillary services with offshore wind generation
- **Joint PhD thesis with the L2EP, Central Lille, France** (2023-2026), decision-focused learning in power system applications
- **Joint PhD thesis with the LSEE, University of Artois, France** (2024-2027), Predictive maintenance and fault detection of the traction chain of EVs using AI techniques

National Funds

- **ADABEL project** (ETF funding: 2020-2024, lead UMONS): data analytics (supervised and unsupervised learning) to improve power system management (reserve sizing, Flow-based domain modelling in adequacy computation, towards a better understanding of reactive power exchanges at TSO/DSO interfaces)
- **BEOWIND project** (ETF funding: 2018-2023, lead UGhent): risk-aware participation of Wind Producers to ancillary services (primary reserve)
- **ALEXANDER project** (ETF funding: 2018-2023, lead VITO): modelling and understanding the behaviours of Low Voltage grid users, in the context of flexibility provision and investment in energy assets
- **DATAGREEN project** (FNRS PostDoc scholarship: 2019-2022): Machine & Reinforcement Learning for an enhanced operation of power systems
- **EMPOWER project** (FNRS PhD scholarship: 2022-2026): Towards Neural Network informed OPFs
- **DISCRETE project** (ETF funding 2022-2027, lead KU Leuven): Data driven optimization models for secure real-time operation of renewable dominated power systems

EPEU — Fundings & projects

Electrical Power Engineering Unit

Regional Funds

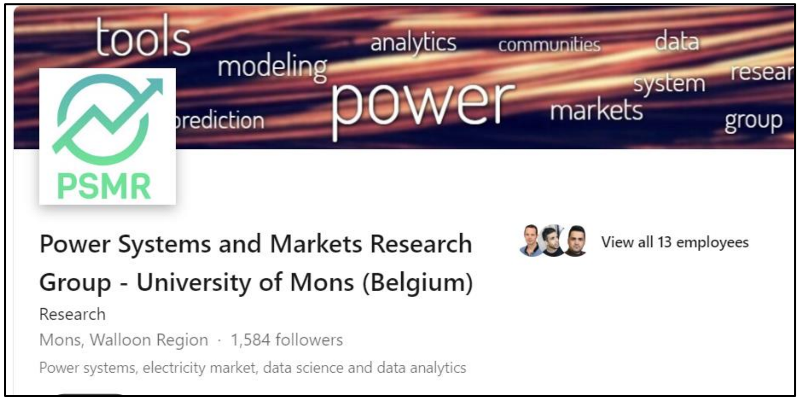
- **LECaaS Project** (Pôle Mecatech, 2022-2024, lead WeSmart): developing software tools and methods for the development of Renewable Energy Communities in Wallonia (operational management of energy exchanges, sizing and investment)
- **SOLHEATAIR Project** (Pôle Mecatech, 2022-2025, lead John Cockerill): high temperature heat production in storage for industry applications, Development of an Energy Management System
- **GREWFARM Project** (Pôle AGRIWAL, 2022-2025, lead GreenEnergy4Seasons): optimal energy management and sizing of photovoltaic greenhouses, under technical and agricultural constraints
- **REDSHInE Project** (Pôle Mecatech, 2024-2027): developing new SiC-based power converters for supporting distribution grids dominated by renewables

Indsutrial Funds

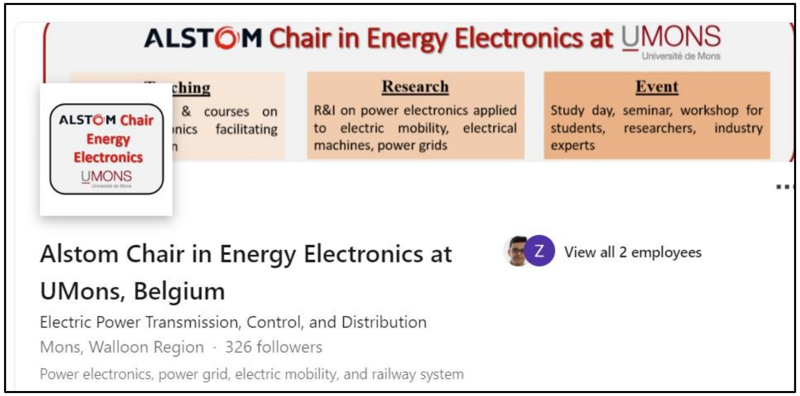
- ***Assessing the impact of local generation and prosumption strategies on the grid infrastructure* project** (ELIA funding: 2022-2023): Challenging and enhancing the current practices in grid planning with better informed modeling of local prosumption mechanisms
- **ForecastPV_IDETA** (IDETA Funding, 2021): developing a Machine Learning tool for the forecast of domestic PV generation, for sites without any previously recorded data
- **Chair in Energy Electronics** (ALSTOM, 2023-2033): Academic Chair with research and teaching missions dedicated to power electronics for energy transition and electric mobility

For more information, please visit

- LinkedIn page of **the PSMR group**: *https://be.linkedin.com/company/power-systems-and-market-research-group-psmr-umons*



- LinkedIn page of **the Chair in Energy Electronics**: *https://be.linkedin.com/company/alstom-chair-in-energy-electronics-at-umons-belgium*



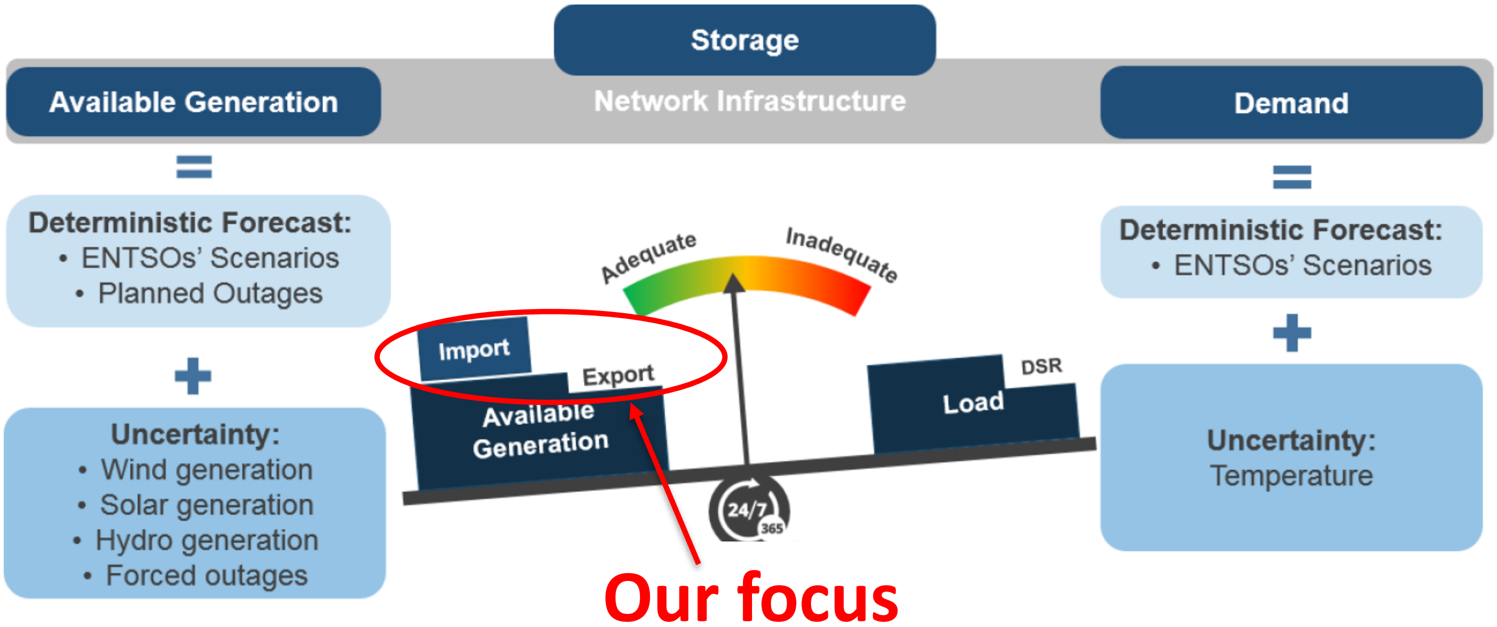
- Website of the **Electrical Power Engineering Unit** (EPEU): *https://www.epeu-umons.be/*

Outline of the presentation

1. **Adequacy assessment considering cross-border exchanges defined by the Flow-Based approach**
2. **Current methodology employed by TSOs for incorporating the flow-based market coupling into adequacy assessment**
3. **Proposed methods and improvements**
4. **Case study, and results**
5. **Conclusion**

1-1: Overview of adequacy assessment

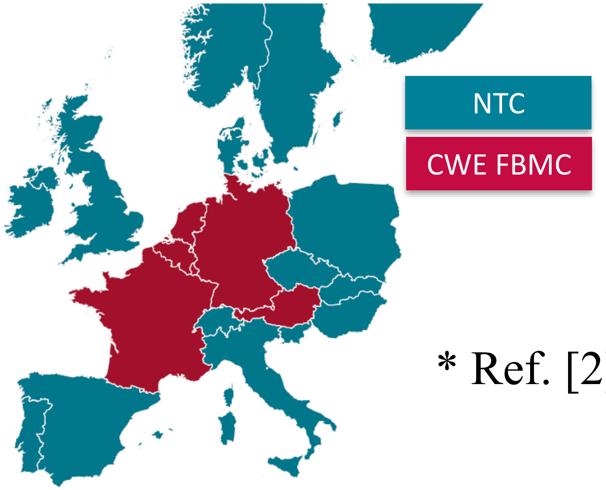
Adequacy study evaluates ability of an electric power system to meet load demand under various working conditions



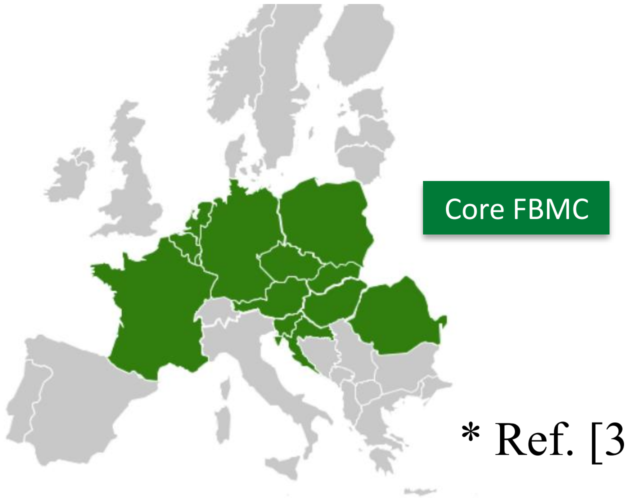
* Ref. [1]

1-2: Interconnection capacities

- Interconnection capacities constitute **important inputs** of adequacy study.
- Monte Carlo simulations aim at reflecting day-to-day operation of power system.
- Interconnection capacities are modelled adopting the capacity calculation method employed in the **operation stage (D-1) of the power system**.
- There are two different approaches:
  1. **Net Transfer Capacity (NTC)**
  2. **Flow-Based (FB)**



* Ref. [2]



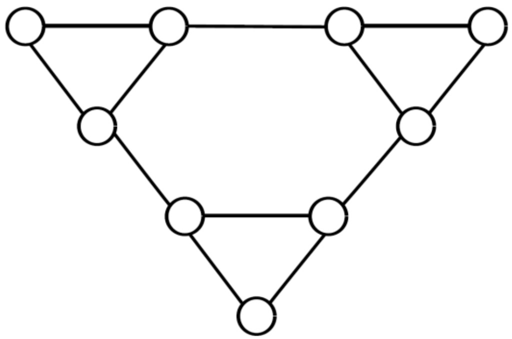
* Ref. [3]

1.3. Flow-Based Market Coupling (FBMC)

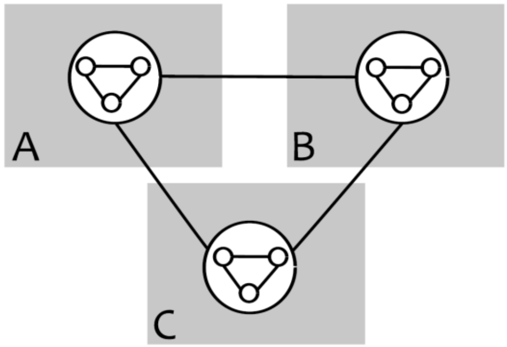
- FBMC aims to **incorporate power grid physical limits and relations in cross-border electricity trading.**
- It was initially implemented in the **CWE region** in 2015 (5 countries).
- Has been extended to **Core region** (13 countries) since summer 2022.
- It relies on a **zonal representation** of the power grid.

Reminder

Nodal representation



Zonal representation



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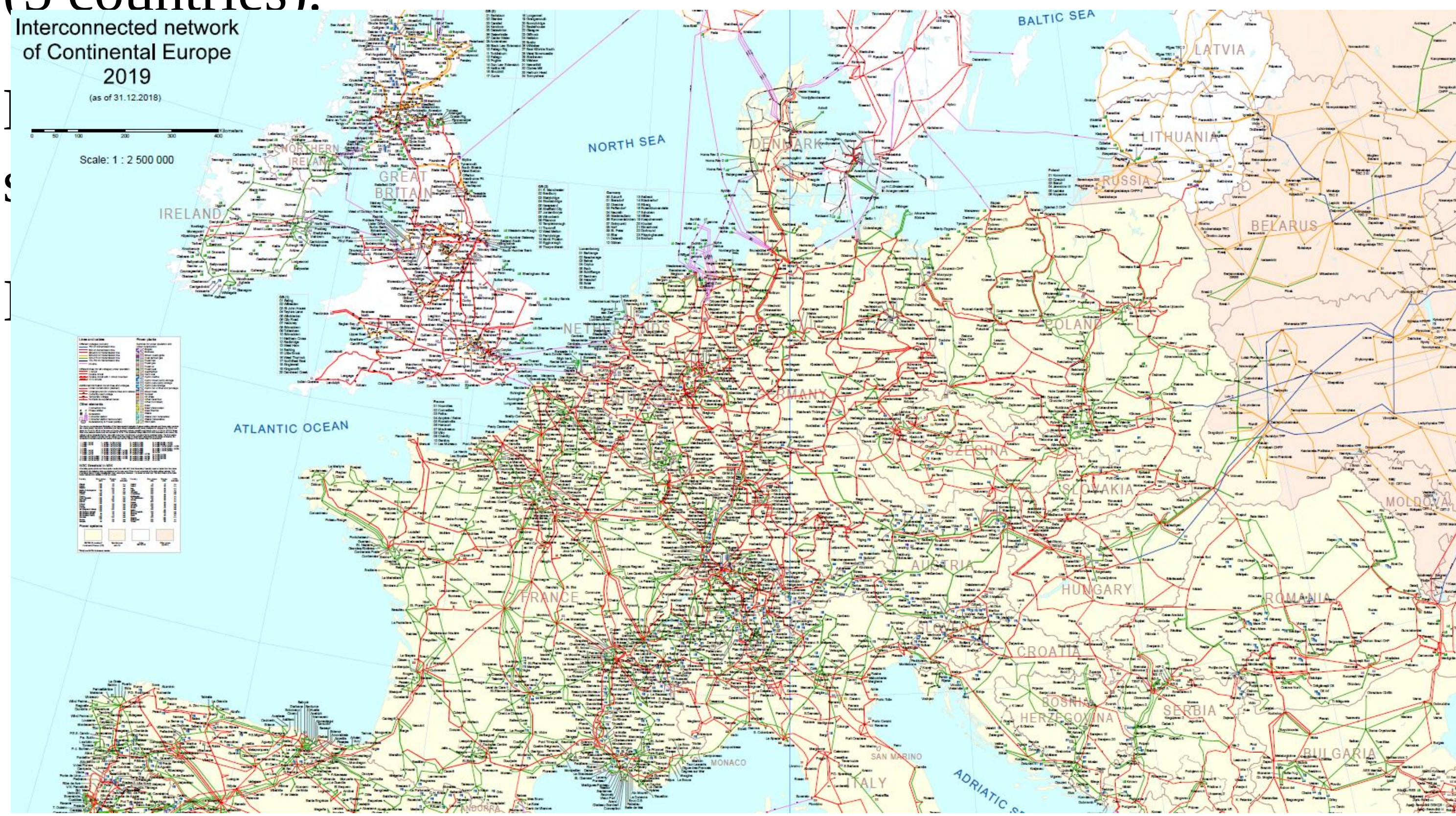
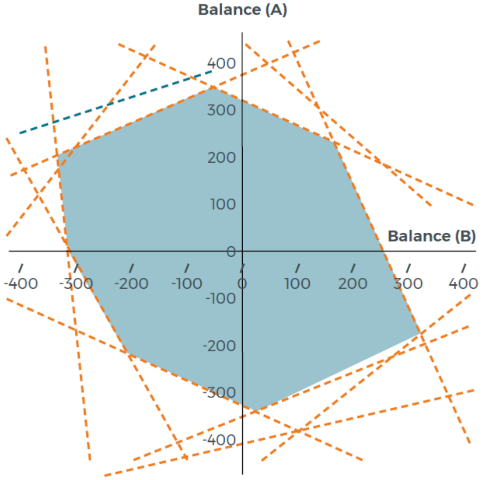


1-4: Flow-based (FB) domains

- **Feasible** cross-zonal exchanges are calculated by **<u>approximating</u> physical grid constraints**.
- Approximation aims at reflecting the **impact** of zonal net position changes on the flows on **<u>selected</u>** critical network elements.
- The load flow analysis is performed on so-called "**base case**".
- **Hourly** FB domain is obtained by a set of **linear constraints**:

$$\mathbf{PTDF \times \Delta NP \leq RAM}$$

- FB domain corresponds to **intersection of all half-spaces** created by linear **constraints**.
- It constitutes a **N-dimensional polytope.**
- **Vertices** of **polytope** define feasible exchanges.



* Ref. [2]

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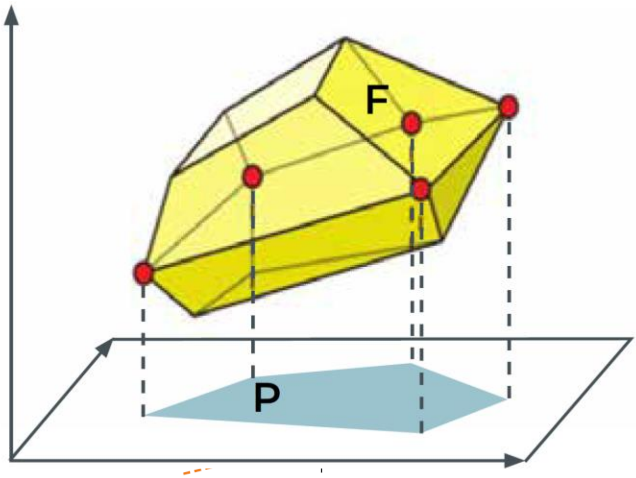


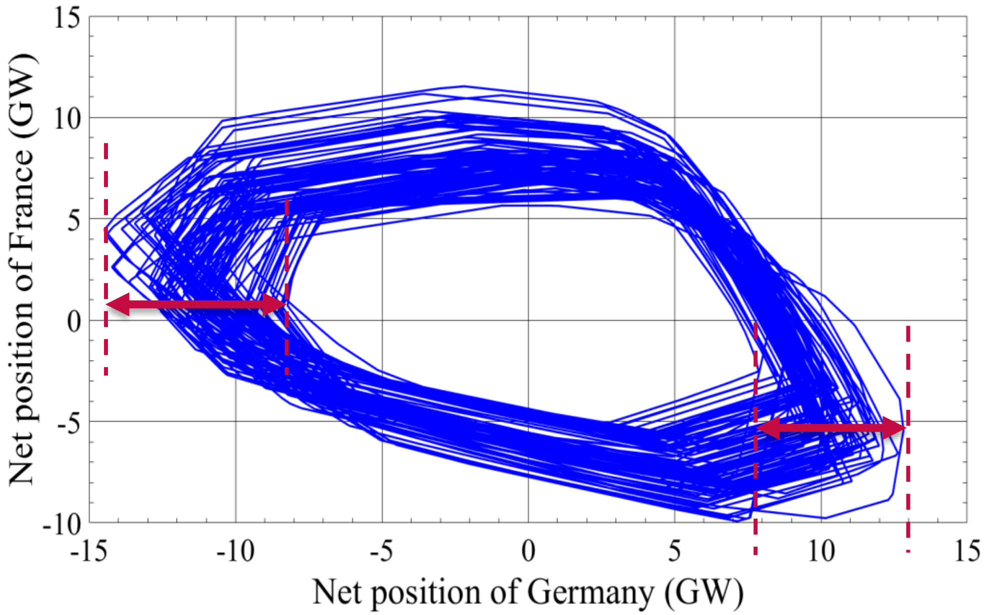
* Ref. [2]

1-5: Incorporating FB domains into adequacy study

Main Challenge

Finding the representative FB domains:

- FB domains **depend on network constraints and exogenous conditions** of the studied Monte Carlo scenario
- Choice of the **internal parameters** of FBMC can have high impacts on FB domains
- FB domains can take **various shapes and sizes:**



4 days of hourly FB data, Ref. [4]

1. Adequacy assessment considering cross-border exchanges

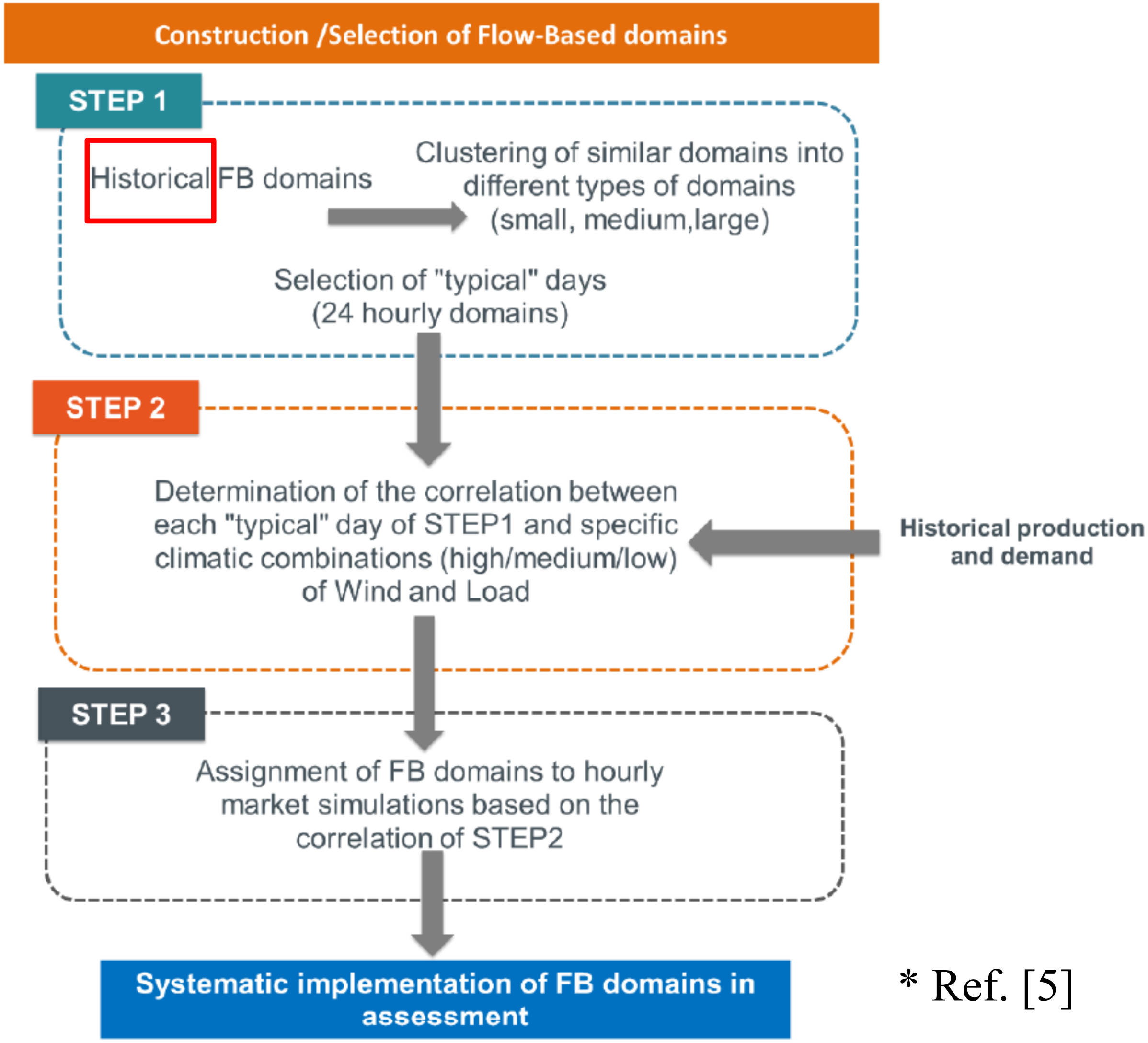
2. **Current methodology employed by TSOs for incorporating the flow-based market coupling into adequacy assessment**

3. Proposed models and improvements

4. Case study, and results

5. Conclusion

2-1: Current methodology employed by the TSOs for <u>one year ahead</u> adequacy study



Clustering FB domains

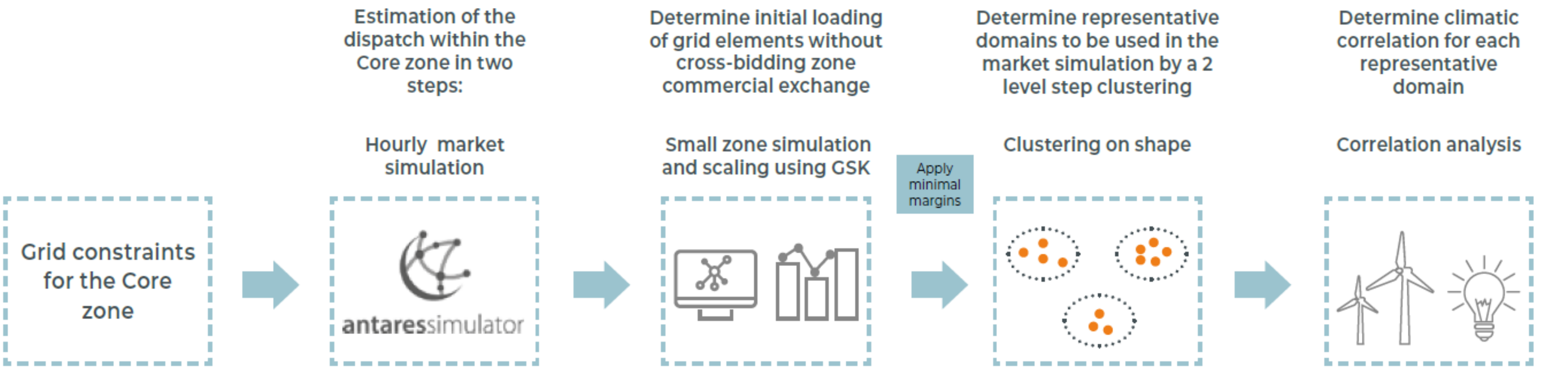
Correlation analysis

FB domain assignment

Adequacy assessment

* Ref. [5]

2-2: Current methodology developed by Elia for multiple years ahead adequacy studies



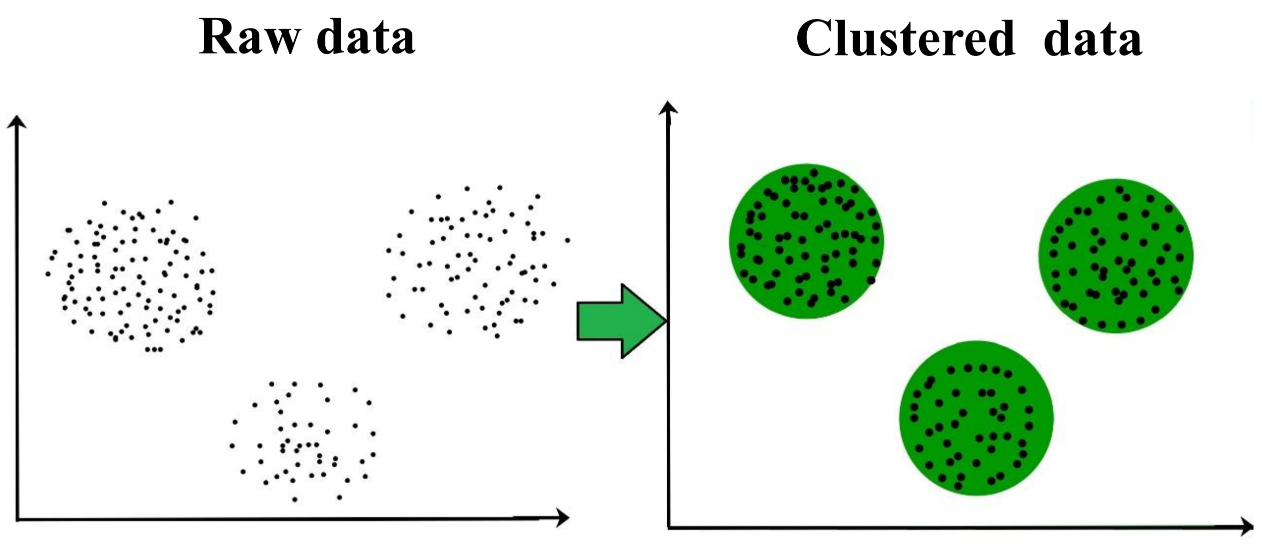
Generating synthetic hourly FB domains on the target year

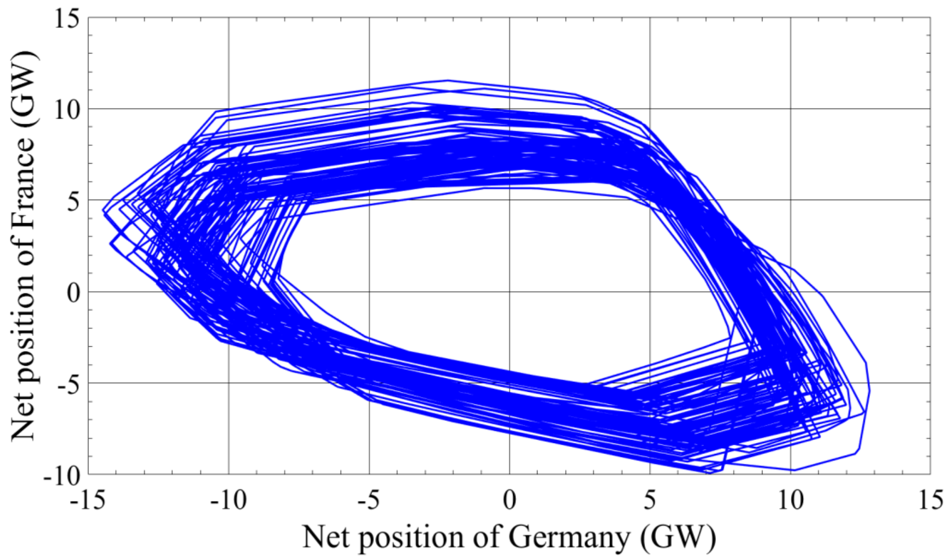
Clustering FB domains

Correlation analysis

* Ref. [6]

Step 1: Clustering study (Unsupervised Learning)





Step 1: Clustering study

- Flow-based domains are grouped to reduced number of clusters according to their **overall geometrical shapes [7]**.
- The **dissimilarity** between each **pair** of the FB domains in the database is calculated using a **shape-based** distance measure.
- The **k-medoid** clustering algorithm is applied to constructed **matrix of distances**.
- The **k-medoid** algorithm tries to find the **best representatives** of the dataset **from its existing components**.

Step 2: Correlation analysis

- Identifies **a link between the selected cluster representatives** and **external (explanatory) variables**.
- Enables to assign to each sample of MC analysis, a cluster representative, in line with generated MC conditions.
- Shape of a FB domain is affected by **several factors**.
- The objective is to find the **most important factors**.
- **French load level** and **German wind infeed** are selected as the two most important factors [2, 8].
- The likelihood of having FB domains in each cluster, within three **predefined thresholds high, medium, low** of selected explanatory variables is calculated.

(x,y,z)
x = Probability of representative domain 1
y = Probability of representative domain 2
z = Probability of representative domain 3

		GERMAN WIND		
		HIGH	MEDIUM	LOW
French load	High	(0.12, 0.69, 0.19)	(0.45, 0.27, 0.27)	(0.58, 0.18, 0.24)
	Medium	(0.24, 0.53, 0.24)	(0.48, 0.24, 0.27)	(0.67, 0.08, 0.24)
	Low	(0.32, 0.25, 0.43)	(0.43, 0.15, 0.43)	(0.47, 0.11, 0.42)

* Ref. [2]

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In the ADABEL project,

novel methods were proposed to improve the performance of the two-step methodology utilized by the TSOs:

https://www.adabel-project-2020-2024.be/

ELSEVIER
Applied Energy
Volume 325, 1 November 2022, 119875

Supervised learning-assisted modeling of flow-based domains in European resource adequacy assessments

Bashir Bakhshideh Zad [a], Jean-François Toubeau [a], Kenneth Bruninx [b c d], Behzad Vatandoust [a], Zacharie De Grève [a], François Vallée [a]

ELSEVIER
Electric Power Systems Research
Volume 201, December 2021, 107507

Enhanced integration of flow-based market coupling in short-term adequacy assessment

Bashir Bakhshideh Zad [a], Jean-François Toubeau [a], Behzad Vatandoust [a], Kenneth Bruninx [b c], Zacharie De Grève [a], François Vallée [a]

Conferences > 2021 IEEE Madrid PowerTech

Advanced Clustering of Flow-Based Domains for Adequacy Study Purposes

Publisher: IEEE Cite This PDF

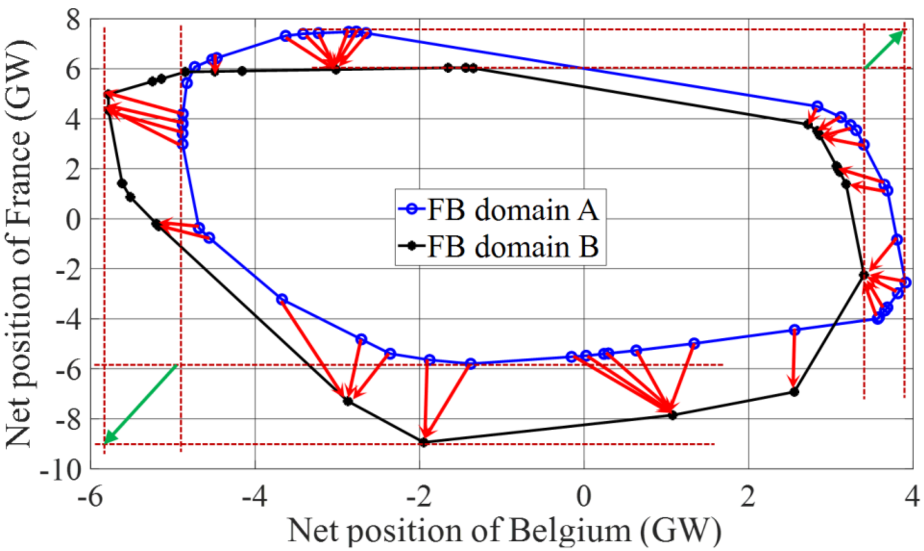
Bashir Bakhshideh Zad ; Behzad Vatandoust ; Jean-François Toubeau ; Zacharie De Grève ; François Vallée All Authors

3-1: Suggested improvements regarding clustering analysis - the choice of the employed distance measure

- It is **currently** based on **overall shape of FB domains.**
- To calculate the **distance between 2 arbitrary FB domains**, the distance between **each vertex** of the first FB domain & its nearest counterpart from the second FB domain **is calculated & added**.
- Considering **several hundred vertices** of a typical 5-D FB domain (thousand vertices for core 13-D), , the **discrepancies of two compared FB domains are covered** in final distance.
- FB domains are eventually estimated rather **similar to each other**.
- It **induces inaccuracies** in FB domain assignment & in subsequent adequacy study.

3-1-1: Proposed Goal-Oriented (GO) clustering [4]

- Focuses on **vertices of flow-based domains** that are **decisive** in an adequacy assessment context.
- During the **scarcity periods**, **net position** of each zone **tends to reach its maximum capacity**, allowed by **flow-based** domain, **to minimize Energy Not Served** (ENS).
- GO calculates the flow-based domain dissimilarities **only w.r.t maximum import and export capacities of each zone:**



* Ref. [4]

3-2: Suggested improvements regarding correlation analysis

- **Two selected explanatory variables** used in correlation study (i.e., FR load and DE wind) would **not be sufficient**.
- Increasing the number of variables creates many more combinations ($= 3^{N_{\exp}} \times N_{cluster}$).
- In specific conditions, **no cluster is sufficiently correlated with any of possible combinations** (having all low probabilities):

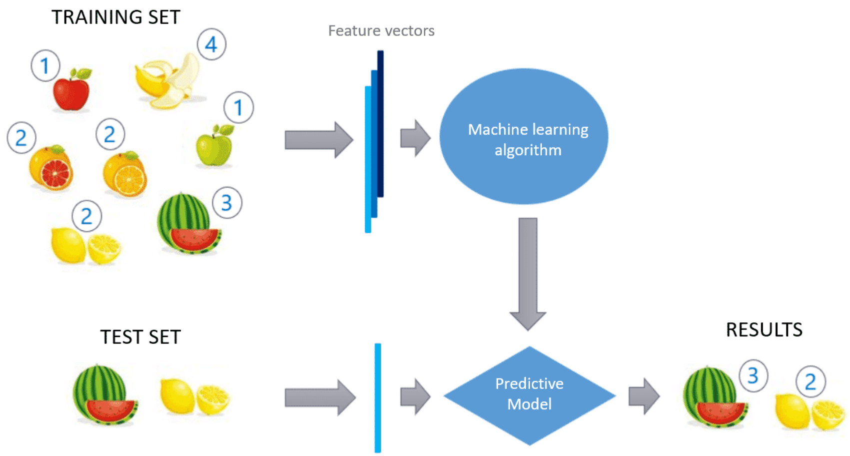
		GERMAN WIND		
		HIGH	MEDIUM	LOW
French load	High	(0.12, 0.69, 0.19)	(0.45, 0.27, 0.27)	(0.58, 0.18, 0.24)
	Medium	(0.24, 0.53, 0.24)	(0.48, 0.24, 0.27)	(0.67, 0.08, 0.24)
	Low	(0.32, 0.25, 0.43)	(0.43, 0.15, 0.43)	(0.47, 0.11, 0.42)

*Ref. [2]
(the case with 3 clusters)

3-2: Suggested improvements regarding <u>correlation</u> analysis: <u>a Classification model</u>

- ✓ A **classification study** (based on **supervised learning**) can be considered as an alternative.
- ✓ It explores the relationships between **<u>several</u> selected** explanatory variables and cluster representatives.
- ✓ Once **classifier is trained**, it can define appropriate cluster based on the received explanatory variables.
- ✓ <u>Different</u> classification methods have been tested [10].
- ✓ Advantages: 1-**No feature scaling**, 2- **<u>Several</u> explanatory variables**.

=> Provides a better **generalization capability**



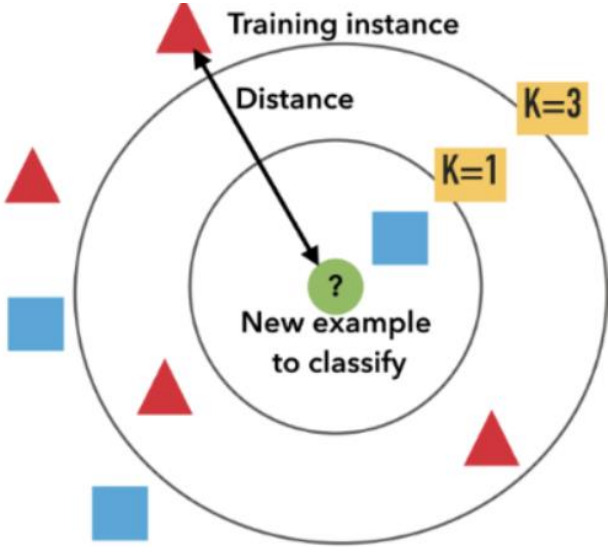
3-3: Direct mapping of explanatory variables of FBMC to FB domains [10]

- Due to various shapes of flow-based domains, **intra-cluster** discrepancies **remain significant**.

=> application of flow-based **cluster representatives leads to erroneous outcomes** in adequacy assessments.

✓ **Supervised learning** is leveraged for **direct mapping** of explanatory variables to FB domains => **no clustering** step

✓ K Nearest Neighbors (KNN) algorithm is adopted.



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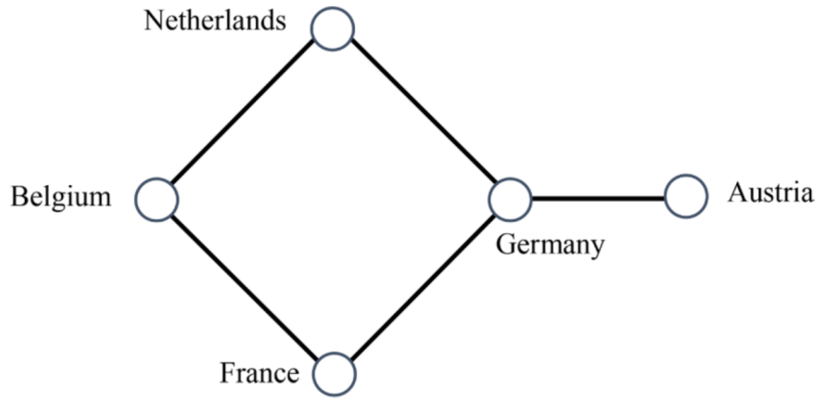
4-1: Database, assumptions, and considerations

- Adequacy assessments are performed on **historical FBMC data** (period from Jan. to Nov. 2020, from [11]).
- Hourly **economic dispatch optimization** defines time steps with **ENS**.
- The **perimeter** of study is **CWE region**.
- Selected explanatory variables of classifier are **aggregated load and generation in 5 CWE zones**.
- "**Fast-kmed**" algorithm is employed for clustering analysis [12].
- Performance of each model is evaluated **w.r.t the groundtruth** (i.e., direct integration of hourly FB domains in economic dispatch study).



4-2: Description of tested models

Case no.	Considered model	Model details		
		Clustering technique	Method for mapping FB data	Impact on adequacy assessment
1	Direct modeling	NA	KNN classification	Predicted FB is considered
2 TSOs	SB clustering-correlation	SB	Correlation	Predicted cluster representative is considered
3	SB clustering-classification	SB	KNN classification	Predicted cluster representative is considered
4	SB clustering, no mapping	SB	NA	True cluster representative is considered
5	GO clustering-correlation	GO	Correlation	Predicted cluster representative is considered
6	GO clustering-classification	GO	KNN classification	Predicted cluster representative is considered
7	GO clustering, no mapping	GO	NA	True cluster representative is considered
Reference case	NA	NA	NA	True FB is considered

Best method (cases 1–7)

vs (cases 2 and 3)

vs (cases 4–7)

vs (cases 5 and 6)

4-3: Results with respect to ground truth

Δ_{LOLP} (in Percentage Point) Obtained using Studied Case 1

Case no.	Considered model	Δ_{LOLP} (Percentage Point)
1	Direct classification	0.73

Δ_{LOLP} (in Percentage Point) Obtained using Studied Cases 2 to 7 for Various Numbers of Clusters

Case no.	Considered model	*Number of clusters (n)*								
		2	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
2 TSOs	SB clustering-correlation	4.8	4.84	3.66	**3.26**	3.58	3.65	3.7	6.35	5.75
3	SB clustering-classification	4.96	5.12	4.91	4.95	4.9	4.9	5.09	5.03	**4.83**
4	SB clustering, no mapping	5.2	5.04	5.03	5.03	5.16	5.16	5.06	**4.9**	4.95
5	GO clustering-correlation	6.71	4.04	4.49	3.48	**3.34**	3.86	4.57	4.69	3.61
6	GO clustering-classification	8.03	8	8	2.42	2.31	1.93	**1.35**	2.22	1.73
7	GO clustering, no mapping	7.87	7.94	8.06	2.48	2.39	1.87	**1.5**	2.82	2

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5: Conclusion

1. GO clustering-classification can **enhance** performance of classical shape-based clustering-correlation method (TSOs).
   - GO clustering **improves accuracy**, **reduces computational burden**, provides a **suitable scalability** considering perspective of FBMC Core extension.
   - Classification can **more accurately** identify the correct cluster representative and **lower inaccuracies** within correlation study.
2. The **direct mapping** of explanatory variables to FB domains **outperforms** **all combinations** of two-step methodologies.
   - It **significantly reduces the errors**.
   - It does **not comprise** of **any hyper parameter (**e.g., number of clusters).
   - It **eliminates the computational complexity** of clustering study.

Thanks for

your attention

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