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Benchmarking of European electricity supply resilience: the case of interacting criteria

13th International Conference on Energy and Climate Change,

October 9th, 2020

Presentation Overview

1. Introduction and scope
2. Basic concepts
3. Problem description and modelling
4. Methodological framework
5. Electricity supply resilience in Europe
6. Conclusions

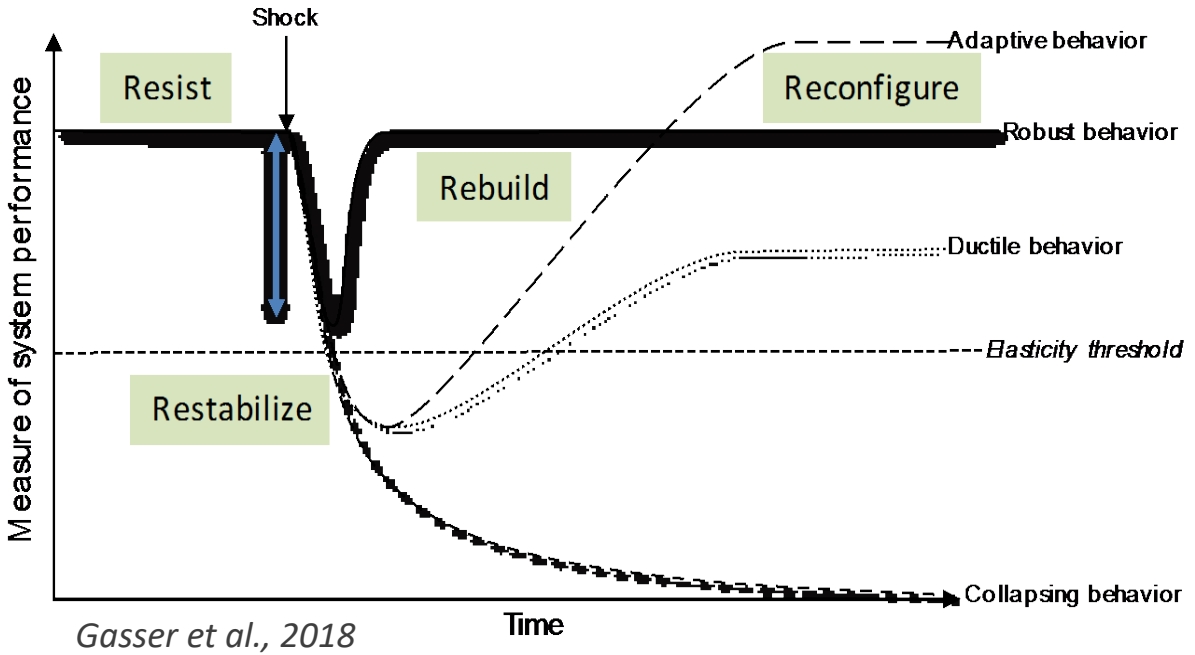
Resilience and energy security definitions

Energy security: *The uninterrupted availability of energy sources at an affordable price (IEA, 2014)*

Energy Resilience: *The ability to prepare and plan for, absorb, respond, recover from, and more successfully adapt to adverse events (US Academies of Sciences)*

Classic Resilience Dimensions:

1. Resist
2. Restabilize
3. Rebuild
4. Reconfigure



Gasser et al., 2018

Rationale and research scope

- ✓ Reliable and secure supply of electricity is critical for modern societies
  - *Energy needs are increasing*
  - *Electricity represents a substantial growing share of EU's total final energy consumption*
  - *Most EU countries are net energy importers while certain strongly rely on a single fuel source or technology for electricity production*

- ✓ *Severe disruptions, as well as minor ones, do occur due to either exogenous or endogenous factors*

- ❑ *Develop a comprehensive decision support model to evaluate the resilience of electricity supply*
- ❑ *Address the potential interactions between the indicators*
- ❑ *Evaluate and rank the 35 ENTSO-E countries*

Problem description

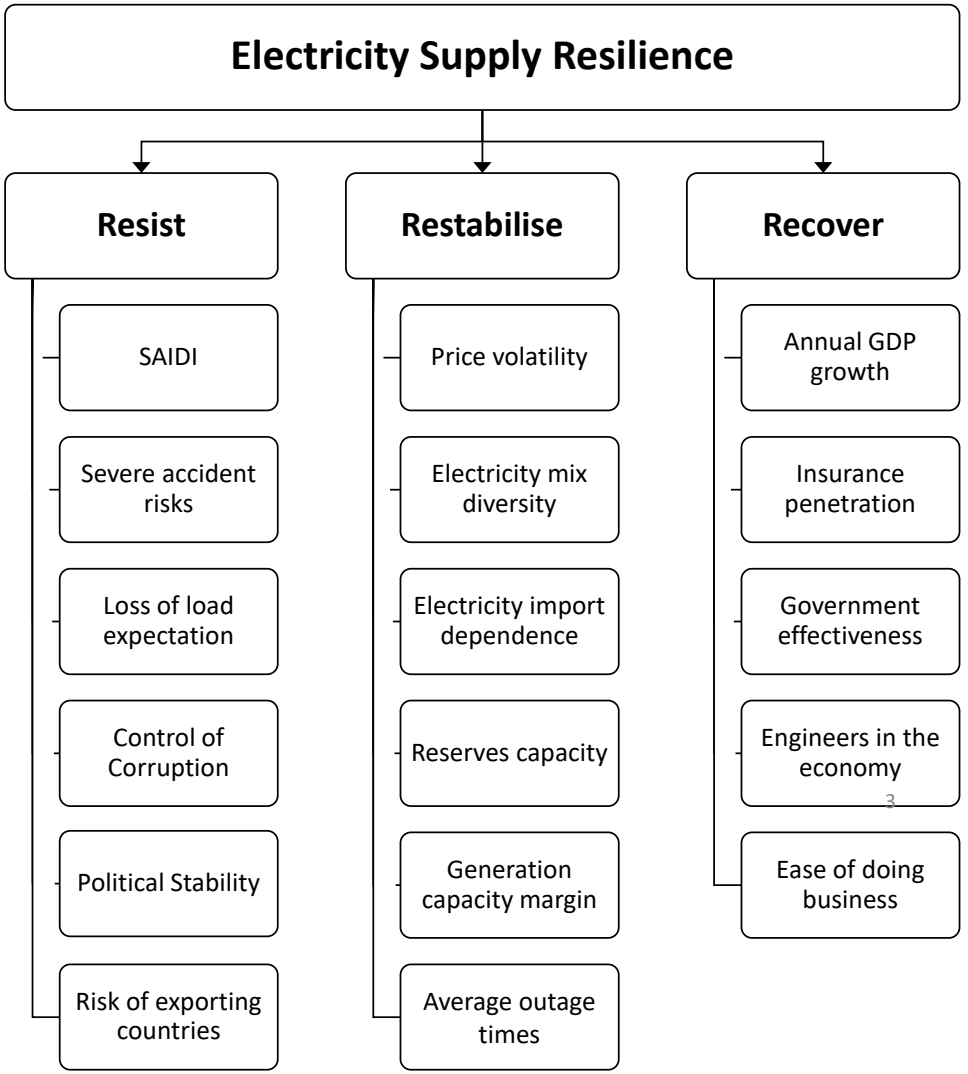
Evaluation of the electricity supply resilience in Europe

- Development of an evaluation model at a country level, based on a consistent and exhaustive set of evaluation criteria
- 35 European ENTSO-E countries under evaluation
- Ranking of the countries in descending order of resilience
- Incorporation to the evaluation system of the preferential parameters of an energy expert (Decision Maker)

Electricity Supply Resilience evaluation system

35 ENTSO-E
European Countries

1. Albania	19. Latvia
2. Austria	20. Lithuania
3. Belgium	21. Luxembourg
4. Bosnia and Herzegovina	22. Montenegro
5. Bulgaria	23. Netherlands
6. Croatia	24. North Macedonia
7. Cyprus	25. Norway
8. Czech Republic	26. Poland
9. Denmark	27. Portugal
10. Estonia	28. Romania
11. Finland	29. Serbia
12. France	30. Slovak Republic
13. Germany	31. Slovenia
14. Greece	32. Spain
15. Hungary	33. Sweden
16. Iceland	34. Switzerland
17. Ireland	35. United Kingdom
18. Italy	



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Consistent family of criteria

#	Criterion	Worst country	Best country	Normalization Range	Measurement unit
1	SAIDI	40.3	0.1	[5, 0]	h/year
2	Severe accident risks	4.92	0.008	[2, 0]	# of fatalities / GWeyr
3	Loss of Load expectation	76.5	0	[5, 0]	h/year
4	Control of Corruption	-0.6	2.2	[-0.6, 2.3]	Composite indicator
5	Political stability	-0.39	1.41	[-0.40, 1.42]	Composite indicator
6	Risk of exporting countries	0.43	0	[1, 0]	0-1 indicator
7	Volatility of prices	0.187	0.024	[0.2, 0.0]	% index
8	Electricity mix diversity	0	0.84	[0, 1]	0-1 indicator
9	Electricity import dependence	3.67	0.79	[2, 0.5]	% dimensionless indicator
10	Reserves capacity	2	20	[2, 20]	% index
11	Generation capacity margin	0.04	0.76	[0, 1]	% index
12	Average outage time	4.40	0.33	[0, 4]	hours
13	Annual GDP growth	0.73	9.45	[-1, 5]	% index
14	Insurance penetration	0.70	7.50	[0, 5]	Composite indicator
15	Government effectiveness	-0.62	2.04	[-0.6, 2.0]	Composite indicator
16	Engineers in the economy	0.06	0.32	[0, 0.3]	% index
17	Ease of doing business	65.4	85.3	[60, 100]	Composite indicator

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Methodological framework (1/6)

The development of the evaluation system for the ranking of the countries is based on a synergy of MCDA methods and techniques;

- ✓ The Simos procedure (method of the cards) for the elicitation of the criteria weights
- ✓ A heuristic framework for the elicitation and quantification of interactions between the criteria
- ✓ Implementation of the Choquet integral for the calculation of the resilience score of each country

Methodological framework (2/6)

- Simos method
  - *Criteria cards*
  - *White cards*
  - *Fasteners*

→ Hierarchy given by the Decision Maker

- Calculation of the criteria weights by the analyst, based on the hierarchy information given by the DM

Methodological framework (3/6)

Implementation of the Simos procedure with the DM

1. The procedure begins with the categorization of the 17 criteria to three categories; **low importance, medium importance and high importance** by the DM.
2. The DM, after confirming his categorization, ranks the criteria in each group **from the most important to the least important one**. For the case of criteria with equal importance, he can clip the corresponding cards with a clipper.
3. The DM is finally asked to indicate the number of **white cards** to be inserted between consecutive criteria and the different importance groups, to indicate a greater importance gap.

Methodological framework (4/6)

The Choquet Integral for the consideration of interacting pairs of criteria

The Choquet integral is a score assigning function, built with the rationale to assign **a bonus** in the case of positive interaction or **a penalty** in the case of negative interaction, incurred for interaction between some pairs of criteria.

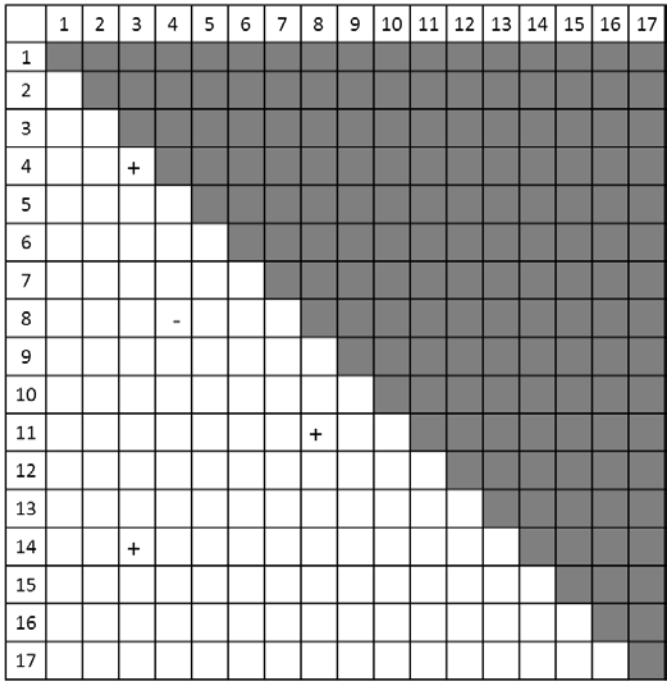
- **Positively interacting criteria:** a pair of criteria that must be simultaneously satisfied so that they can impact the aggregation result (complementary effect)
- **Negatively interacting criteria:** a pair of criteria, for which a high aggregation value can be obtained even when only one of the criteria presents a good score (redundancy effect)

$$C_\mu(a) = \sum_{i \in G} m_i \; g_i(a) + \sum_{\{i,j\} \in G} m_{i,j} \; min\{g_i(a), g_j(a)\}$$

Methodological framework (5/6)

Completion of the interaction table by the DM. (+) for positive interactions (-) for negative interactions

- Guidance and dialogue with the analyst for the completion
- Data correlations can also guide the completion. In general:
  - ✓ Positive correlation indicates a potential negative interaction
  - ✓ Negative correlation indicates a potential positive interaction
- Just a small number of interacting pairs is usually the case, and needs to be identified



An example of a completed interactions table

Methodological framework (6/6)

Quantification of interactions

1. The DM is asked to **categorize the interacting pairs** in two categories, based on the **intensity** of these interactions
2. The DM provides some simple additional information, such as pairwise comparisons, most and least intense interactions, etc.

The analyst then, builds an equations and inequalities system, based on the DM's input, in order to estimate the intensity of the interactions and feed the Choquet integral

ESR evaluation

Implementation of the Simos procedure

Categorization of the 17 criteria to three importance categories/priorities by the DM

High Importance	Medium Importance	Low Importance
g_1. SAIDI	g_3. Loss of load expectation	g_7. Volatility of electricity prices
g_2. Severe accident risks	g_4. Control of corruption	g_{11}. Generation capacity margin
g_5. Political stability and absence of violence/ terrorism	g_6. Risk of exporting countries	g_{12}. Average outage times
g_8. Electricity mix diversity	g_{13}. Average GDP growth	g_{14}. Insurance penetration
g_9. Electricity import dependence	g_{15}. Government effectiveness	g_{16}. Engineers in the economy
g_{10}. Reserves capacity		g_{17}. Ease of doing business

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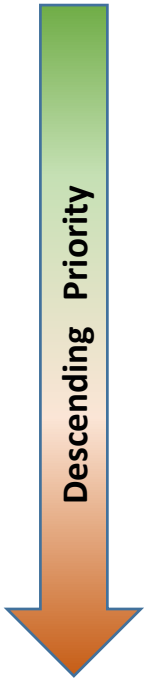
ESR evaluation

Implementation of the Simos procedure

Rank-ordering of the criteria in each category from the most important to the least important one



High Importance	Medium Importance	Low Importance
g_1. SAIDI	g_6. Risk of exporting countries	g_{11}. Generation capacity margin
g_8. Electricity mix diversity	g_3. Loss of load expectation, g_{15}. Government effectiveness	g_{12}. Average outage times
g_9. Electricity import dependence	g_{13}. Average GDP growth	g_{17}. Ease of doing business, g_{14}. Insurance penetration
g_5. Political stability and absence of violence/ terrorism	g_4. Control of corruption	g_7. Volatility of electricity prices
g_{10}. Reserves capacity, g_2. Severe accident risks		g_{16}. Engineers in the economy

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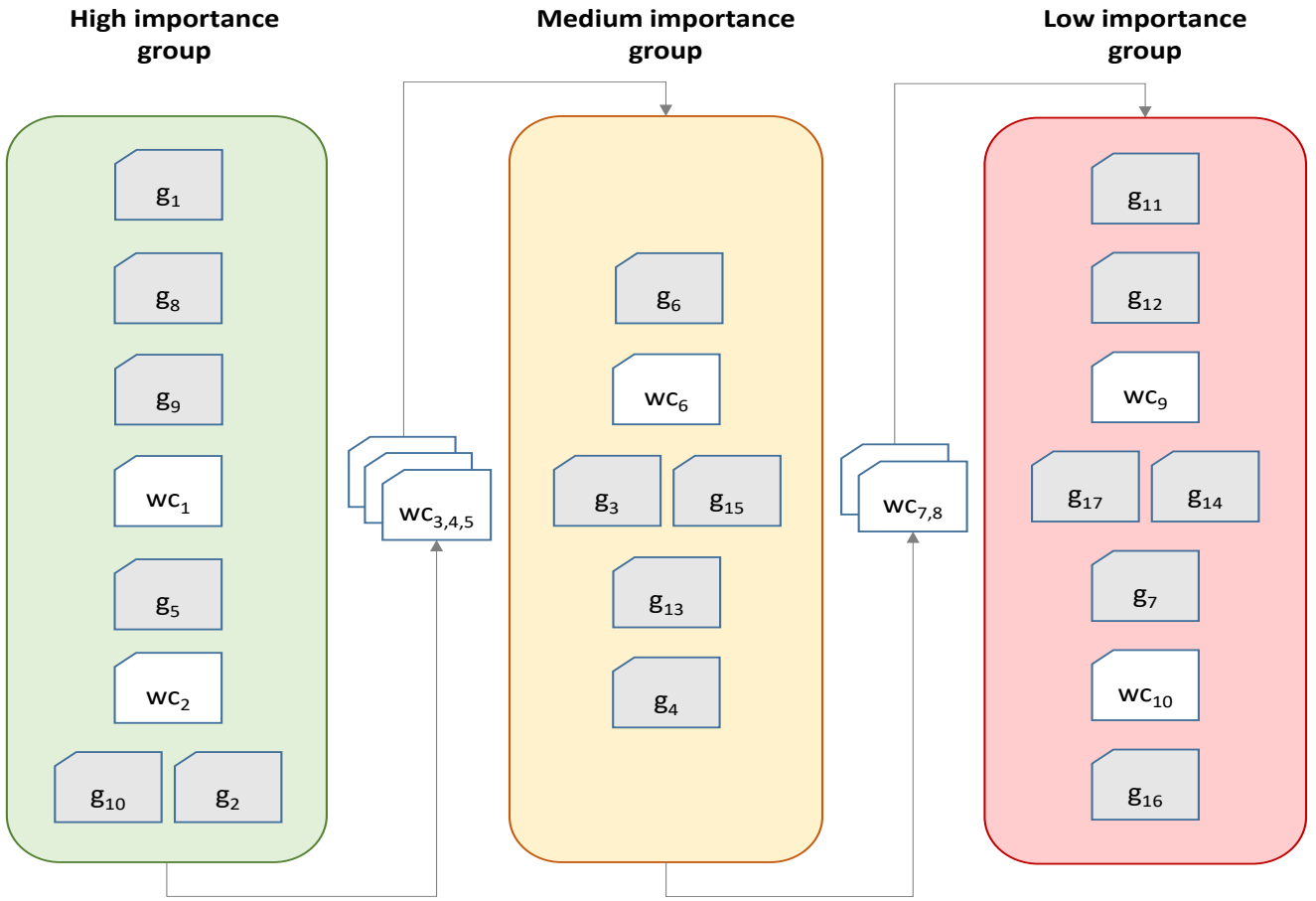
ESR evaluation

Implementation of the Simos procedure

Insertion of white cards between subsequent criteria and importance groups



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ESR evaluation

Identification of interacting criteria pairs

Completion of the interactions chart by the DM

Partial guidance by the correlations chart, provided by the analyst

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1																	
2																	
3	-																
4		-															
5																	
6																	
7																	
8						+											
9								+									
10																	
11									+	-							
12																	
13																	
14																	
15				-													
16																	
17															-		

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ESR evaluation

Quantification of interactions

Categorization of the interacting pairs in two categories; weak and strong interactions

Positive and negative interactions are treated equally here

	Strong interactions		Weak interactions
$m_{4,15}$	g_4 & g_{15} Control of Corruption & Government effectiveness	$m_{2,4}$	g_2 & g_4 Severe accident risks & Control of Corruption
$m_{1,3}$	g_1 & g_3 SAIDI & Loss of Load expectation	$m_{10,11}$	g_{10} & g_{11} Reserves capacity & Generation capacity margin
$m_{15,17}$	g_{15} & g_{17} Government effectiveness & Ease of doing business	$m_{8,9}$	g_8 & g_9 Electricity mix diversity & Electricity import dependence
$m_{6,8}$	g_6 & g_8 Risk of exporting countries & Electricity mix diversity		
$m_{9,11}$	g_9 & g_{11} Electricity import dependence & Generation capacity margin		

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ESR evaluation

Quantification of interactions

Additional information are provided by the DM, with a view to quantifying the defined interactions:

- $m_{4,15}$ is the most intense interaction of all 8
- $m_{15,17}$ is the second most intense interaction
- $m_{2,4}$ is the least intense interaction of all 8
- $m_{10,11}$ is the second least intense interaction
- $m_{4,15}$ is 4 to 5 times more intense than $m_{2,4}$

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ESR evaluation

Calculation of the model parameters

- The transformation of the criteria hierarchy to mathematical equations and inequalities leads to a system, the solution of which generates the criteria weights, m_i
- Accordingly, the solution of the interactions equations and inequalities system results in the quantification of the interactions, $m_{\mathrm{i,j}}$

Criteria weights

$m_1 = 0.133,\quad m_2 = 0.112,\quad m_3 = 0.104,$
$m_4 = 0.114,\quad m_5 = 0.094,\quad m_6 = 0.098,$
$m_7 = 0.068,$

$m_8 = 0.057,\quad m_9 = 0.036,\quad m_{10} = 0.062,$
$m_{11} = 0.033,\quad m_{12} = 0.019,\quad m_{13} = 0.034,$
$m_{14} = 0.015,$

$m_{15} = 0.029,\ m_{16} = 0.012,\ m_{17} = 0.001$

Negative interactions

$m_{4,15} = -0.019$
$m_{1,3} = -0.012$
$m_{15,17} = -0.014$
$m_{2,4} = -0.004$
$m_{10,11} = -0.008$

Positive interactions

$m_{9,11} = 0.012$
$m_{6,8} = 0.012$
$m_{8.9} = 0.010$

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ESR evaluation

Choquet Integral implementation

Calculation of the Choquet Integral and ranking of the countries

Rank	Countries	Score
1	Denmark	0.802
2	Switzerland	0.794
3	Iceland	0.768
4	Sweden	0.765
5	Germany	0.743
6	Ireland	0.731
7	Slovenia	0.728
8	Austria	0.728
9	Netherlands	0.727
10	Slovak Republic	0.699
11	Lithuania	0.698
12	Finland	0.698
13	Luxembourg	0.698
14	Czech Republic	0.695
15	Belgium	0.694
16	Estonia	0.693
17	Portugal	0.690
18	Norway	0.677
19	Spain	0.650
20	France	0.640
21	Poland	0.621
22	United Kingdom	0.617
23	Latvia	0.617
24	Croatia	0.601
25	Hungary	0.601
26	Cyprus	0.586
27	Romania	0.581
28	Italy	0.532
29	Greece	0.482
30	Montenegro	0.467
31	Bosnia and Herzegovina	0.466
32	North Macedonia	0.410
33	Serbia	0.409
34	Bulgaria	0.408
35	Albania	0.361

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Conclusions

- ✓ The importance and need for measuring and benchmarking national electricity supply resilience is highlighted.
- ✓ The incorporation of interacting criteria in a large scale real decision problem constitutes a novelty in the field of Decision Theory and Operational Research
- ✓ A generalized MCDA methodology is proposed, in order to aggregate the evaluation indicators and soundly accommodate interacting criteria.
- ✓ Big winners of the benchmark the interconnected northern EU countries, Balkans still lack behind and more susceptible to electricity disruptions
- ✓ This research work aims to support energy policy decision making in Europe and provide guidelines and areas for improvement at a country level

Wir schaffen Wissen – heute für morgen

The authors:
Dr. Siskos E. and
Dr. Burgherr P.

acknowledge funding from the:

Swiss Competence Center for Energy Research (SCCER) - Supply of Electricity (SoE)

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SUPPLY of ELECTRICITY

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 701647