

Power System Modeling and Market Integration

Dr. ir. Pieter Schavemaker

DIAM-TU DELFT Seminar on Future Challenges in Modeling Power Systems

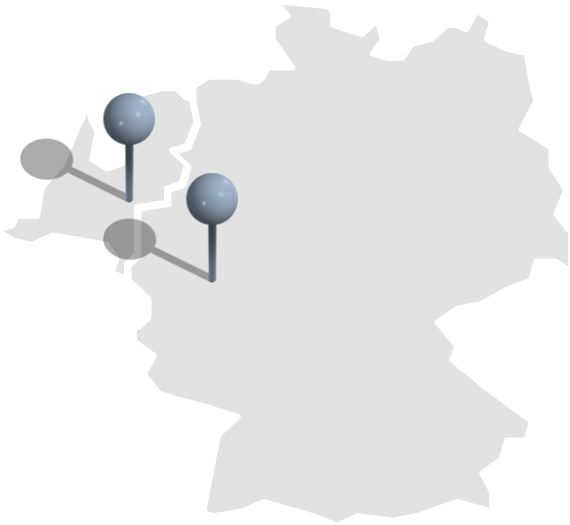
TU Delft, The Netherlands

22 November 2012

E-Bridge
competence in energy

Who is E-Bridge

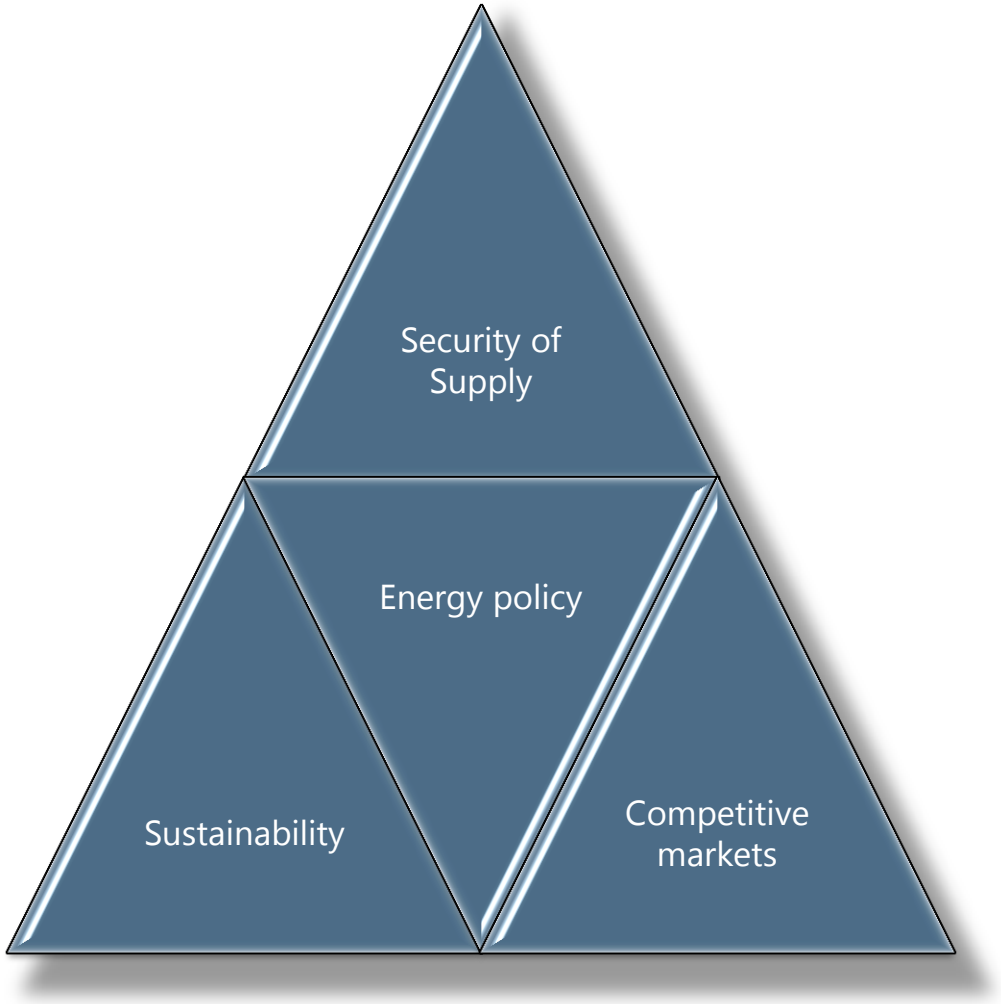
- E-Bridge is an international consulting firm specialized in the electricity and gas supply industries. E-Bridge bridges the gap between high-level corporate strategy and technical implementation
- Extensive experience in market restructuring and regulation
  - From CWE to the Nordic region, Germany, Austria, Poland, South-Korea, Belarus and Bulgaria
- Linked with an extensive operational experience in the energy industry
- Strong competence in adapting operating and planning processes to balance "quality of supply", "costs" and "risks"
- E-Bridge operates from two offices
  - Germany, Bonn, with 15 consultants and associate consultants
  - The Netherlands, Oosterbeek (Arnhem area), with 2 consultants



Contents

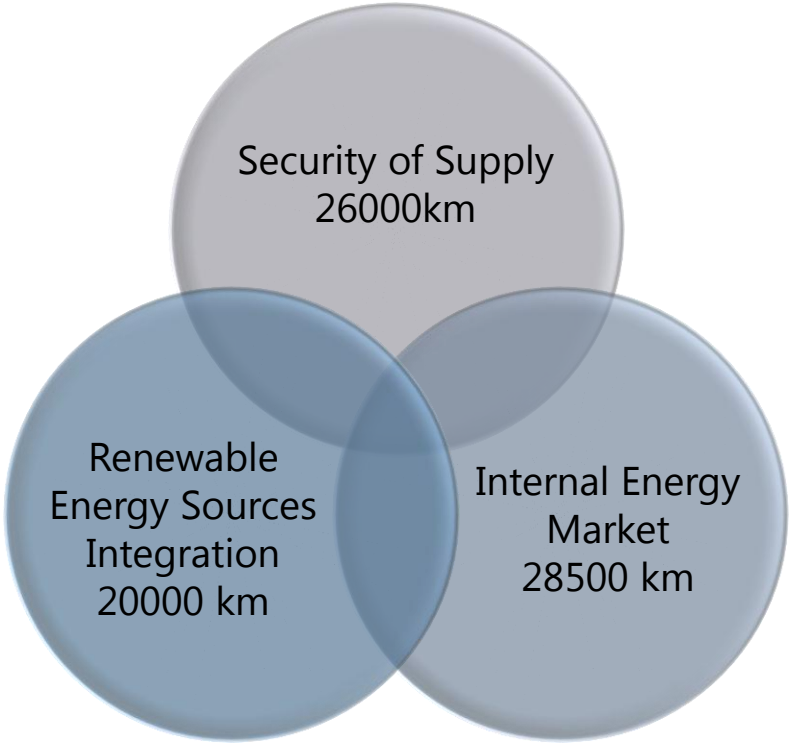
- European energy policy
- Focus on the Day-Ahead market
  - Market coupling
  - Flow based grid modelling
  - Zone delineation

Three cornerstones of energy policy

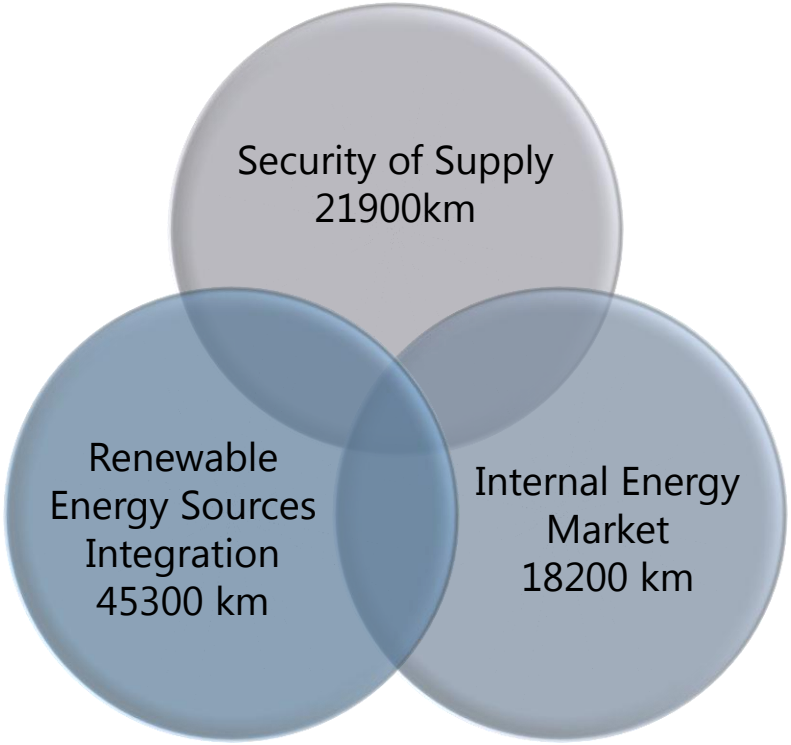


ENTSO-E's Ten Year Network Development Plan

TYNDP 2010



TYNDP 2012



Source: ENTSO-E TYNDP

Increased cooperation and coordination on European level
TSO cooperations to safeguard the Security of Supply

TSOs served by Coreso

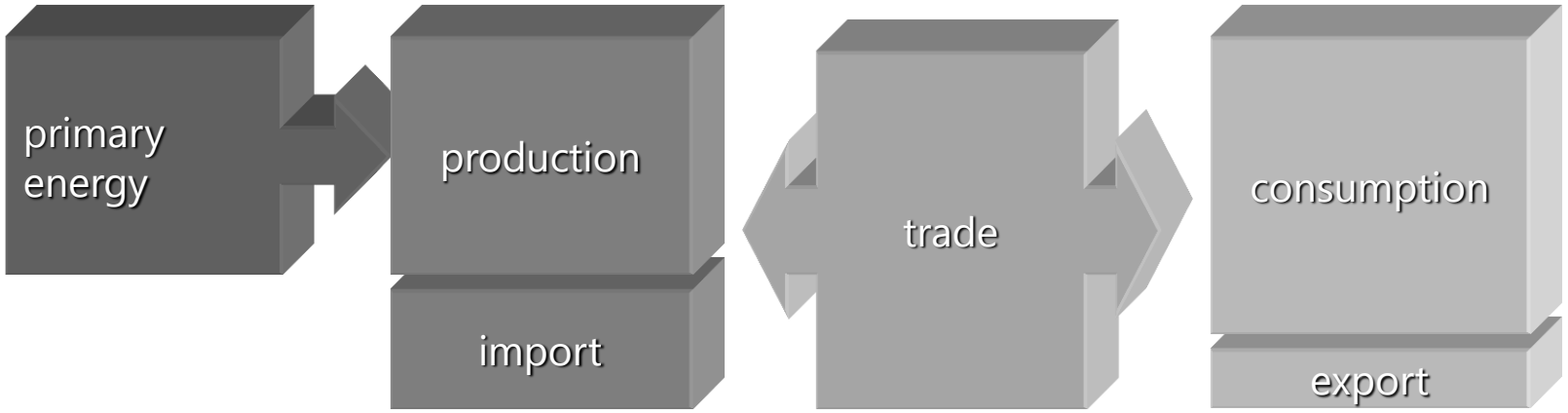
TSOs cooperating in TSC

Increased cooperation and coordination on European level
Central auction offices to facilitate the market

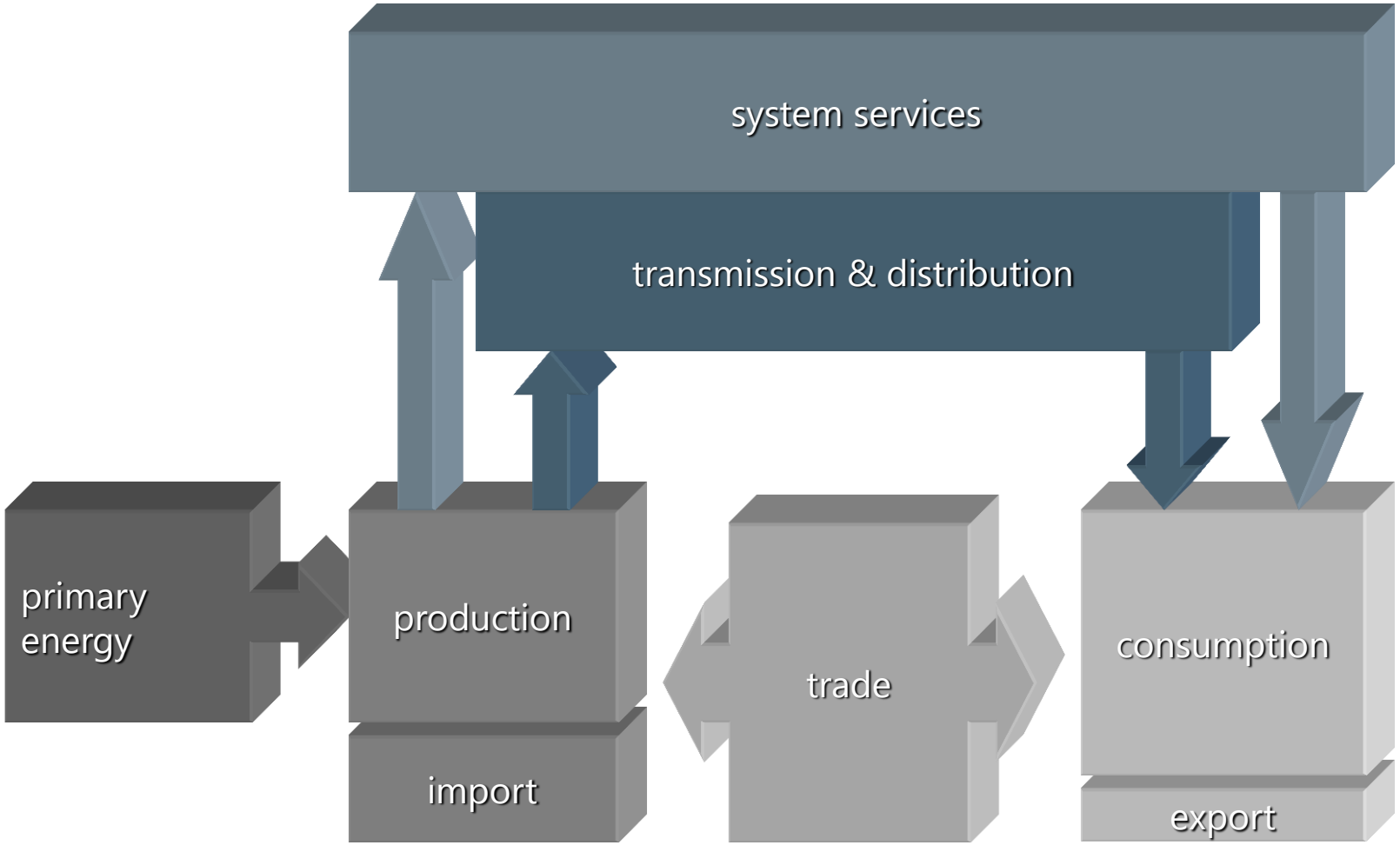
Borders served by CASC

Borders served by CAO

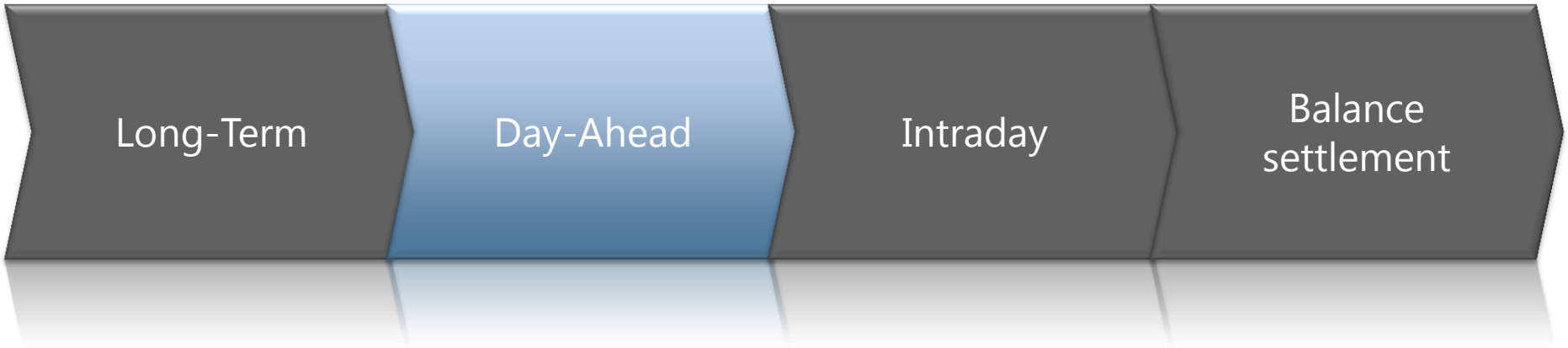
Organization of the electricity market



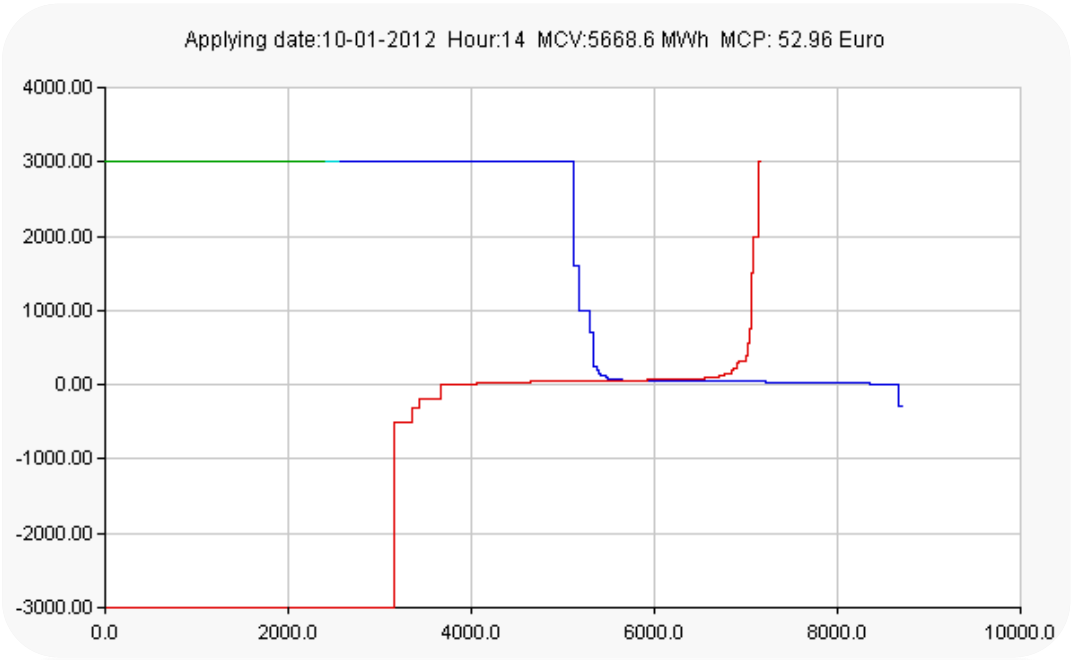
Organization of the electricity market



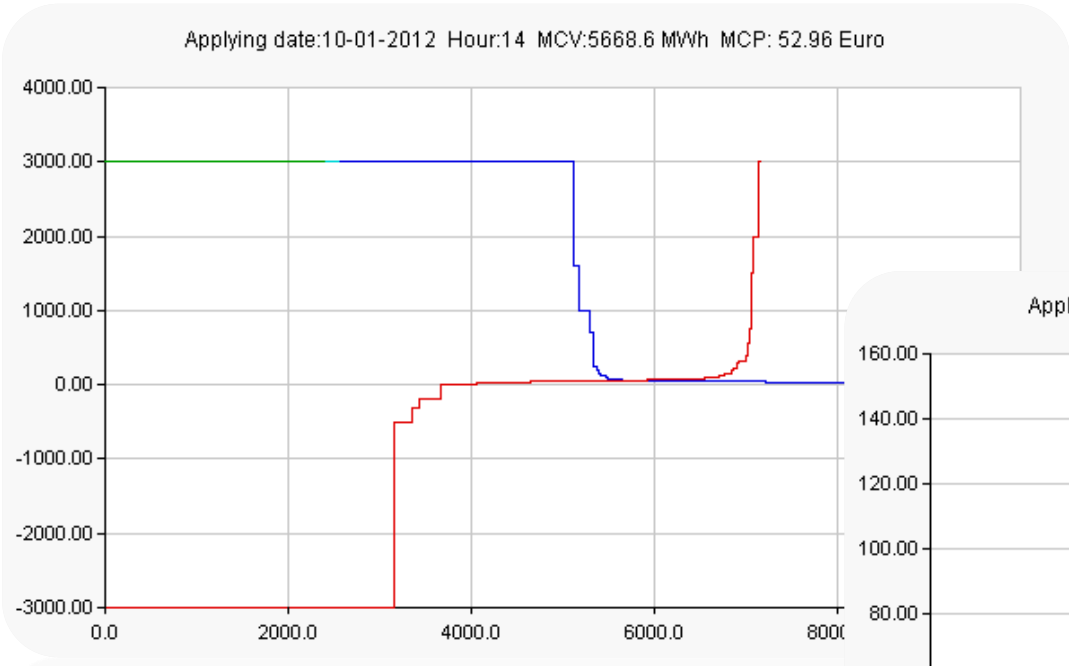
Market segments

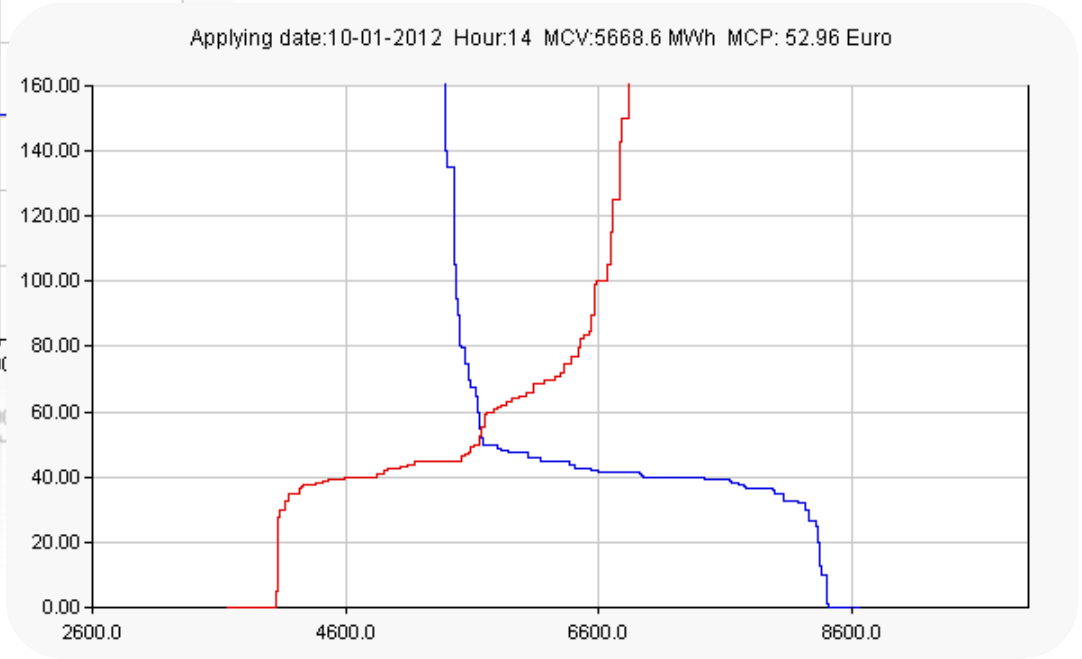


Example bid curves APX (Amsterdam Power Exchange)



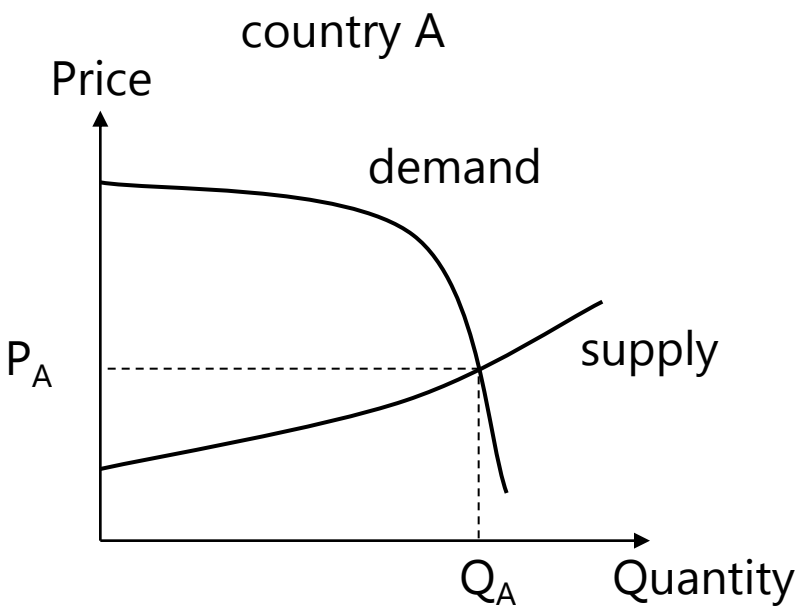
Example bid curves APX (Amsterdam Power Exchange)





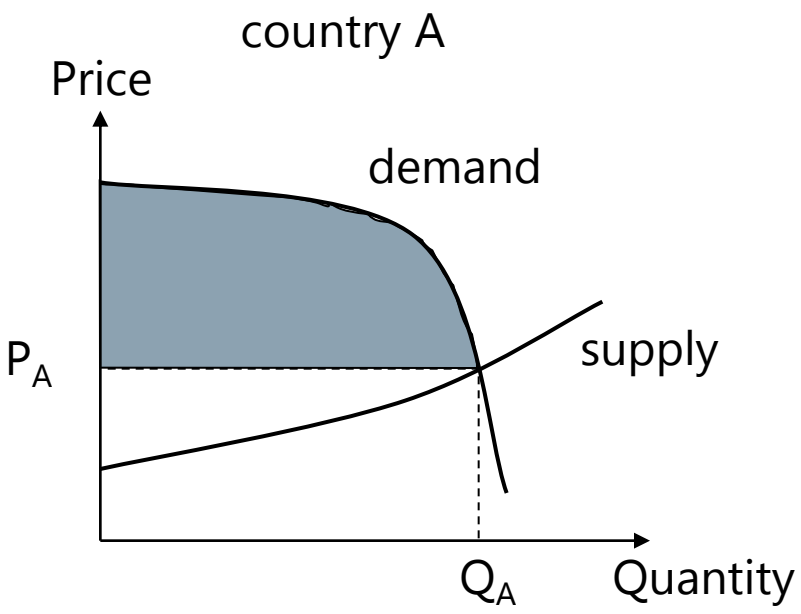
Net Position
Purchase Block Orders
Purchase Limit Orders
Sale Block Orders
Sale Limit Orders

Social Welfare



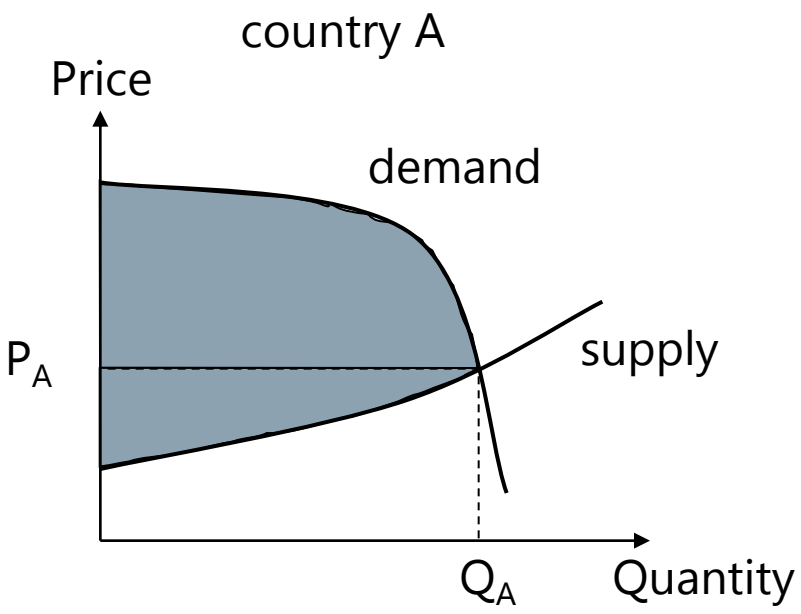
Social welfare = consumer surplus + producer surplus

Social Welfare



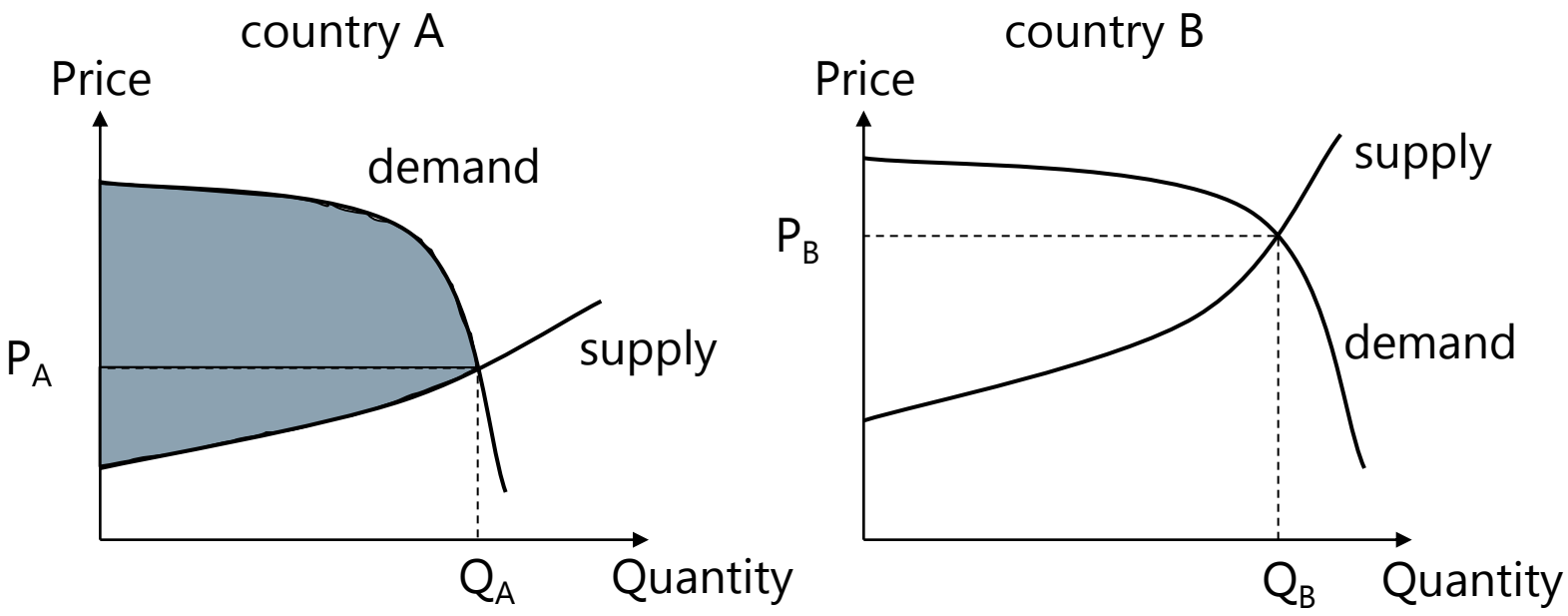
Social welfare = consumer surplus + producer surplus

Social Welfare



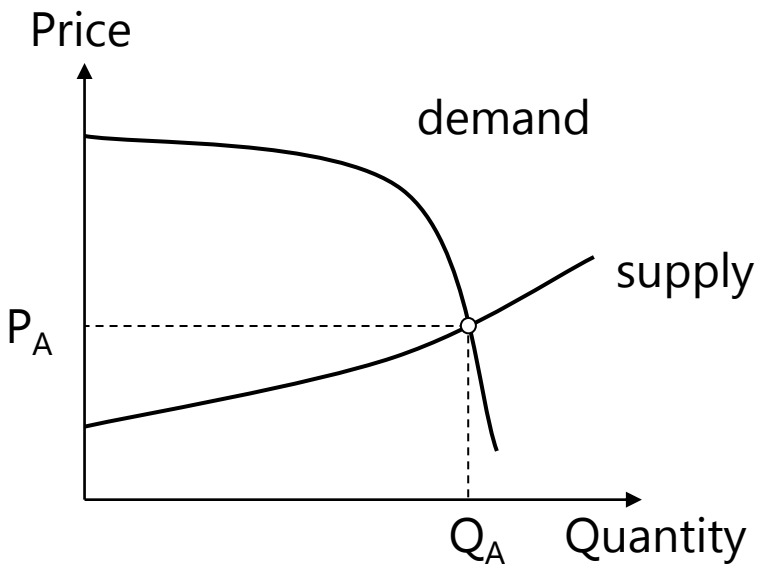
Social welfare = consumer surplus + producer surplus

Social Welfare

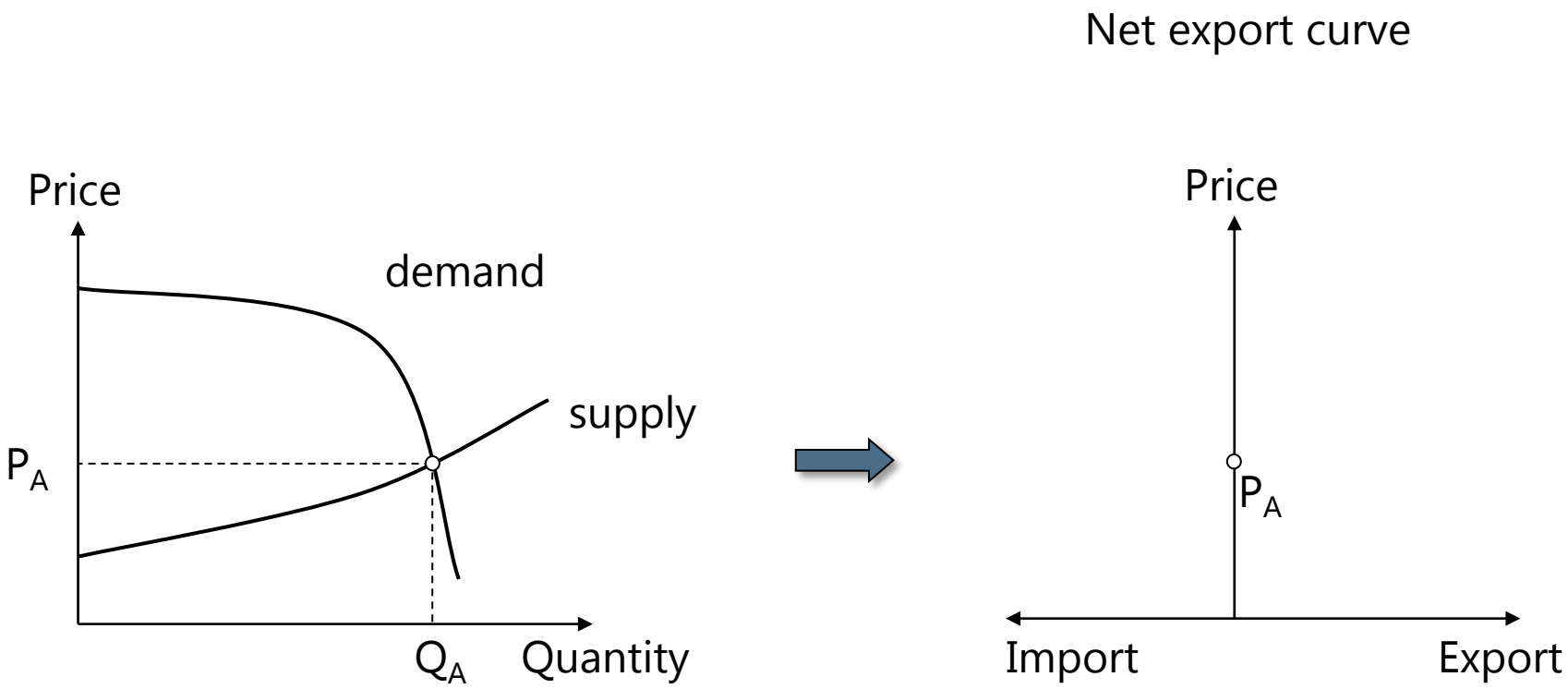


Social welfare = consumer surplus + producer surplus

Relation between price and import and export

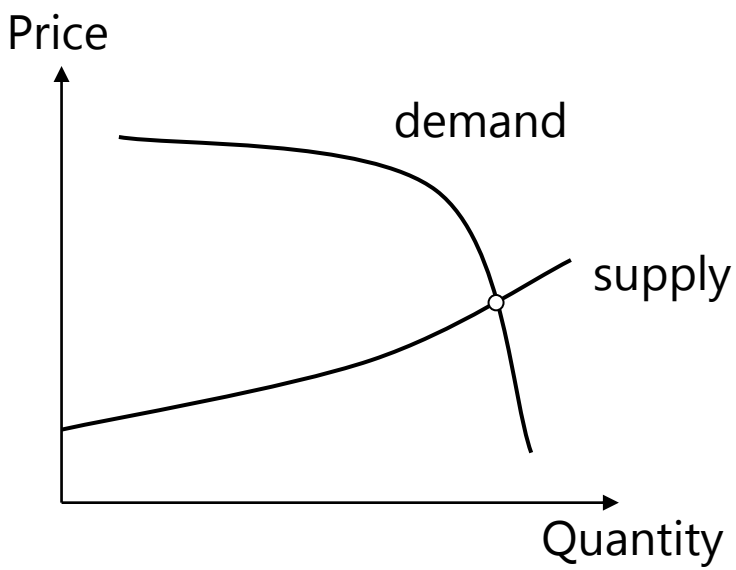


Relation between price and import and export

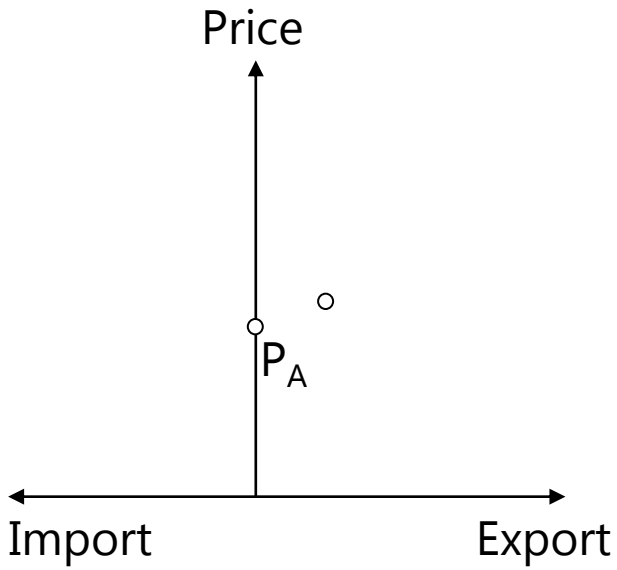


Relation between price and import and export

A: export

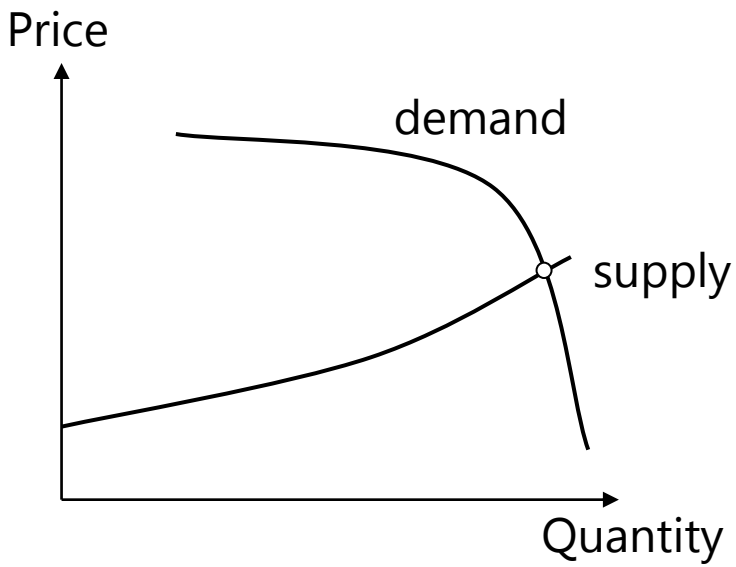


Net export curve

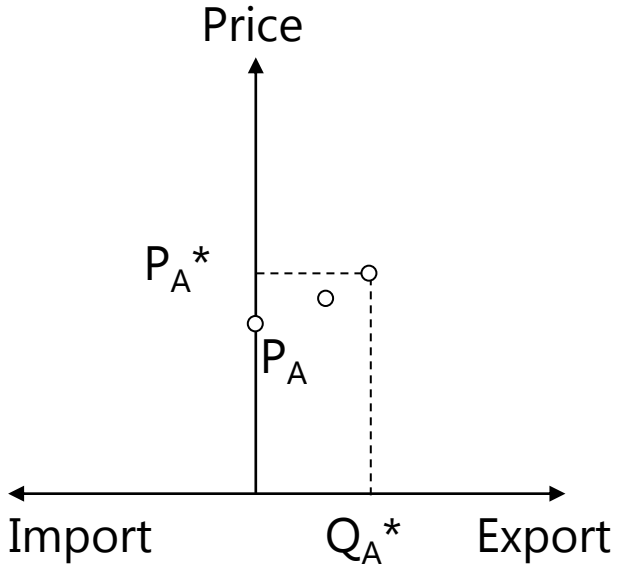


Relation between price and import and export

A: export

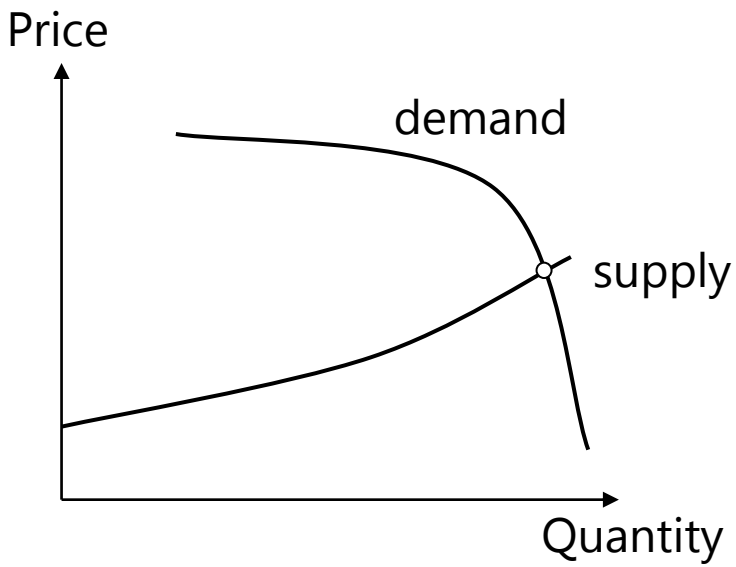


Net export curve

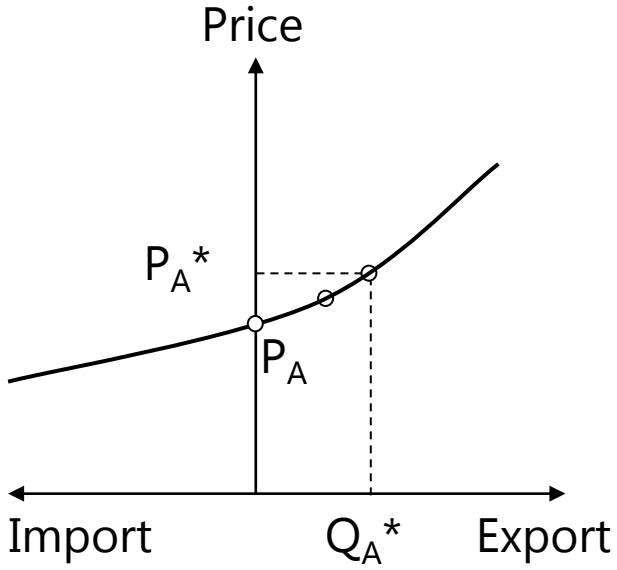


Relation between price and import and export

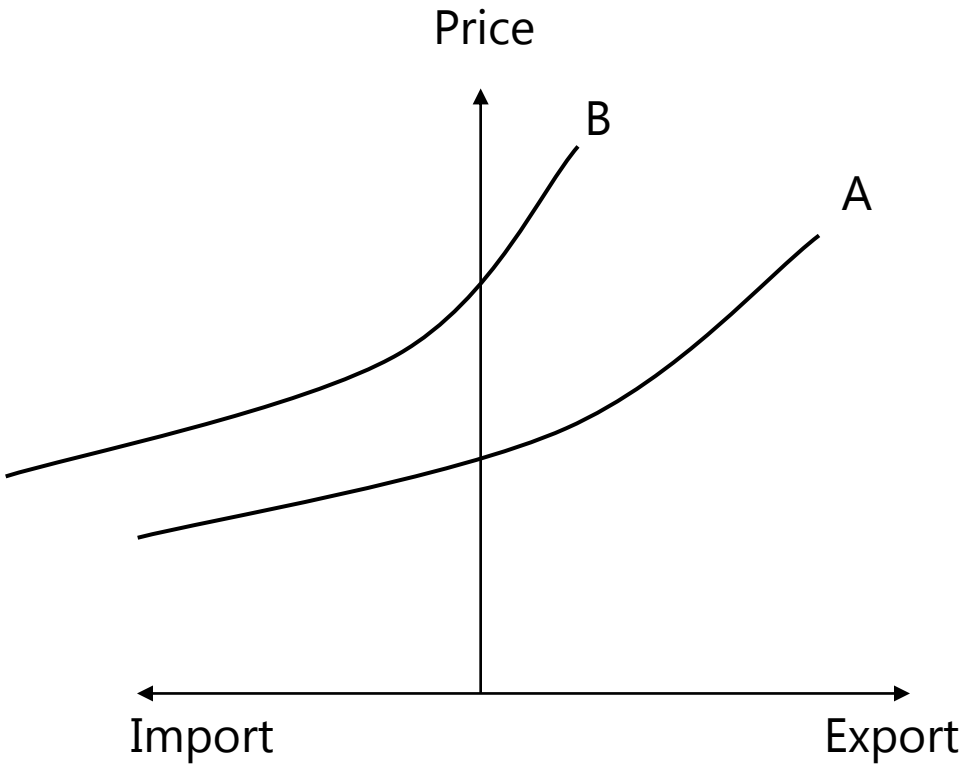
A: export



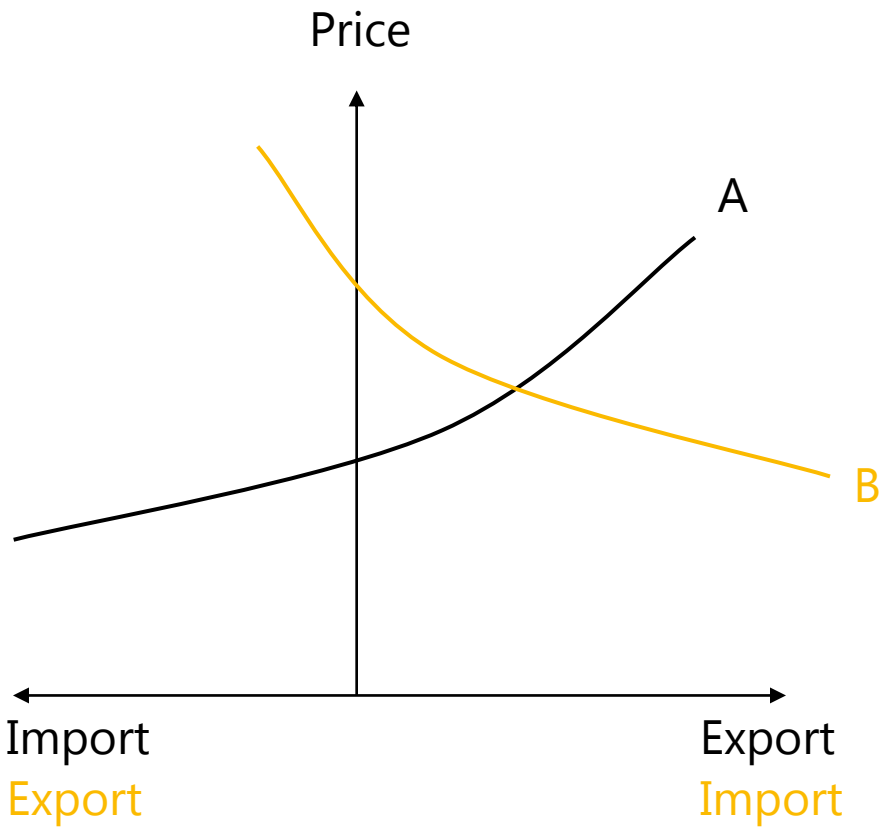
Net export curve



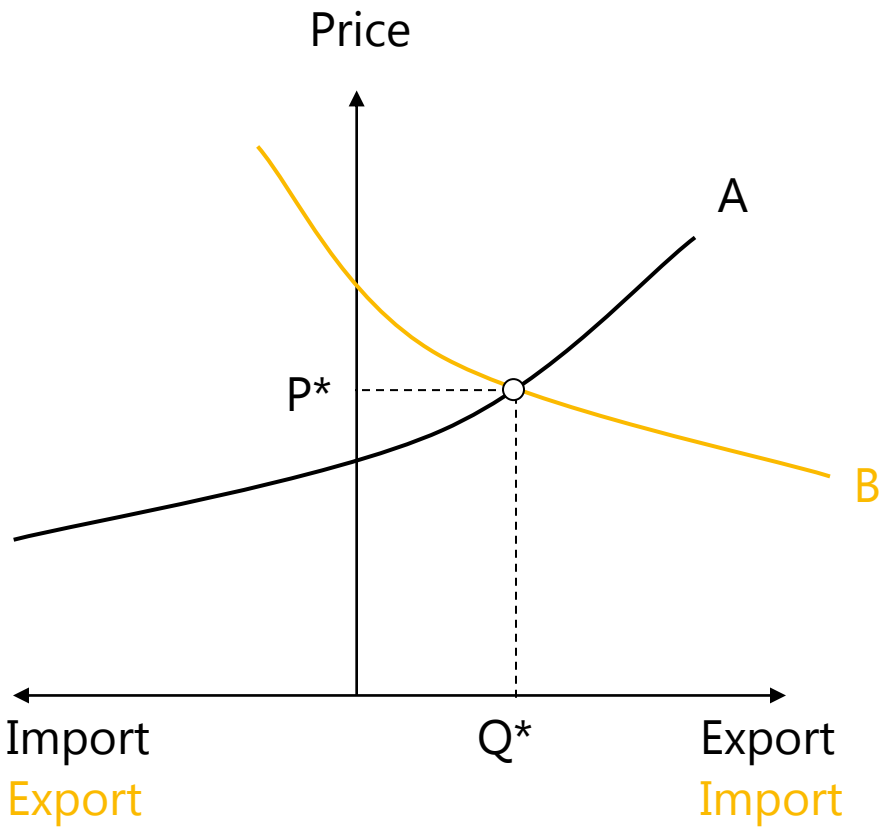
Increase of Social Welfare by Import and Export



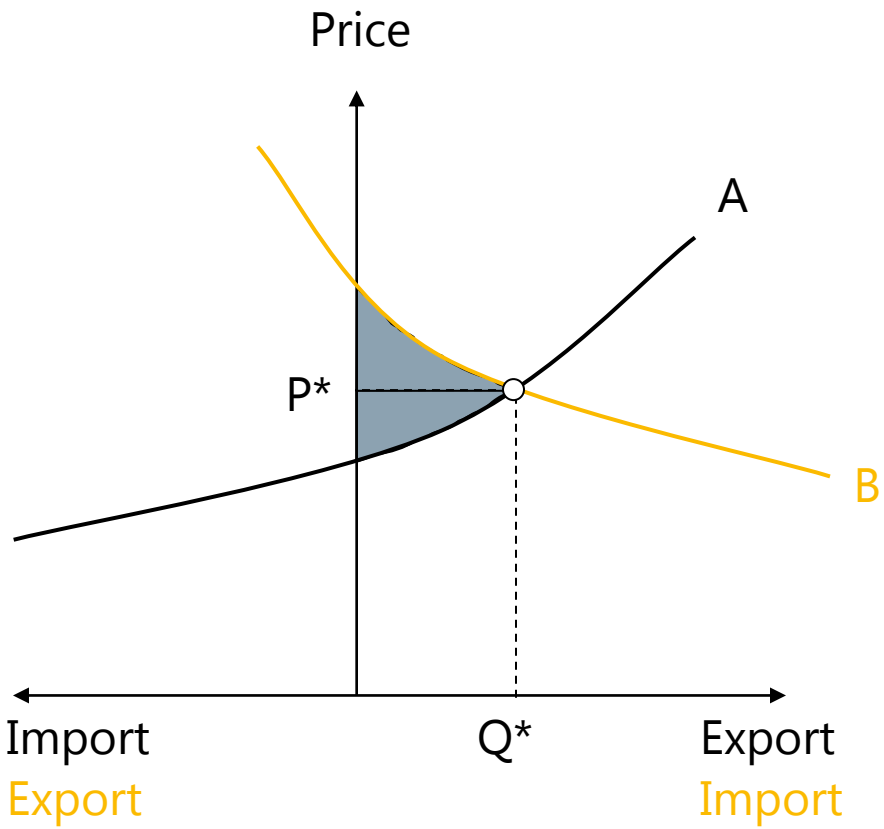
Increase of Social Welfare by Import and Export



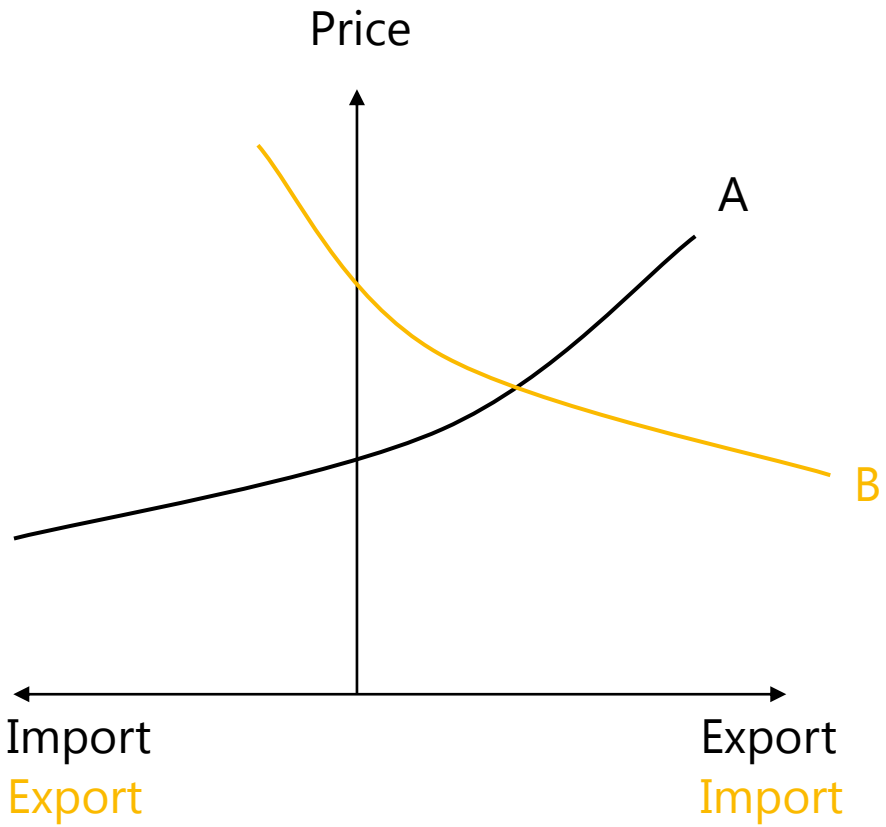
Increase of Social Welfare by Import and Export



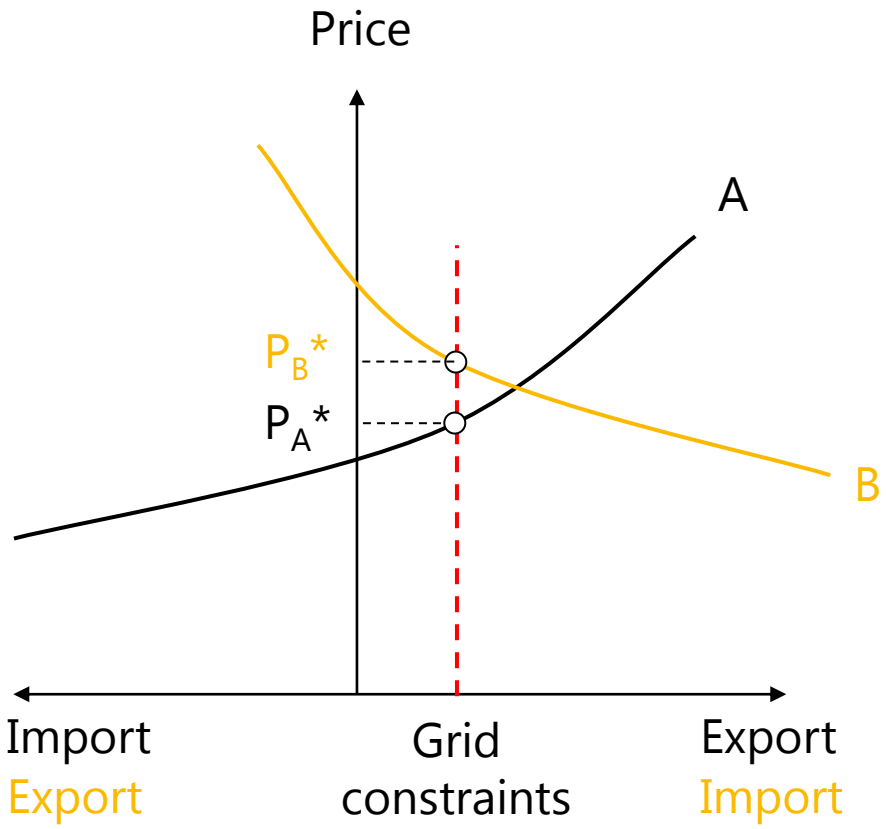
Increase of Social Welfare by Import and Export



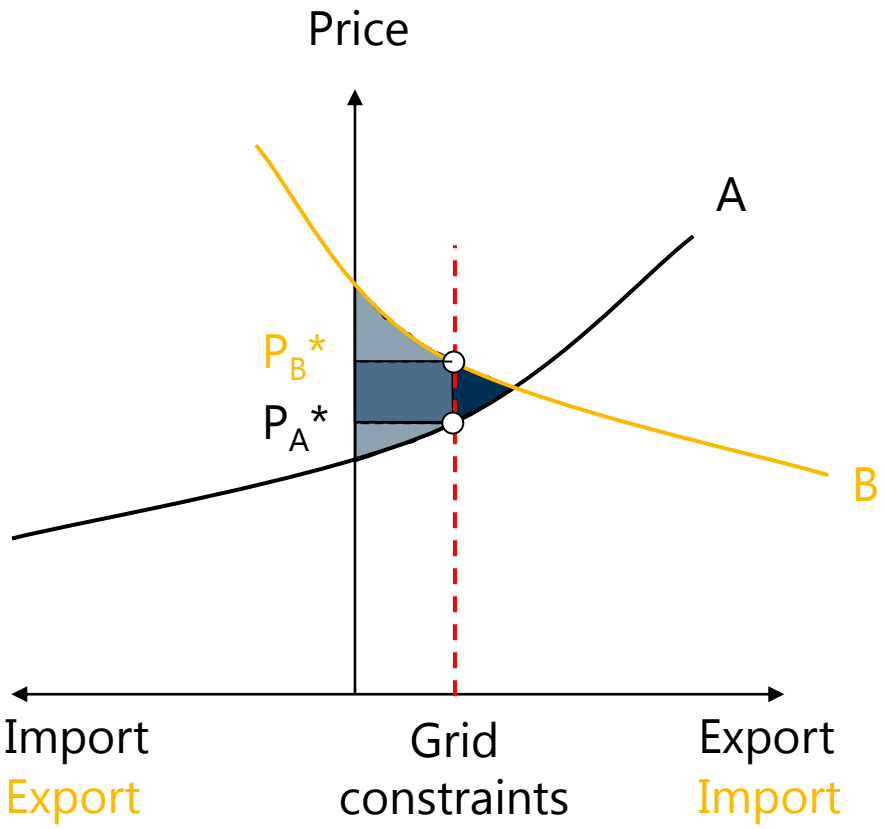
But how about the grid?



But how about the grid?

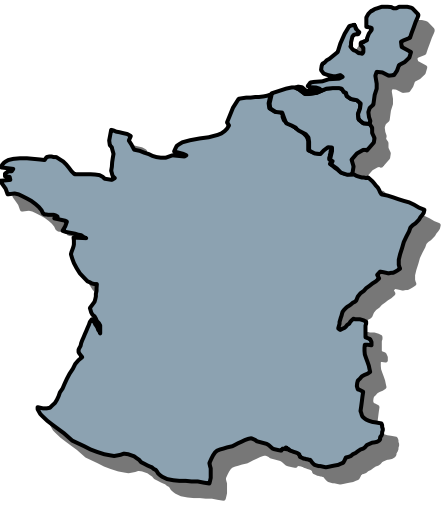


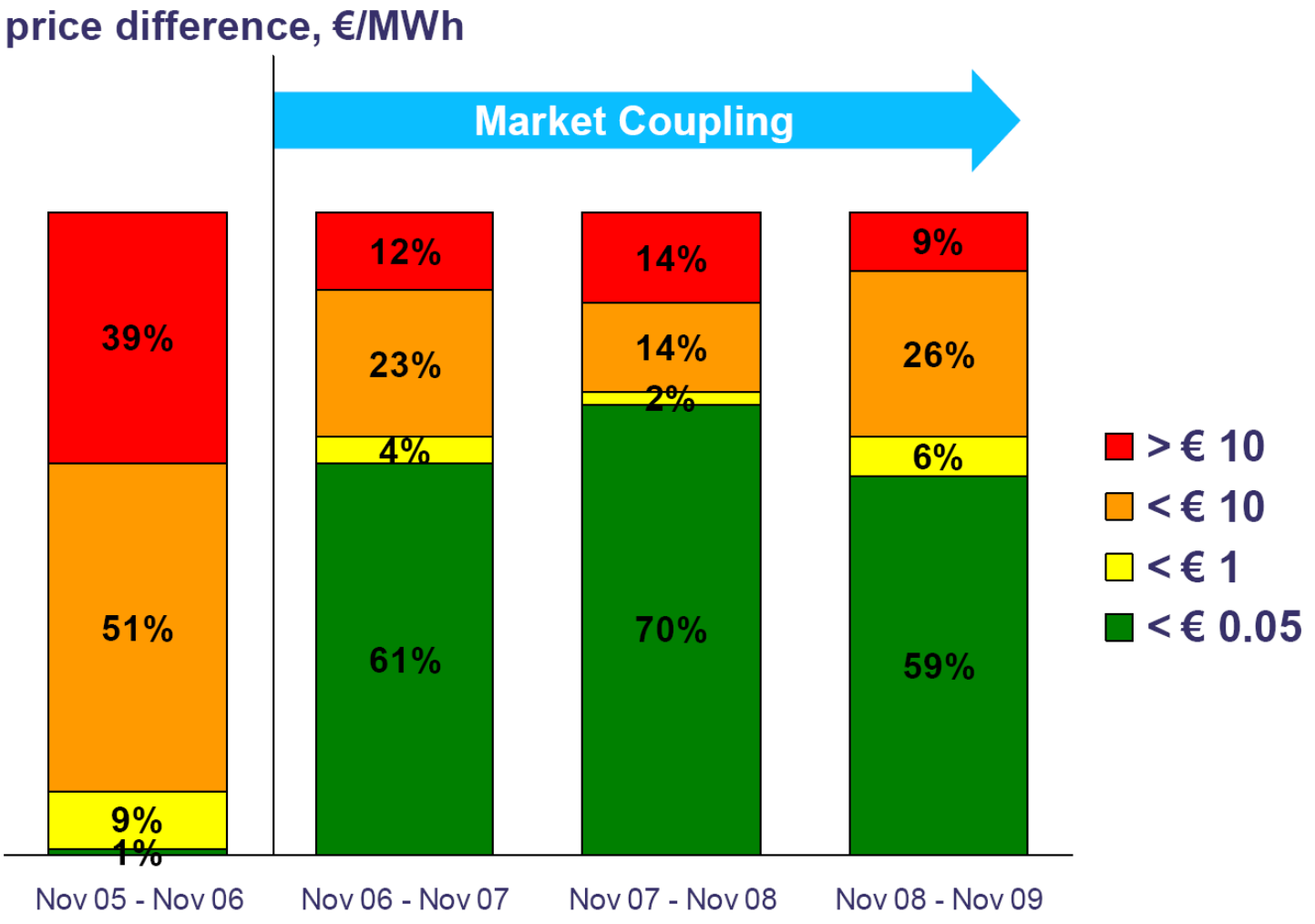
But how about the grid?



Social welfare = consumer surplus + producer surplus + congestion revenue

Price difference between NL-FR
With a Market coupling of FR-BE-NL as of Nov 06

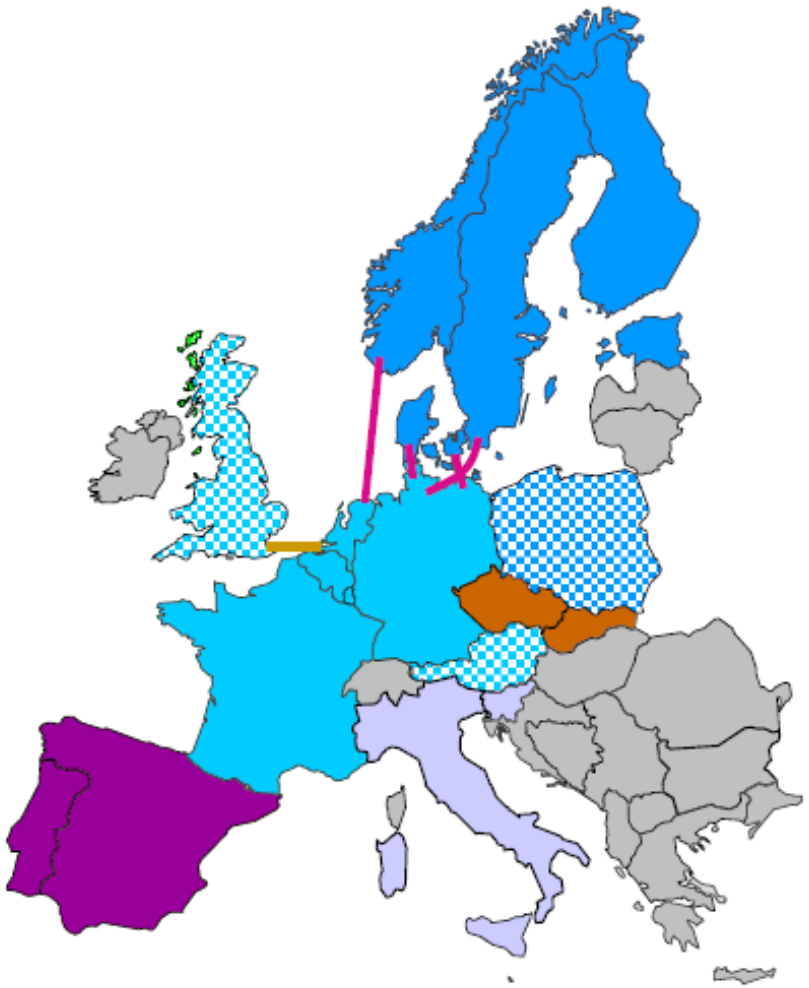




E-Bridge
competence in energy

Source: APX-ENDEX

Current status of price coupling in Europe

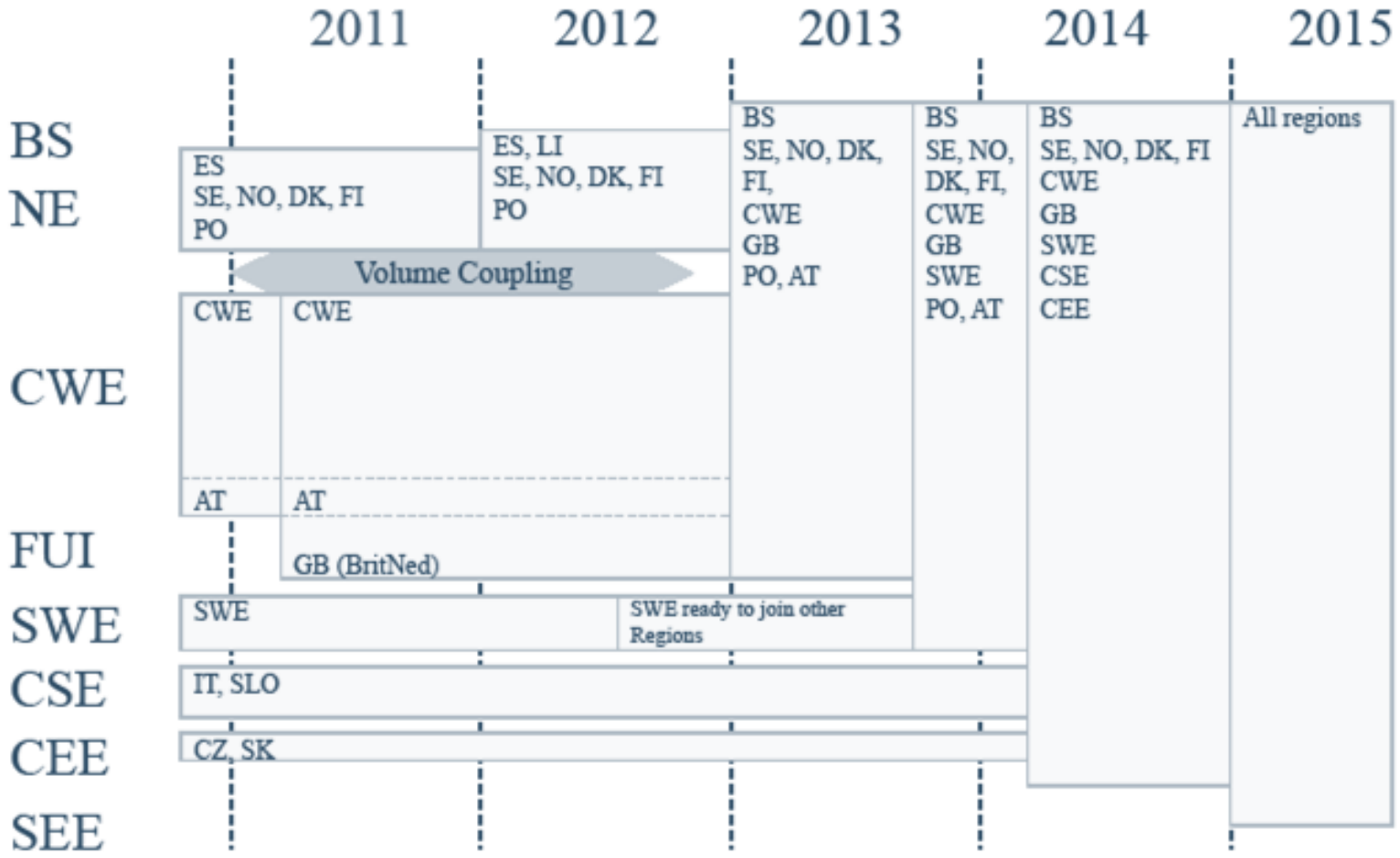


REGIONAL IMPLICIT AUCTIONS		
	CWE	Price coupling
	Austria	1 AT PX price coupled to GE (no congestion)
	GB	1 GB PX price coupled to NL via BritNed only
	Nordic + Estonia	Price coupling, also Poland via Swepol
	ITVC	Volume coupling CWE - Nordic
	Italy - Slovenia	Price coupling
	Mibel	Price coupling
	Czech - Slovak	Price coupling

E-Bridge
competence in energy

Source: 20th Florence Forum

Preliminary roadmap of price coupling in Europe



Open planning issues: CEE, SEE, Ireland (SEM), CH and the joining of SWE to the other Regions

Market Coupling: a constrained optimization problem

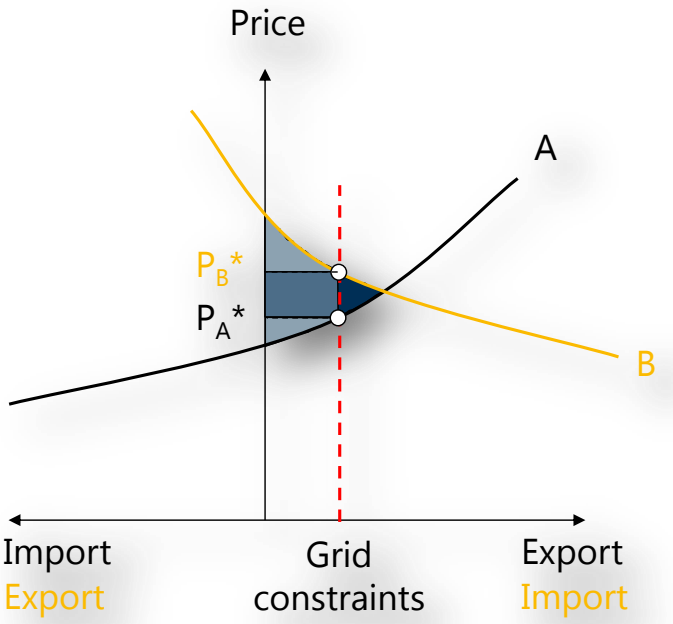
- All the bids of the local/national Power eXchanges are brought together in order to be matched by a centralized algorithm

- Objective function: Maximize social welfare

- Control variables: Net positions

- Subject to: ∑ net positions = 0

Grid constraints

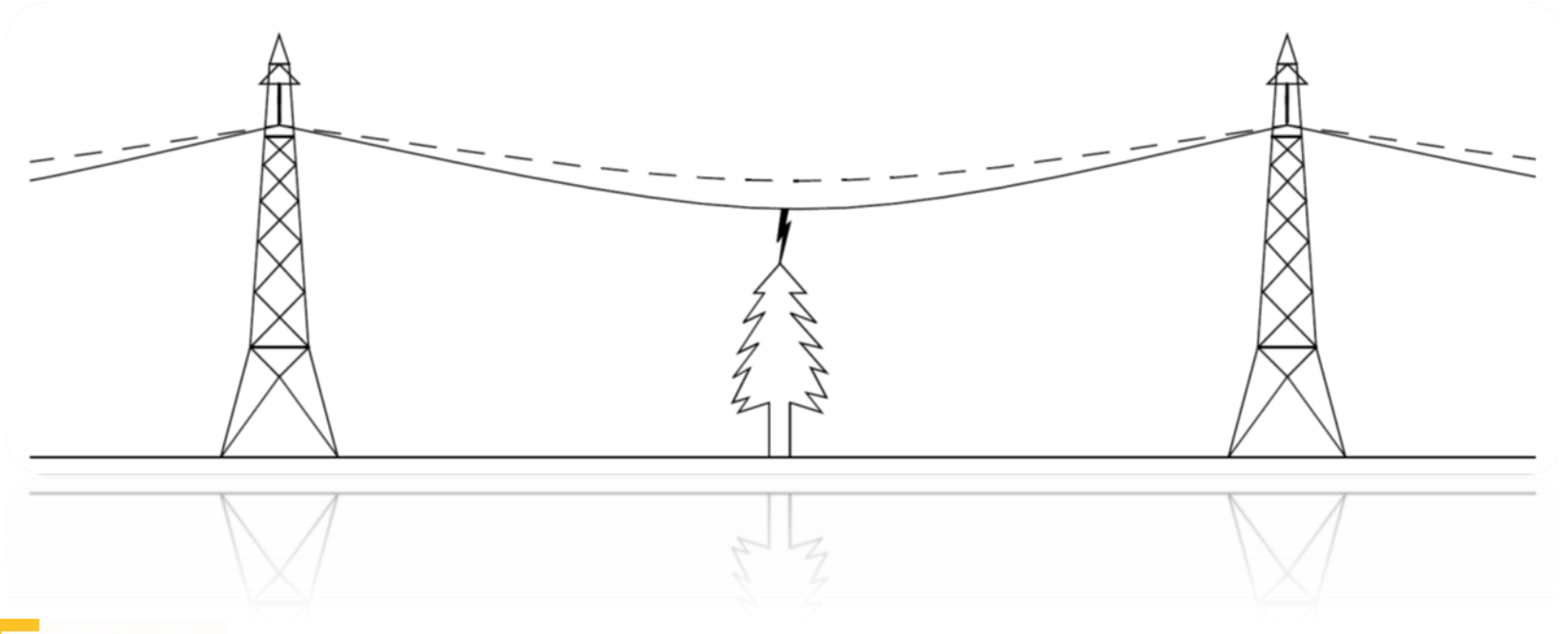


What is congestion?

Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

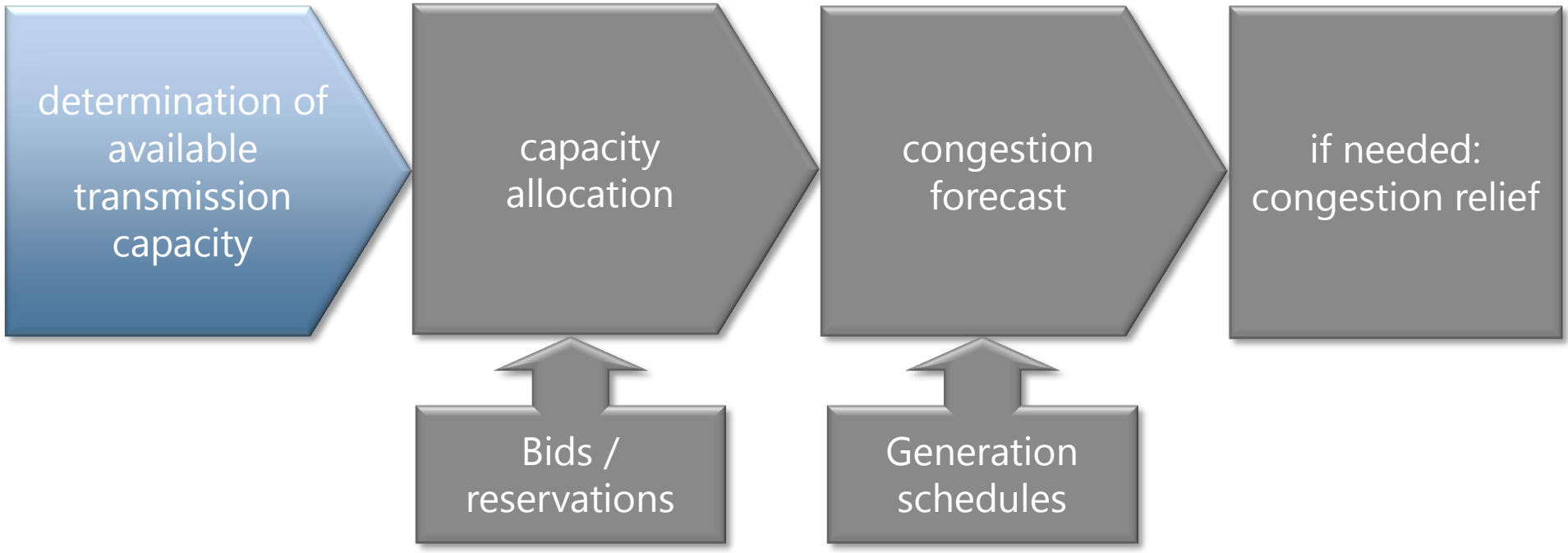
What is congestion?

- commercial: more capacity requested by the market than is available
- physical: overloaded transmission lines leading to outages



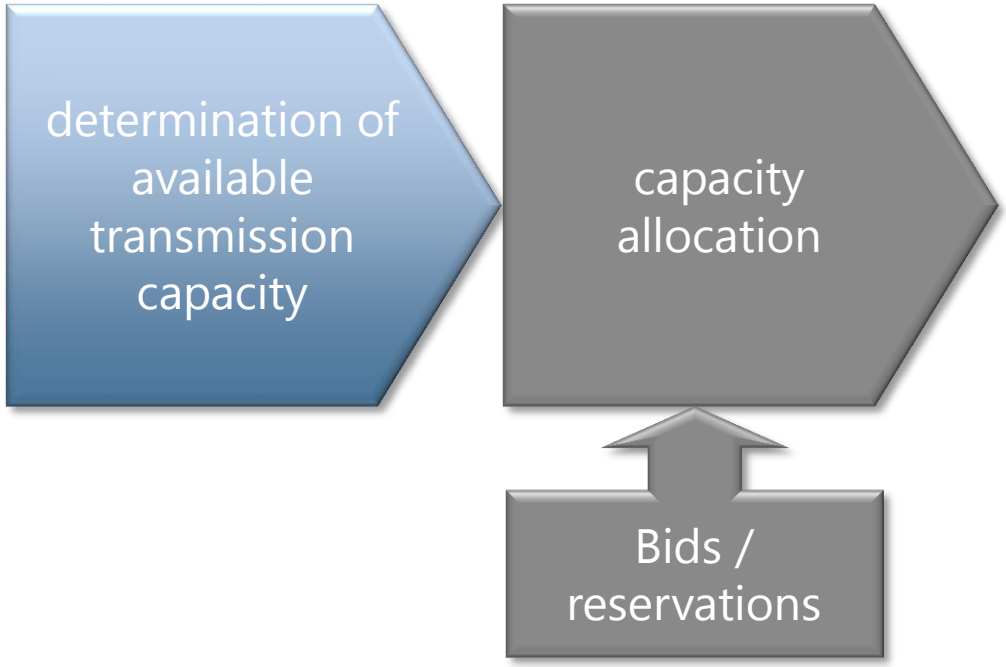
Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

Congestion management in the broadest sense



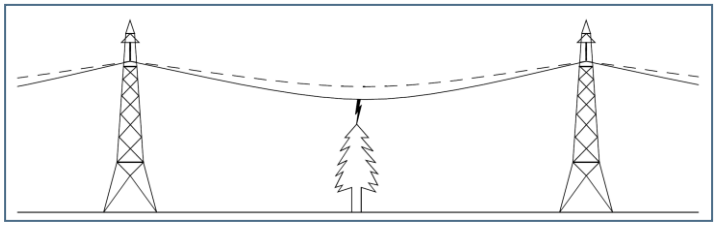
Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

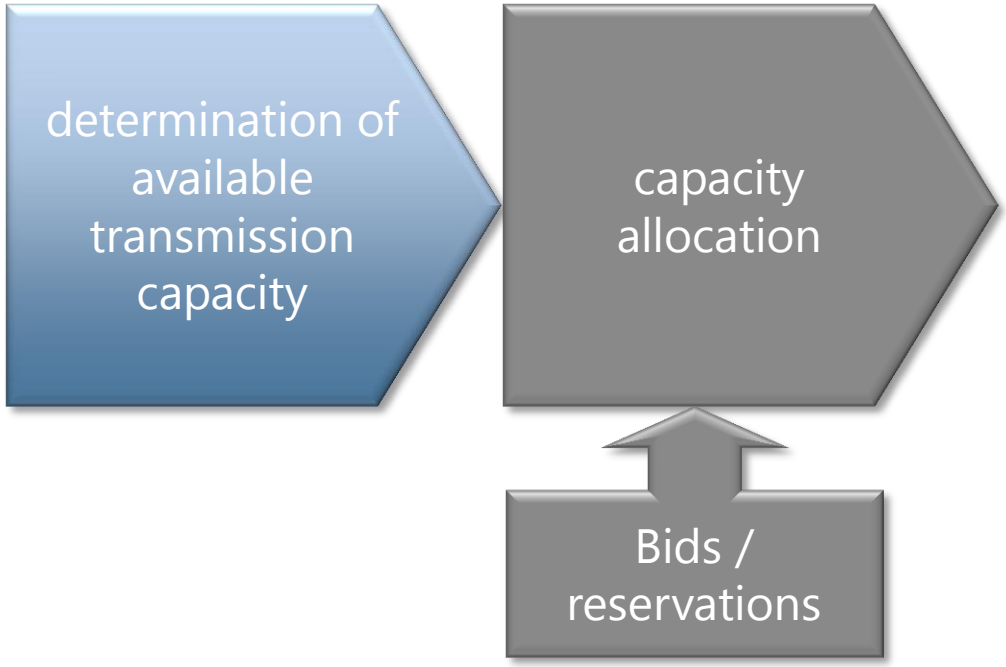
Assessment of the security of supply domain



Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

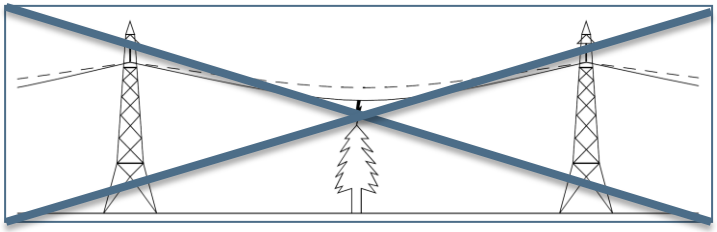
Assessment of the security of supply domain





Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

Assessment of the security of supply domain



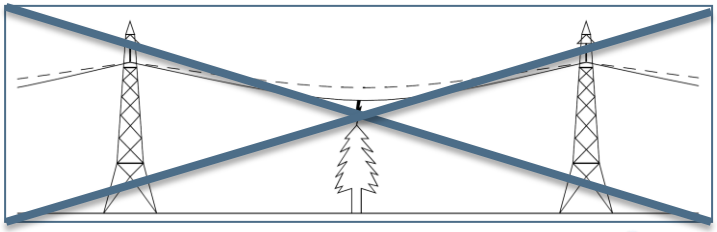
determination of available transmission capacity

capacity allocation

Bids / reservations

Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

Assessment of the security of supply domain



determination of available transmission capacity

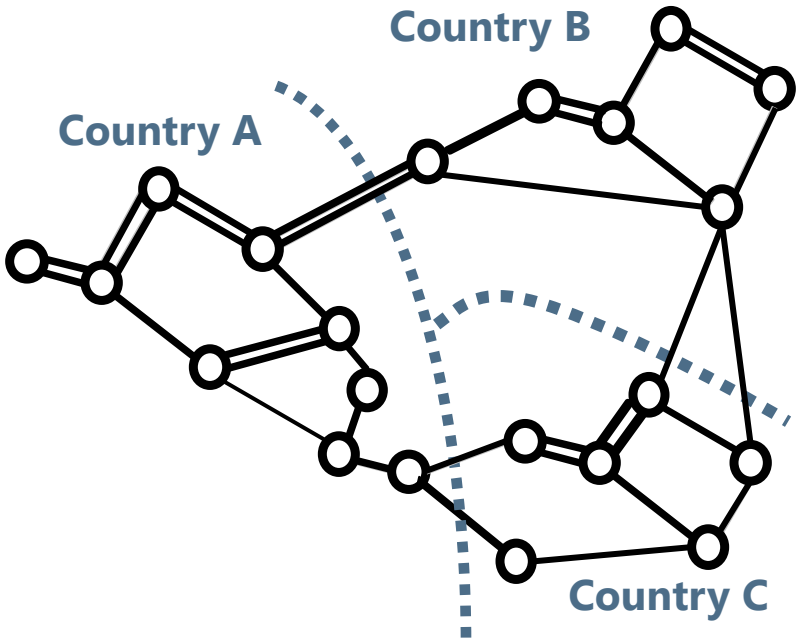
capacity allocation

Bids / reservations

NTC/ATC or FB constraints respecting the Security of Supply domain

Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

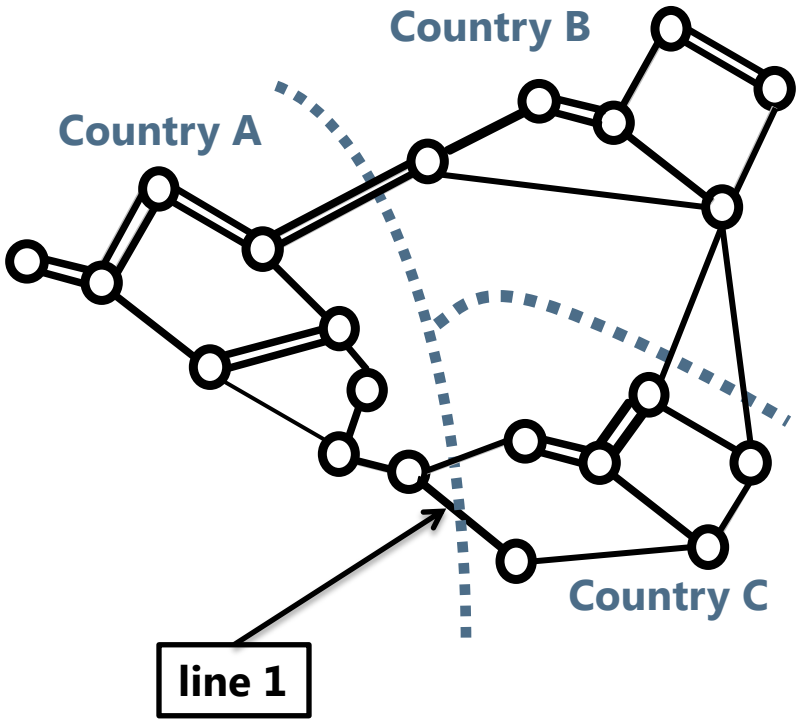
How to approximate the security of supply domain - example with 3 countries -



Monitored lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage				
	…				
	…				
Line 2	…				
	…				
Line 3	…				
	…				

Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

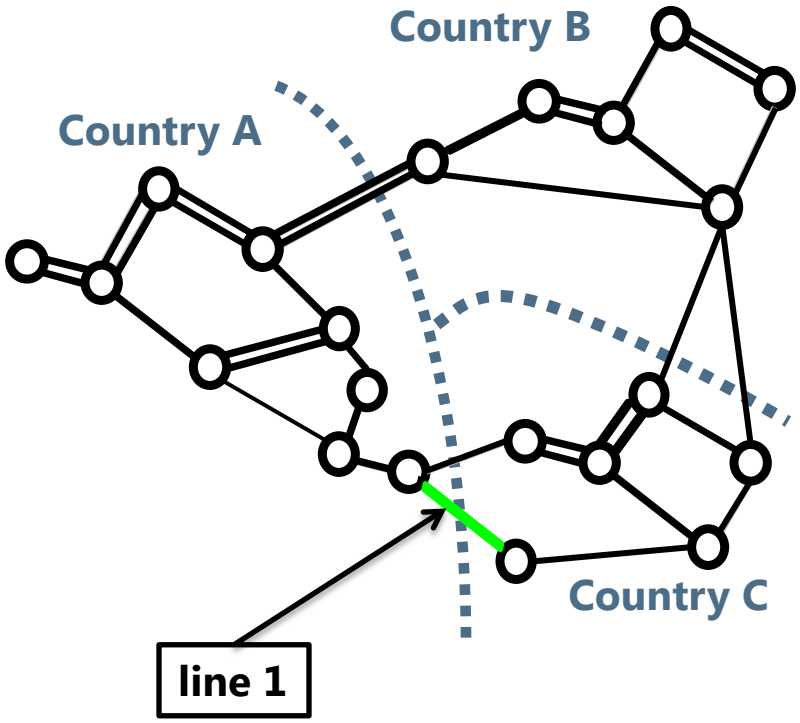
How to approximate the security of supply domain - example with 3 countries -



Monitored lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage				
	…				
	…				
Line 2	…				
	…				
Line 3	…				
	…				

Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

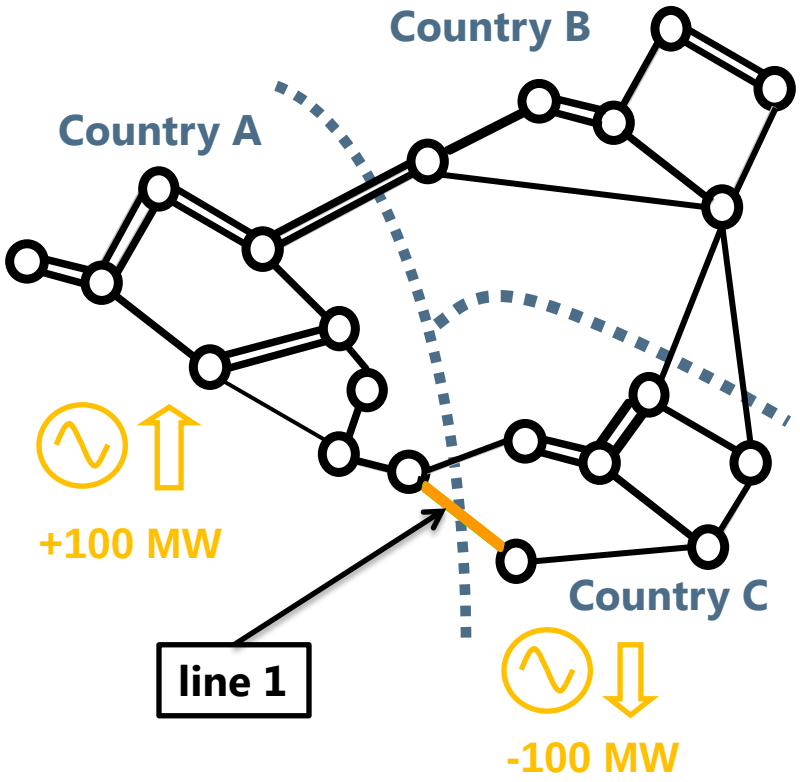
How to approximate the security of supply domain - example with 3 countries -



Monitored lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage	150			
	…				
	…				
Line 2	…				
	…				
Line 3	…				
	…				

Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

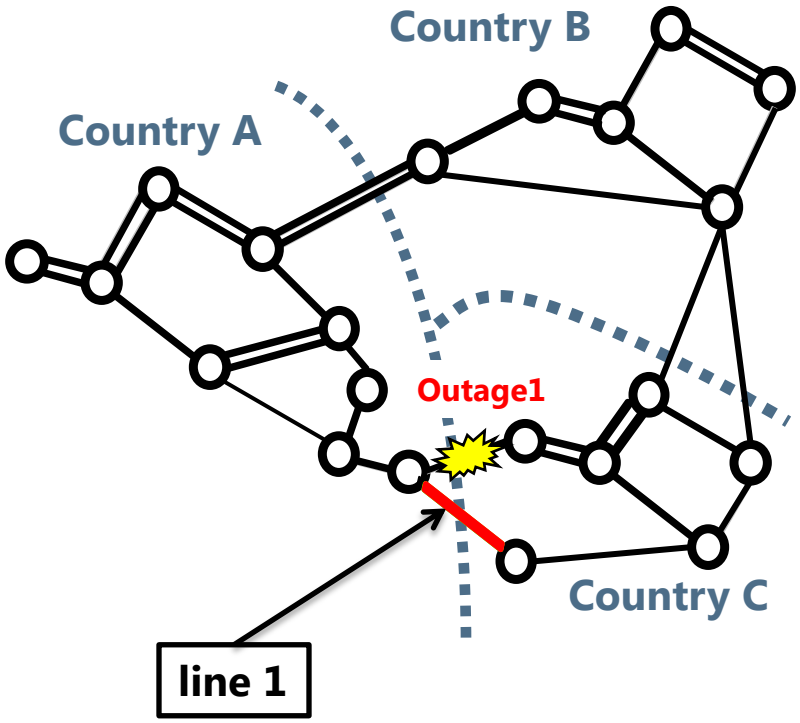
How to approximate the security of supply domain - example with 3 countries -



Monitored lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage	150		10%	
	…				
	…				
Line 2	…				
	…				
Line 3	…				
	…				

Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

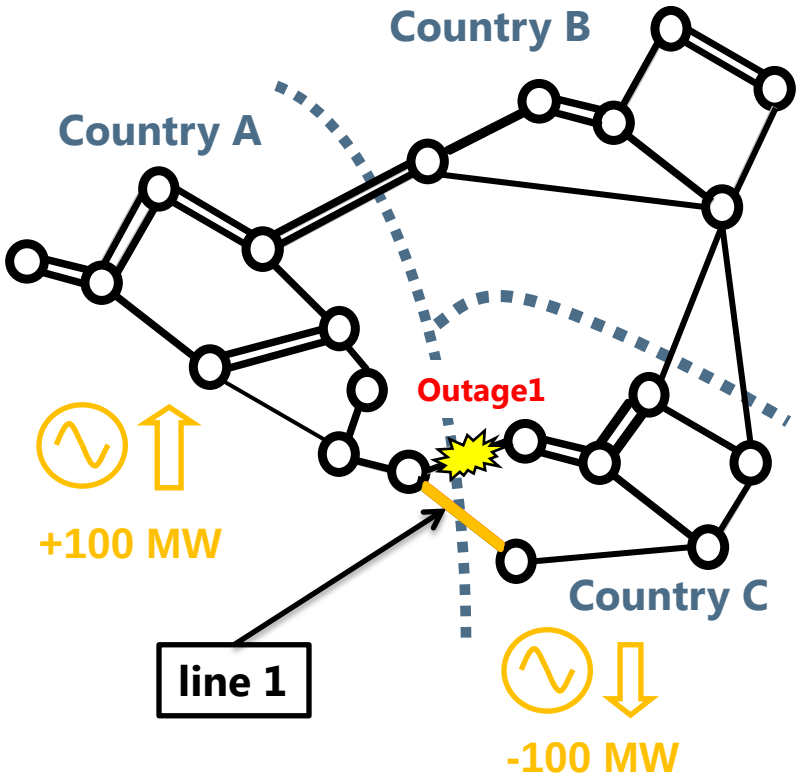
How to approximate the security of supply domain - example with 3 countries -



Monitored lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage	150		10%	
	Outage 1	120			
	…				
Line 2	…				
	…				
Line 3	…				
	…				

Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

How to approximate the security of supply domain - example with 3 countries -



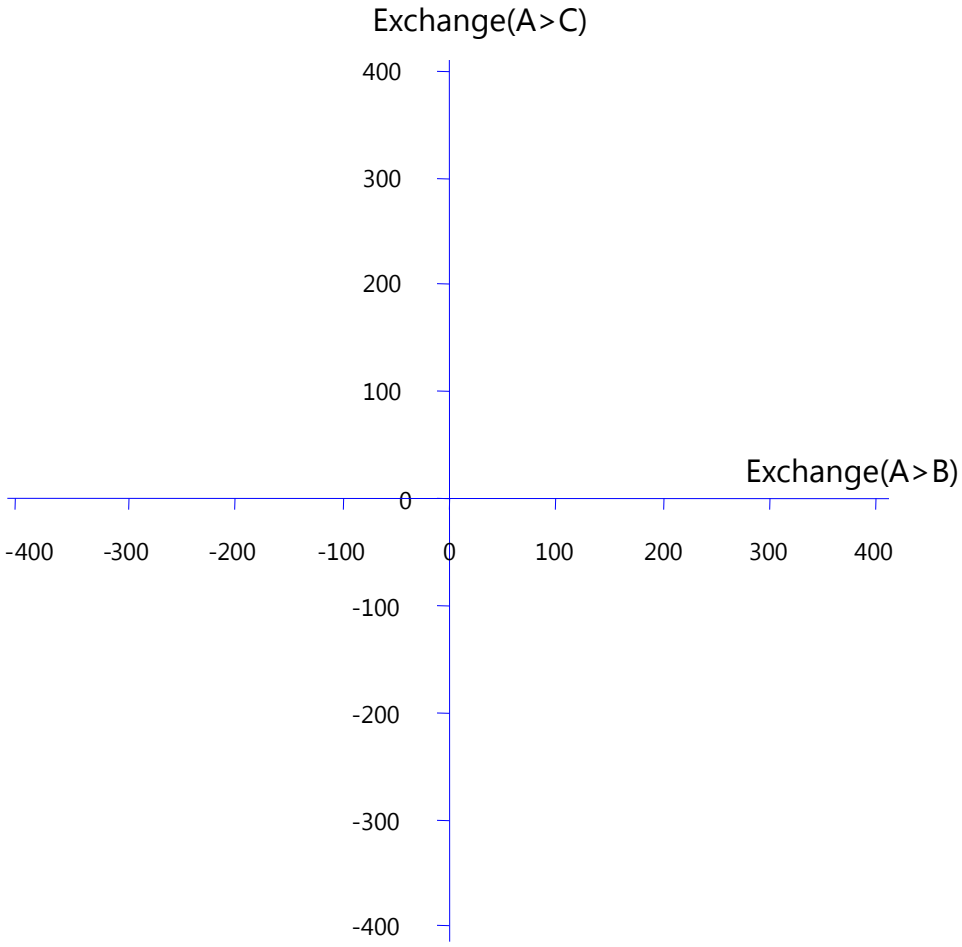
Monitored lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage	150		10%	
	Outage 1	120		20%	
	…				
Line 2	…				
	…				
Line 3	…				
	…				

Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

The security of supply domain

Numbers are for illustration only

Monitored Lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage	150	1%	10%	3%
	Outage 1	120	5%	20%	1%
	Outage 2	100	6%	25%	1%
Line 2	No outage	150	-2%	0	5%
	Outage 3	100	-12%	0	10%
Line 3	No outage				
	Outage 4				

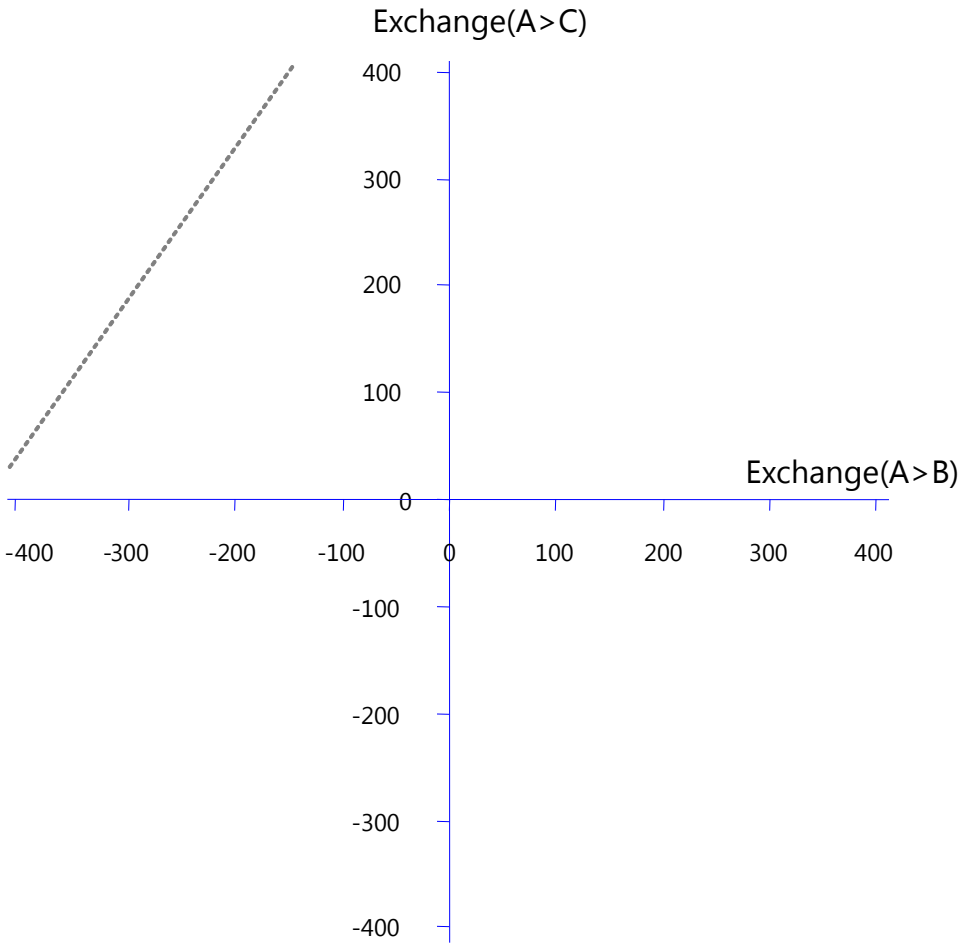


Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

The security of supply domain

Numbers are for illustration only

Monitored Lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage	150	1%	10%	3%
	Outage 1	120	5%	20%	1%
	Outage 2	100	6%	25%	1%
Line 2	No outage	150	-2%	0	5%
	Outage 3	100	-12%	0	10%
Line 3	No outage				
	Outage 4				



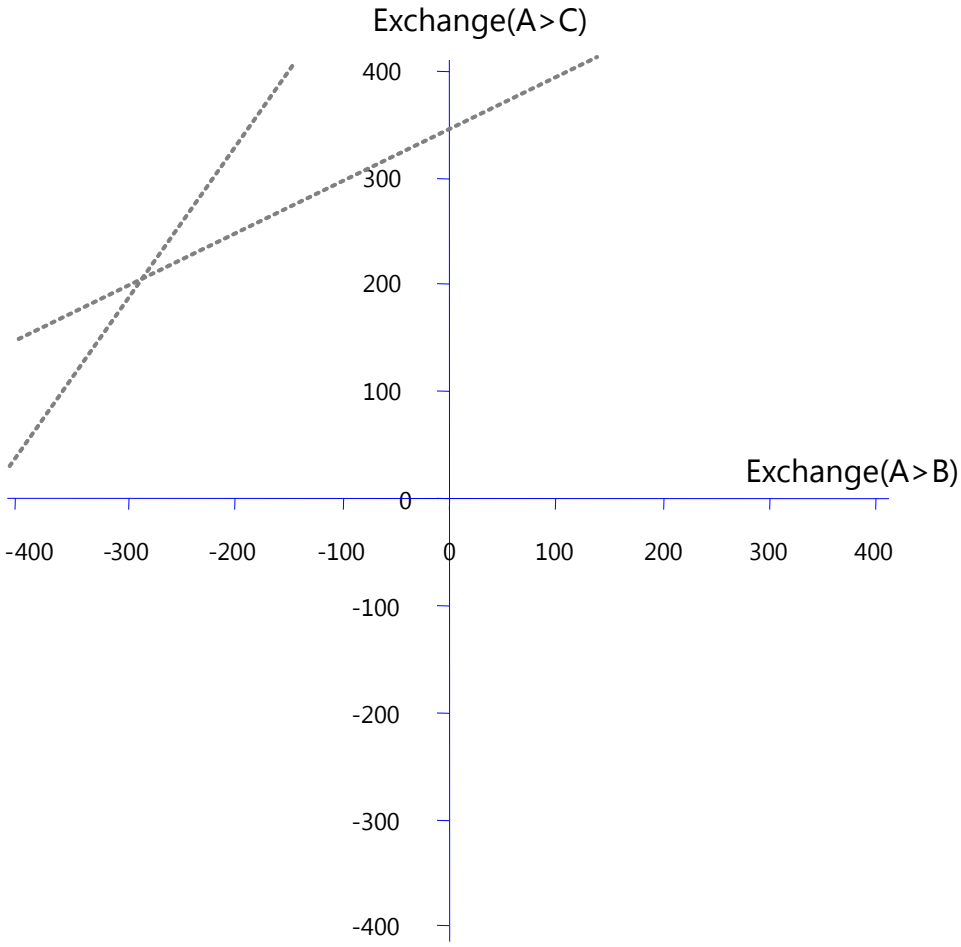
Constraints

Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

The security of supply domain

⚠ Numbers are for illustration only

Monitored Lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage	150	1%	10%	3%
	Outage 1	120	5%	20%	1%
	Outage 2	100	6%	25%	1%
Line 2	No outage	150	-2%	0	5%
	Outage 3	100	-12%	0	10%
Line 3	No outage				
	Outage 4				



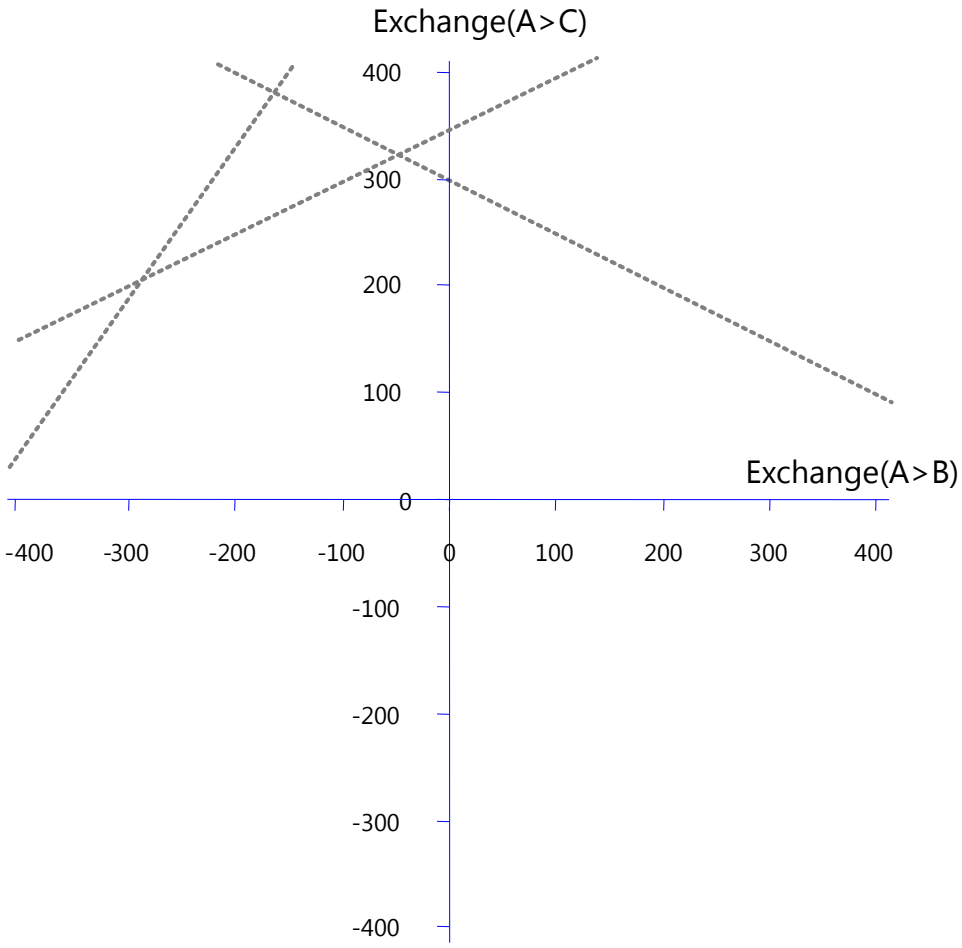
Constraints

Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

The security of supply domain

⚠ Numbers are for illustration only

Monitored Lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage	150	1%	10%	3%
	Outage 1	120	5%	20%	1%
	Outage 2	100	6%	25%	1%
Line 2	No outage	150	-2%	0	5%
	Outage 3	100	-12%	0	10%
Line 3	No outage				
	Outage 4				



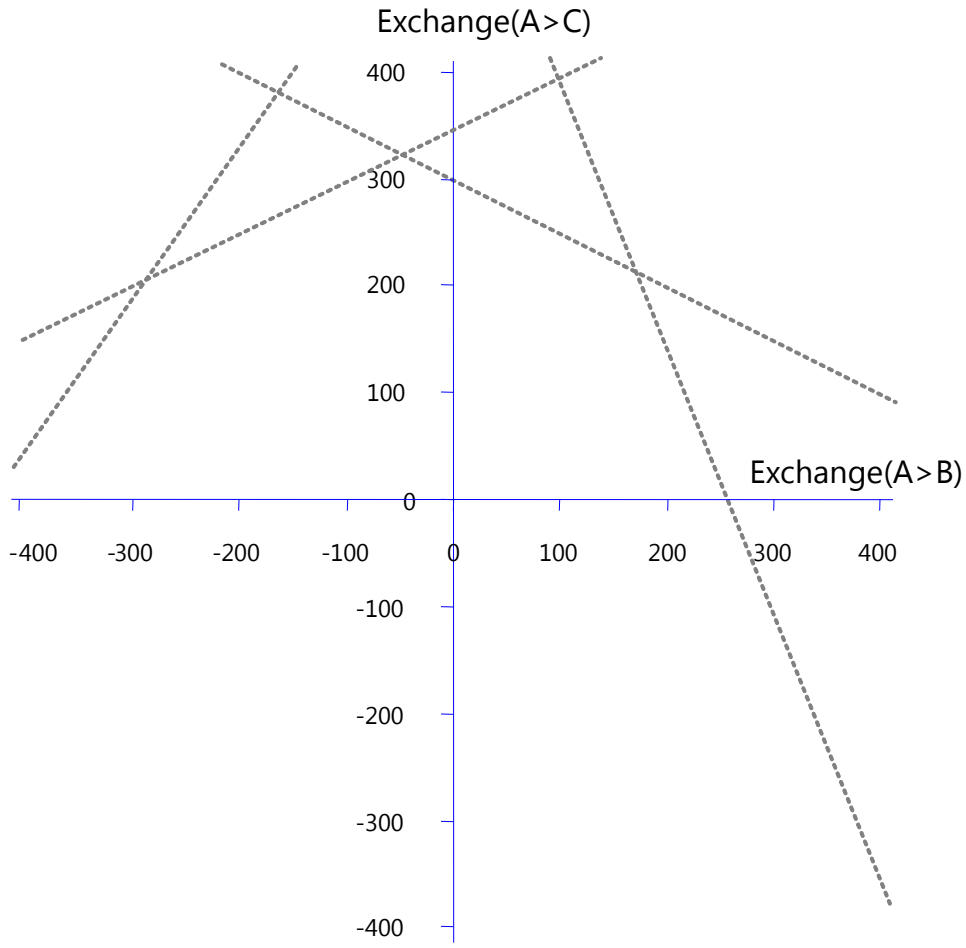
Constraints

Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

The security of supply domain

Numbers are for illustration only

Monitored Lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage	150	1%	10%	3%
	Outage 1	120	5%	20%	1%
	Outage 2	100	6%	25%	1%
Line 2	No outage	150	-2%	0	5%
	Outage 3	100	-12%	0	10%
Line 3	No outage				
	Outage 4				

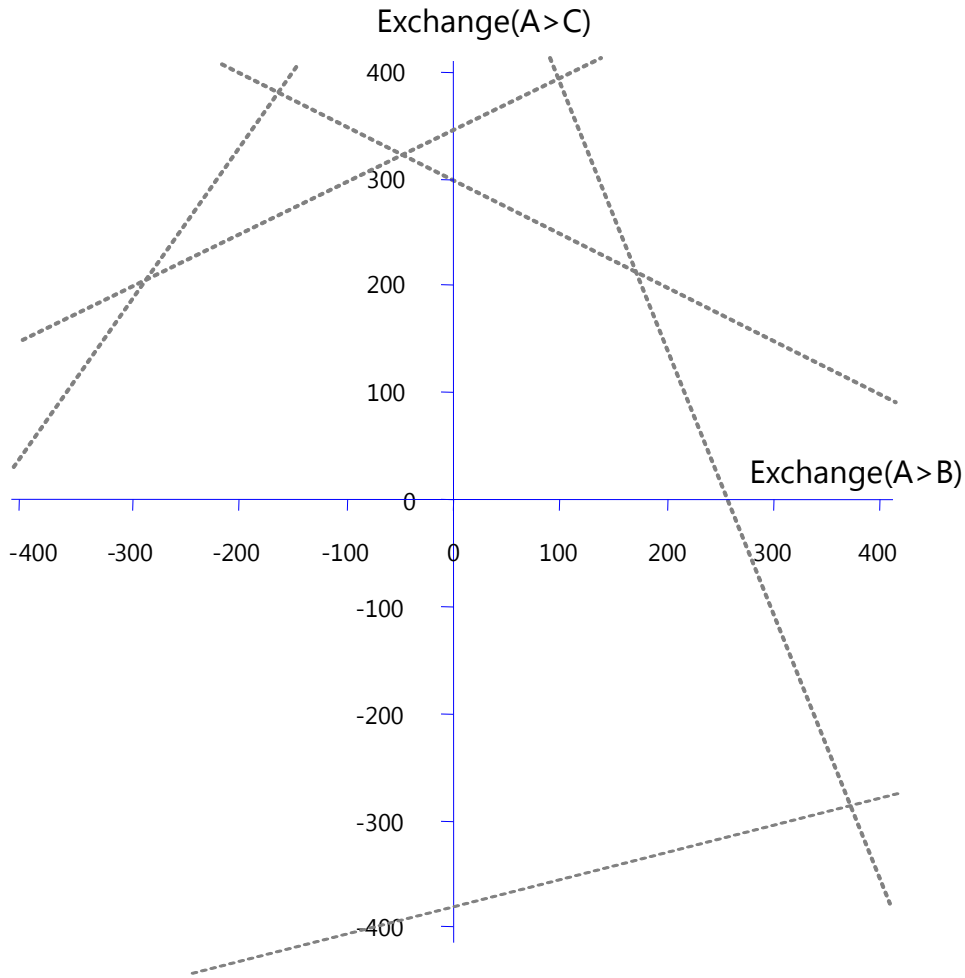


Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

The security of supply domain

Numbers are for illustration only

Monitored Lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage	150	1%	10%	3%
	Outage 1	120	5%	20%	1%
	Outage 2	100	6%	25%	1%
Line 2	No outage	150	-2%	0	5%
	Outage 3	100	-12%	0	10%
Line 3	No outage				
	Outage 4				



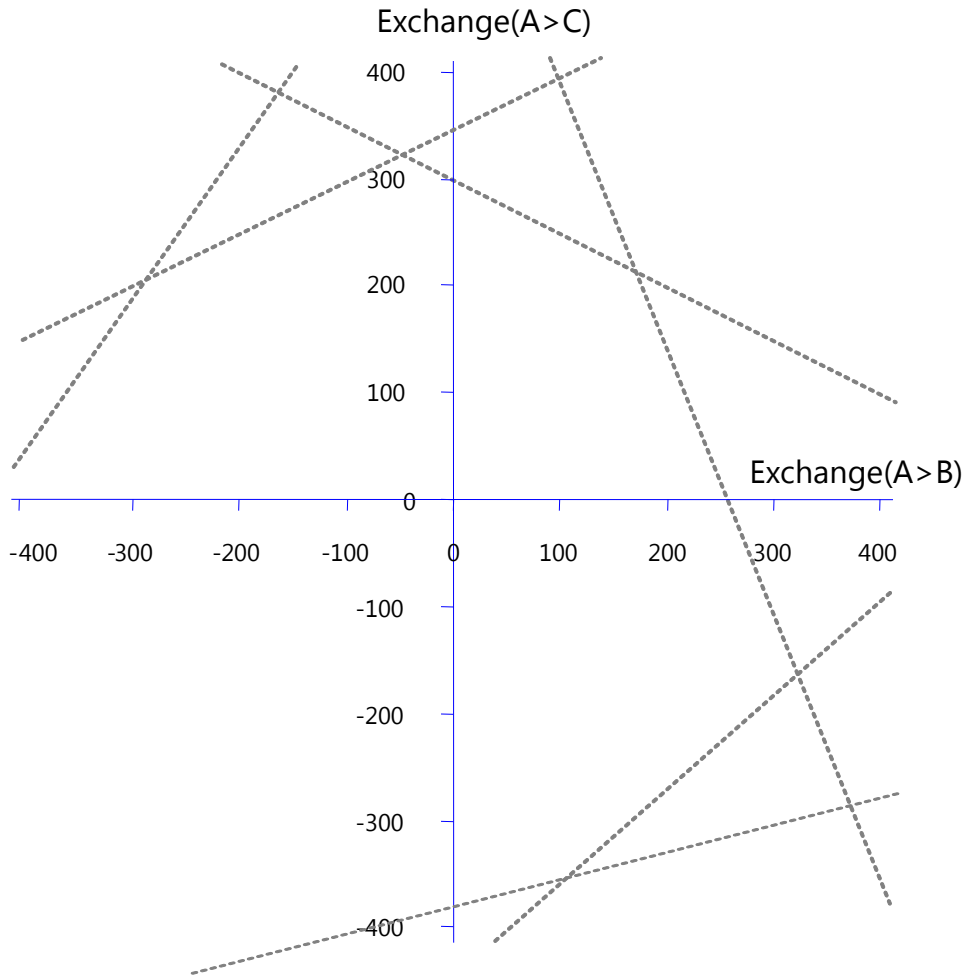
Constraints

Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

The security of supply domain

Numbers are for illustration only

Monitored Lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage	150	1%	10%	3%
	Outage 1	120	5%	20%	1%
	Outage 2	100	6%	25%	1%
Line 2	No outage	150	-2%	0	5%
	Outage 3	100	-12%	0	10%
Line 3	No outage				
	Outage 4				



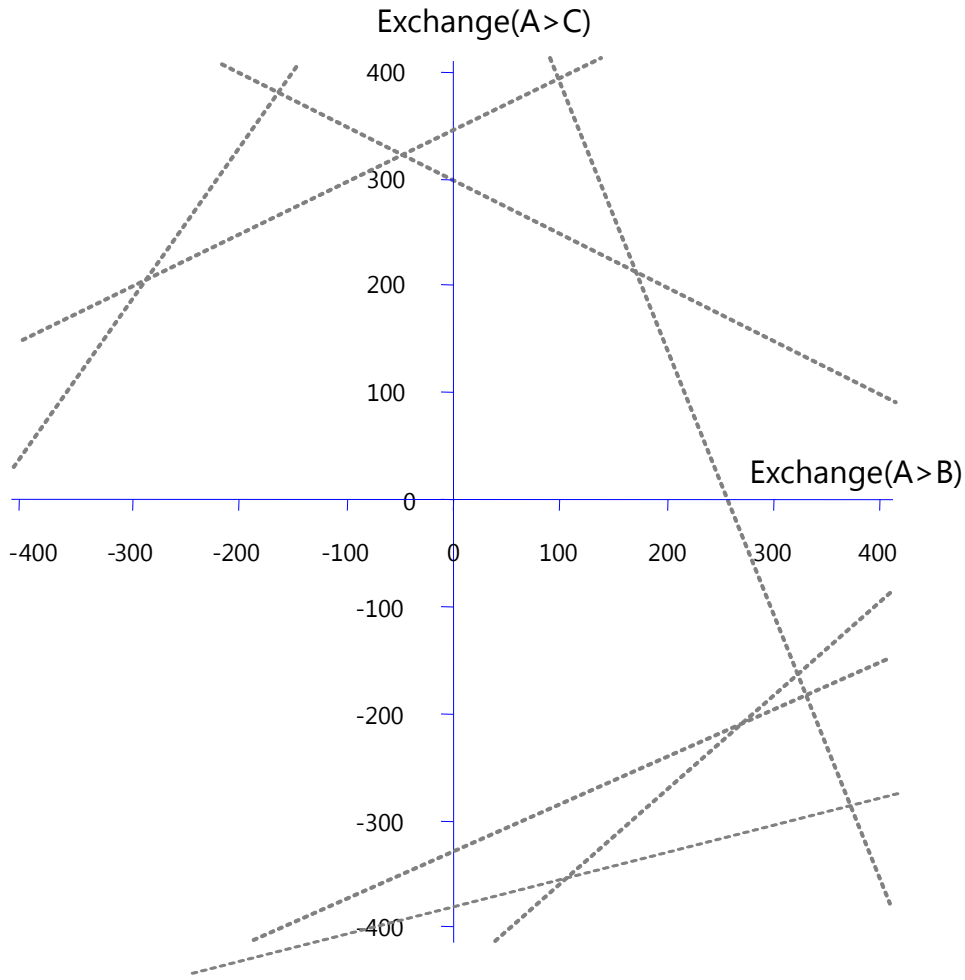
Constraints

Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

The security of supply domain

⚠ Numbers are for illustration only

Monitored Lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage	150	1%	10%	3%
	Outage 1	120	5%	20%	1%
	Outage 2	100	6%	25%	1%
Line 2	No outage	150	-2%	0	5%
	Outage 3	100	-12%	0	10%
Line 3	No outage				
	Outage 4				

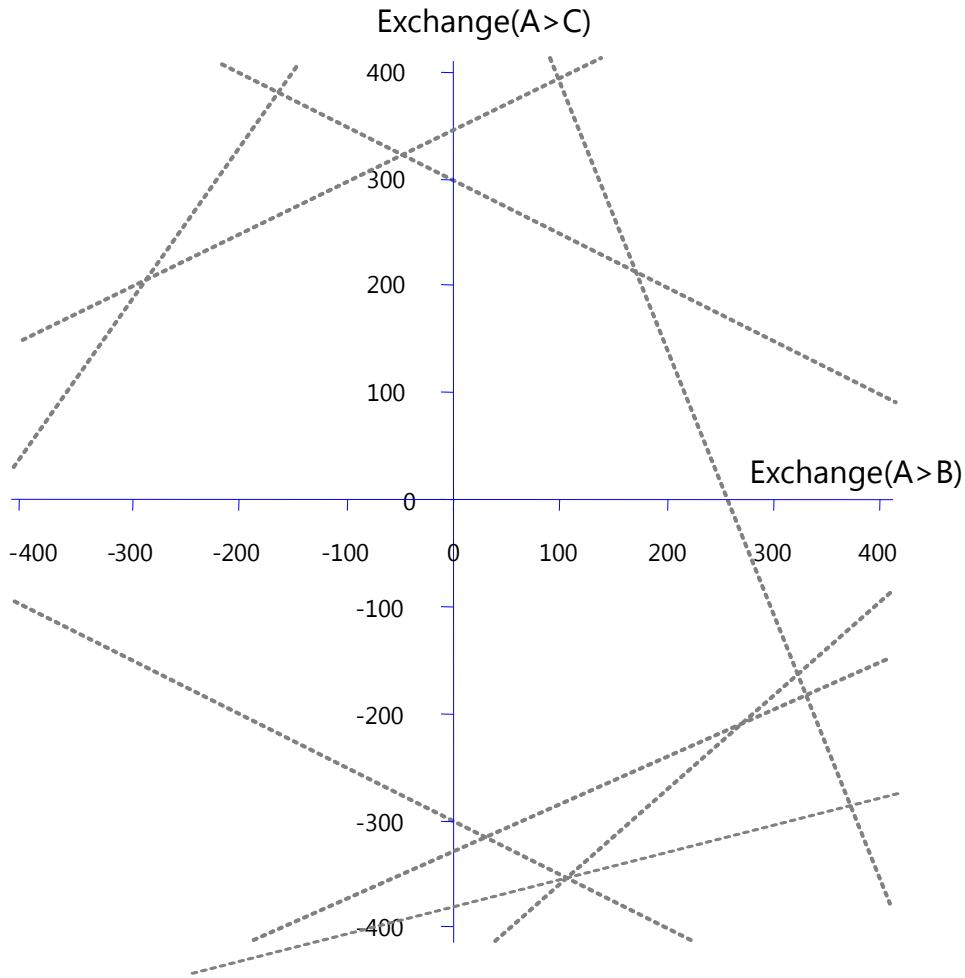


Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

The security of supply domain

Numbers are for illustration only

Monitored Lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage	150	1%	10%	3%
	Outage 1	120	5%	20%	1%
	Outage 2	100	6%	25%	1%
Line 2	No outage	150	-2%	0	5%
	Outage 3	100	-12%	0	10%
Line 3	No outage				
	Outage 4				



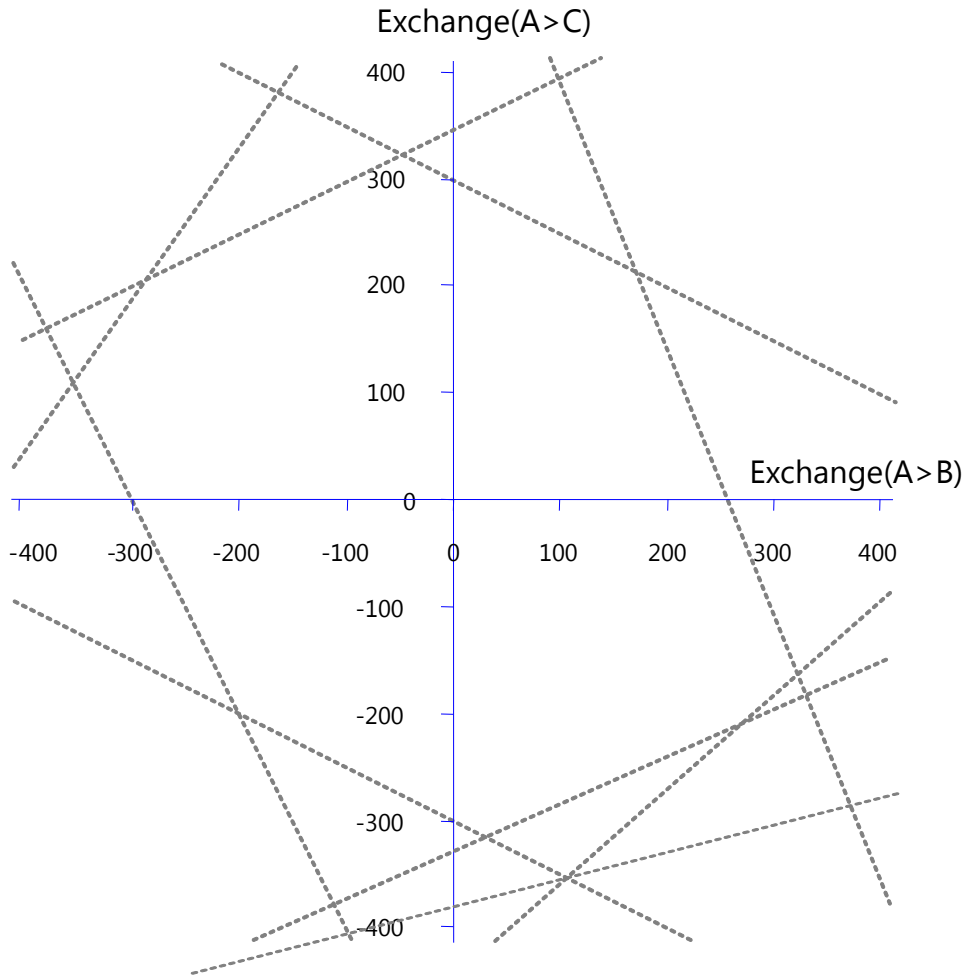
Constraints

Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

The security of supply domain

Numbers are for illustration only

Monitored Lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage	150	1%	10%	3%
	Outage 1	120	5%	20%	1%
	Outage 2	100	6%	25%	1%
Line 2	No outage	150	-2%	0	5%
	Outage 3	100	-12%	0	10%
Line 3	No outage				
	Outage 4				



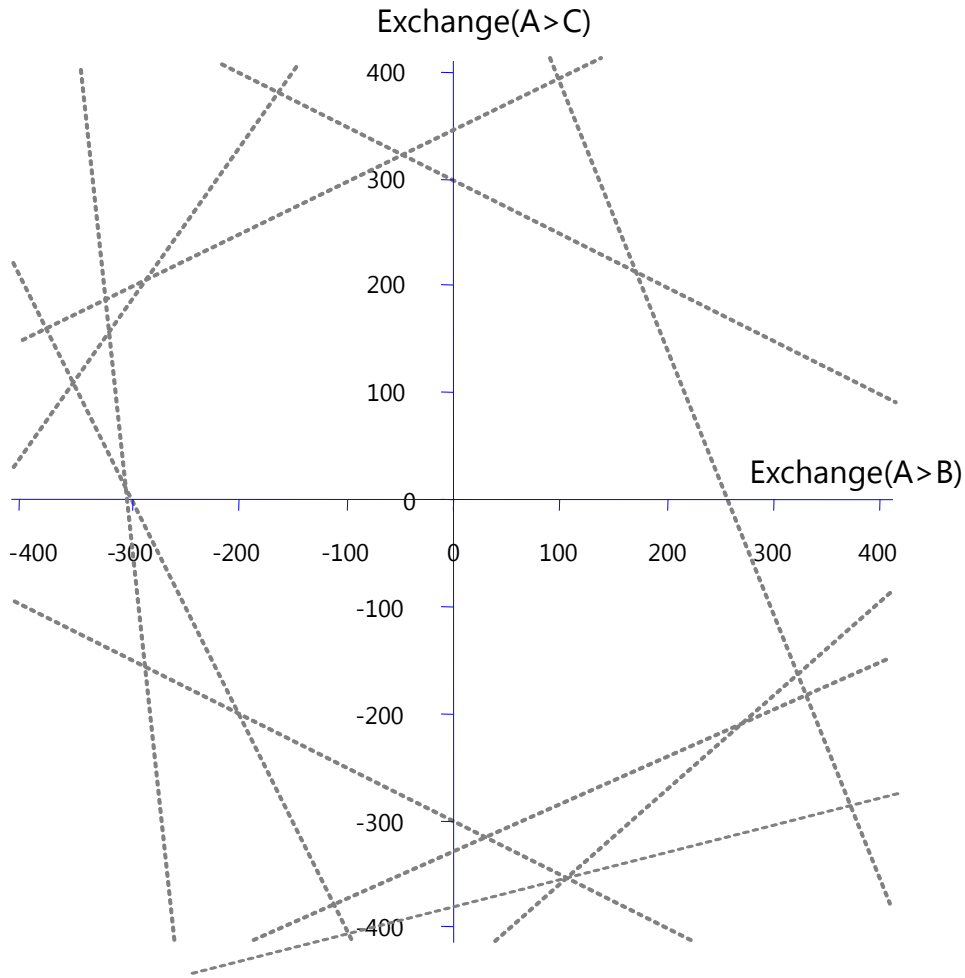
Constraints

Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

The security of supply domain

⚠ Numbers are for illustration only

Monitored Lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage	150	1%	10%	3%
	Outage 1	120	5%	20%	1%
	Outage 2	100	6%	25%	1%
Line 2	No outage	150	-2%	0	5%
	Outage 3	100	-12%	0	10%
Line 3	No outage				
	Outage 4				

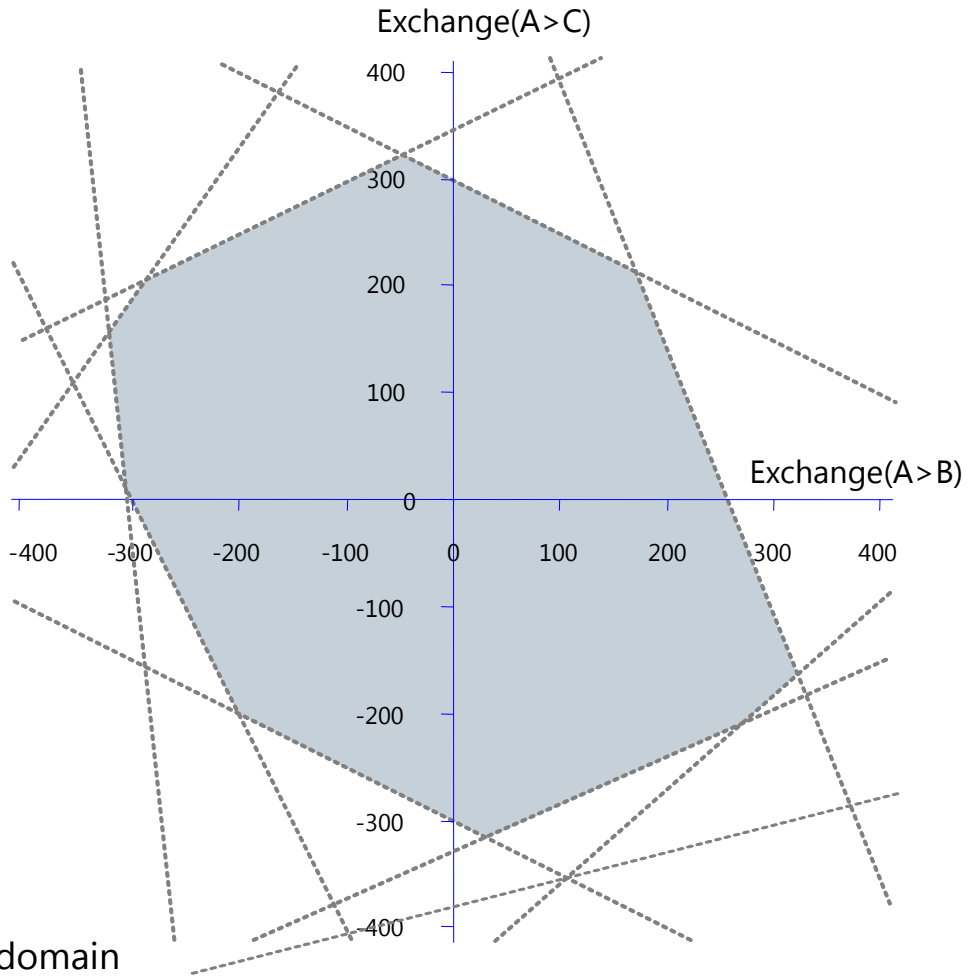


Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

The security of supply domain

⚠ Numbers are for illustration only

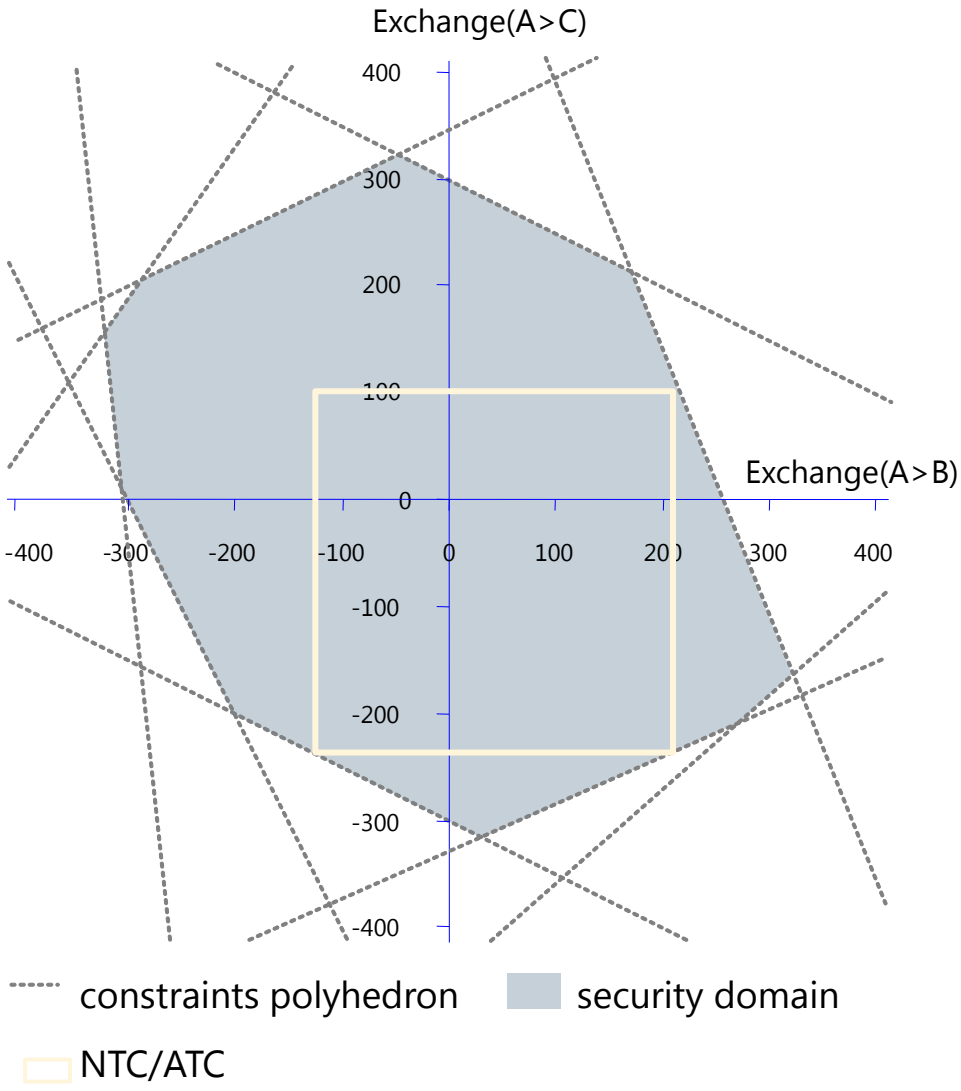
Monitored Lines	Outage scenario	Margin left (MW)	Influence of exchange on lines (PTDF)		
			A→B	A→C	B→C
Line 1	No outage	150	1%	10%	3%
	Outage 1	120	5%	20%	1%
	Outage 2	100	6%	25%	1%
Line 2	No outage	150	-2%	0	5%
	Outage 3	100	-12%	0	10%
Line 3	No outage				
	Outage 4				



Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

ATC & FB grid constraints

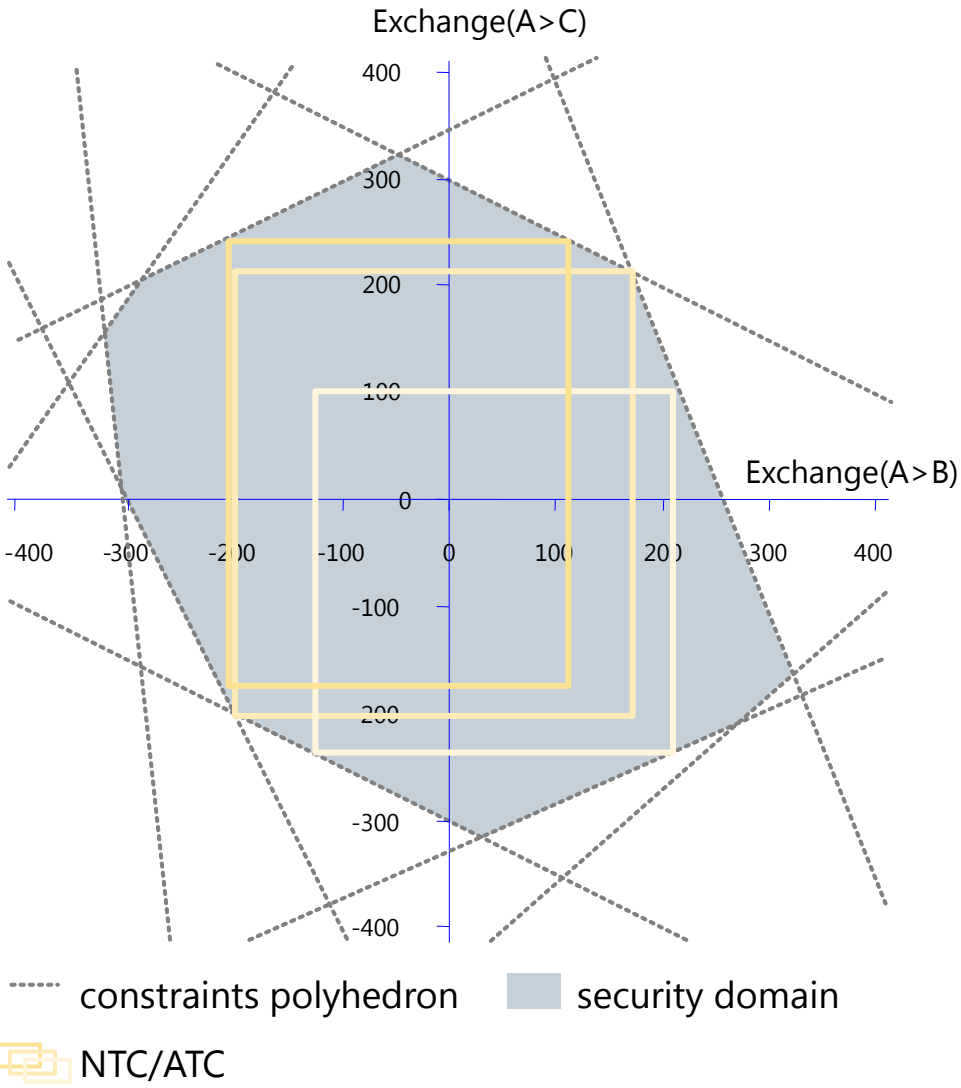
- Given the security domain, NTC/ATC constraints and the corresponding NTC/ATC domain are a choice made by the TSO



Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

ATC & FB grid constraints

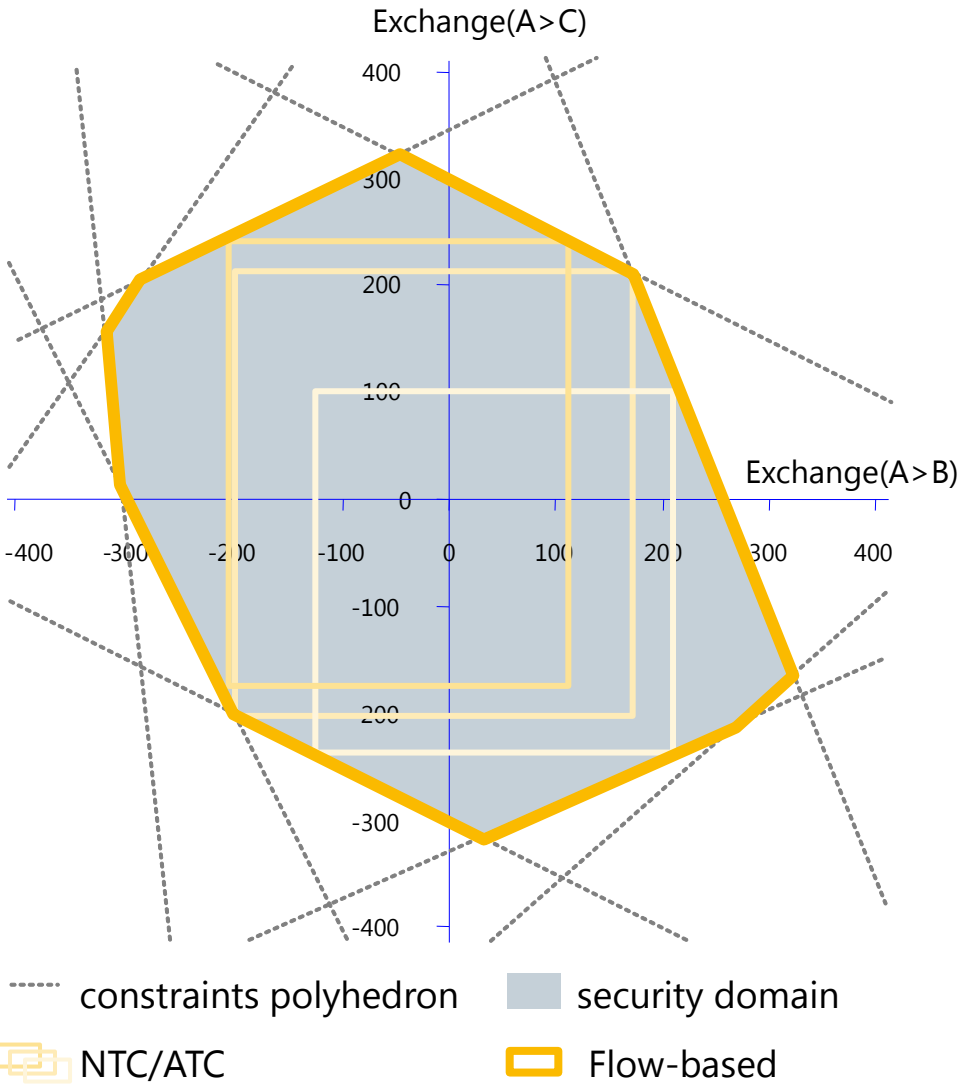
- Given the security domain, NTC/ATC constraints and the corresponding NTC/ATC domain are a choice made by the TSO



Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

ATC & FB grid constraints

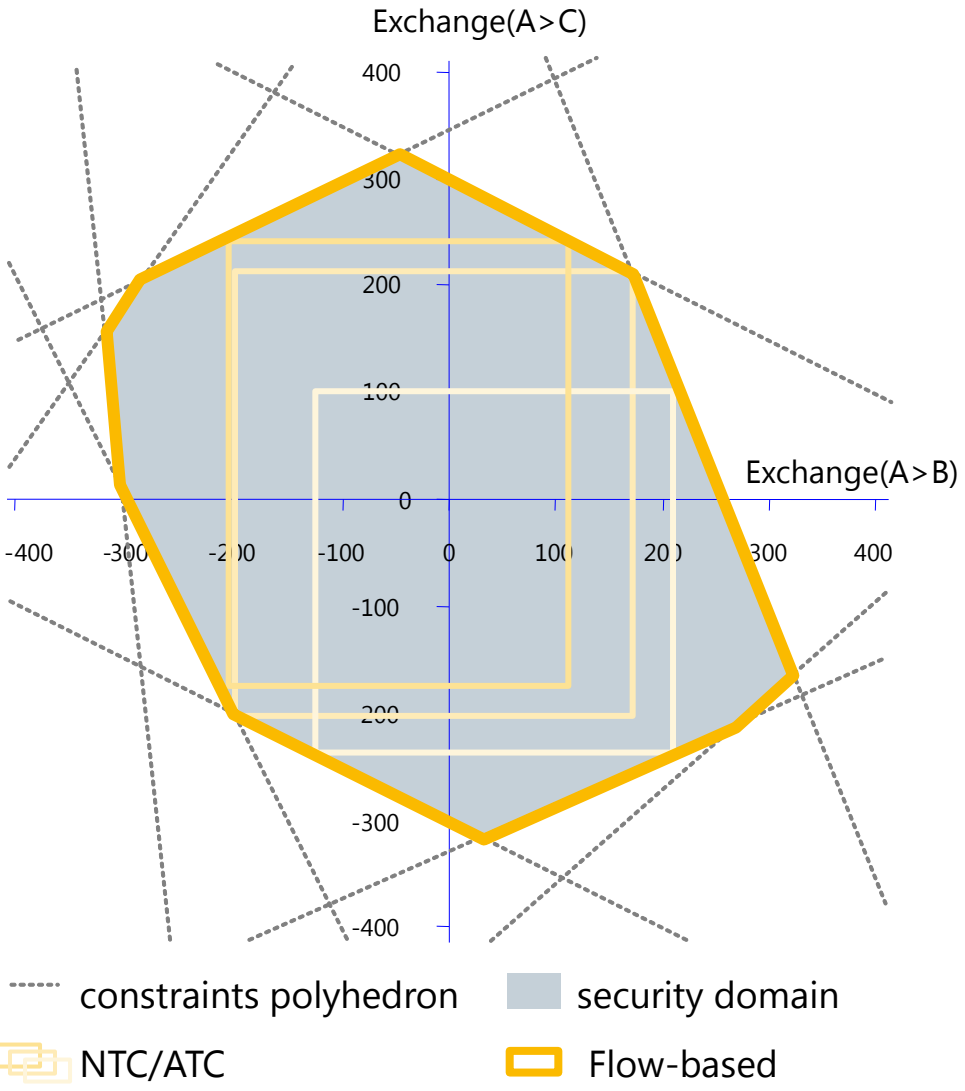
- Given the security domain, NTC/ATC constraints and the corresponding NTC/ATC domain are a choice made by the TSO
- The FB domain is the security domain itself



Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

ATC & FB grid constraints

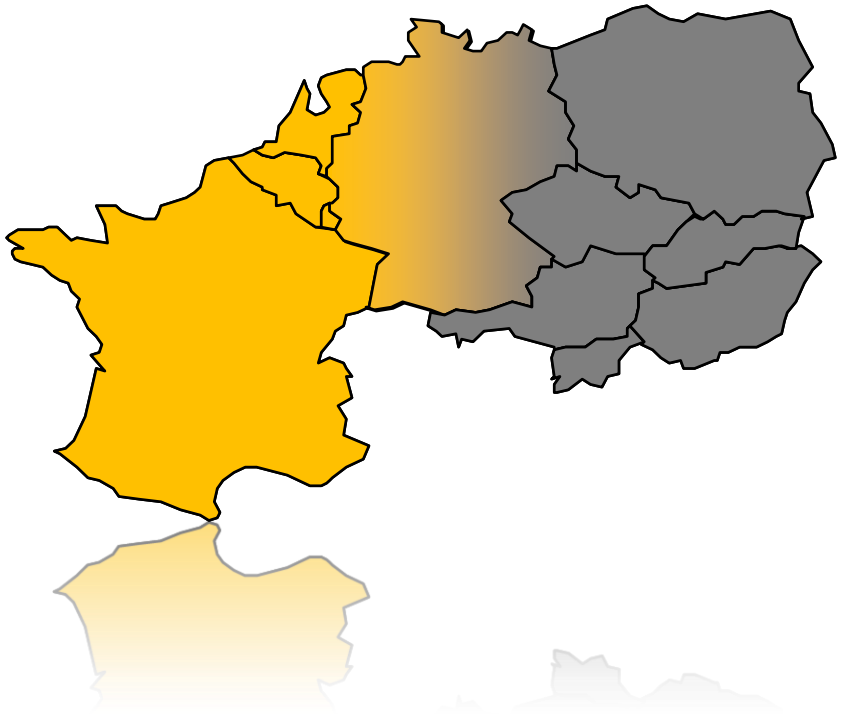
- Given the security domain, NTC/ATC constraints and the corresponding NTC/ATC domain are a choice made by the TSO
- The FB domain is the security domain itself
- In FB capacity split is not a choice of the TSO, but is market driven (at the time of allocation)
- FB offers more trading opportunities with the same level of security of supply



Source: Schavemaker and Noury, CWE Flow-Based Market Coupling: on the Eve of Implementation (2012)

Current status of Flow Based

CWE



CEE

Flow-based Market Coupling

- Implementation go-live: end 2013
- External Parallel run start: dec 2012

Flow-based

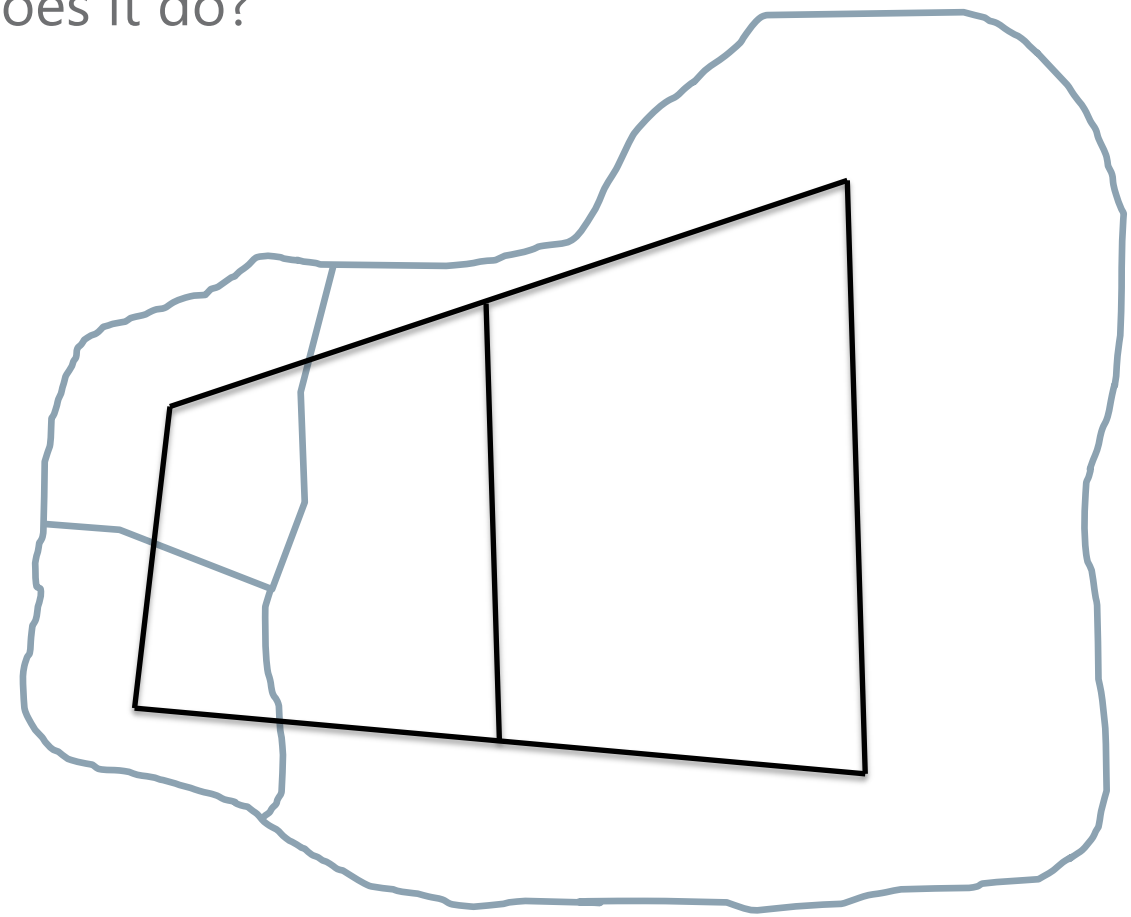
- Started FB development for FB explicit auctions
- Currently on hold

Zone delineation

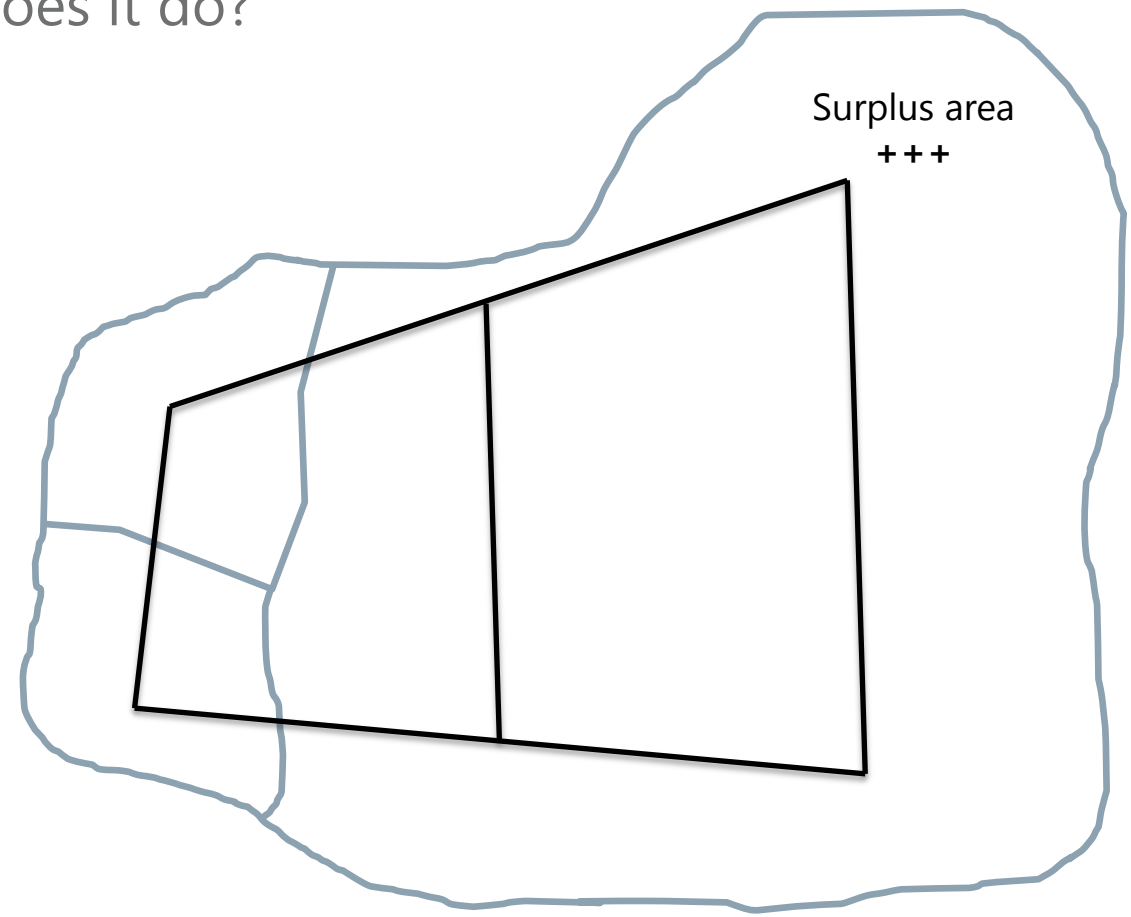
Zone delineation is one way to manage congestions in the transmission network. Three systems may be distinguished:

- the uniform system, where no exchanges are subject to an allocation mechanism;
- the nodal system, where exchanges between all nodes are subject to an allocation mechanism;
- the zonal system, where only exchanges between zones are subject to an allocation mechanism.

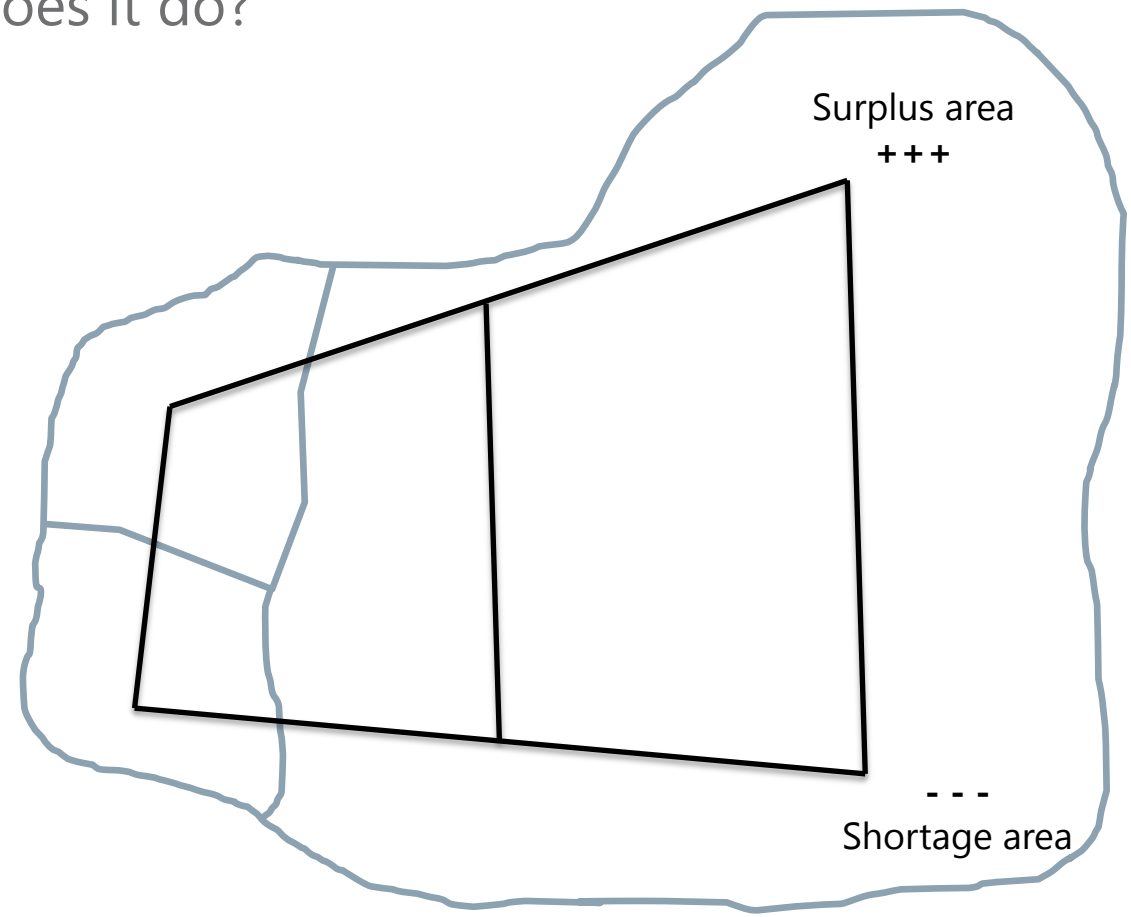
Zone delineation: what does it do?



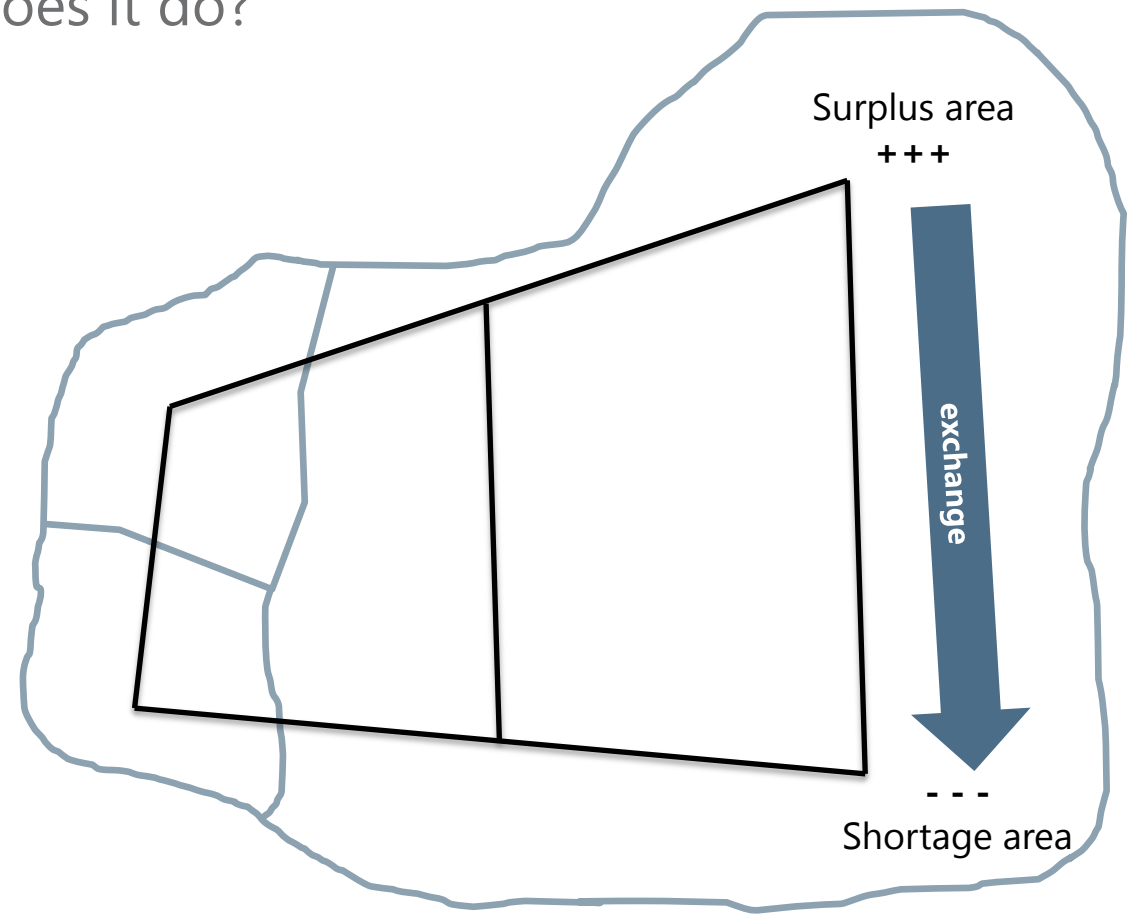
Zone delineation: what does it do?



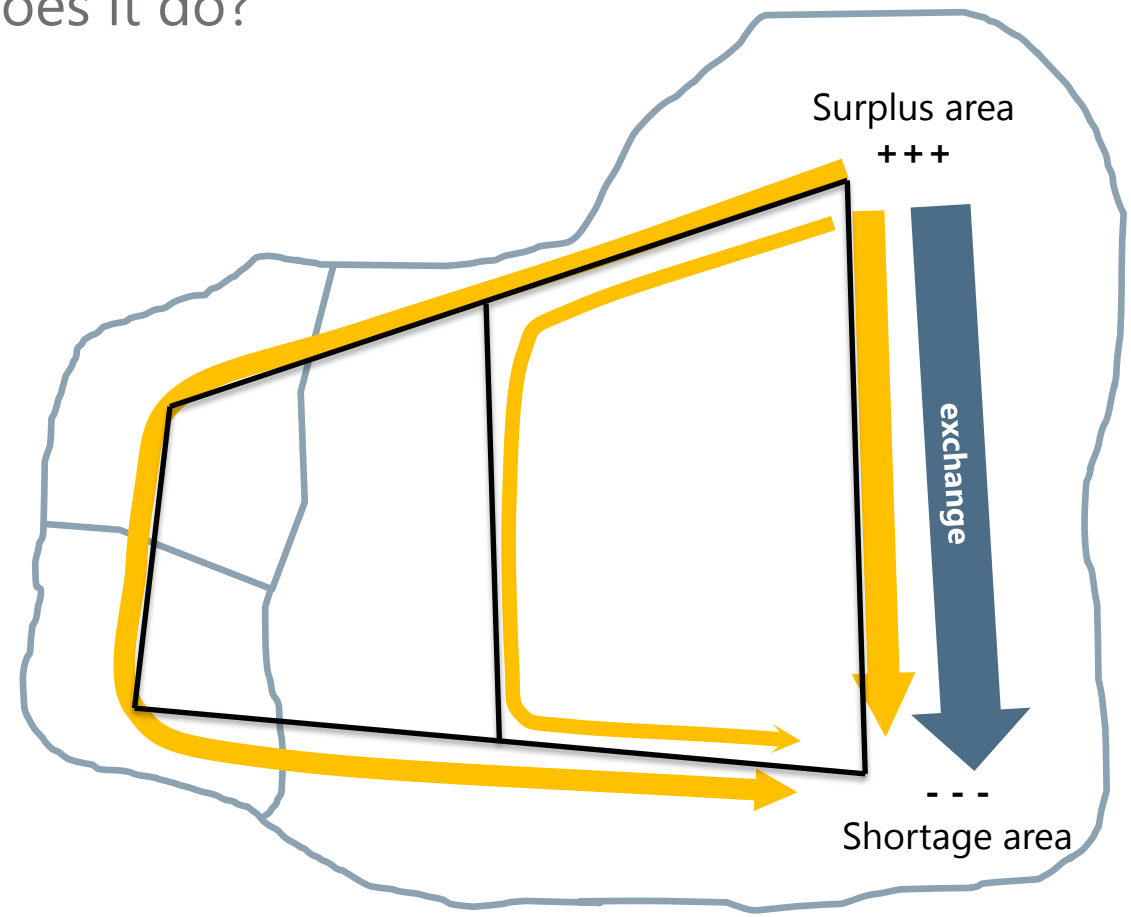
Zone delineation: what does it do?



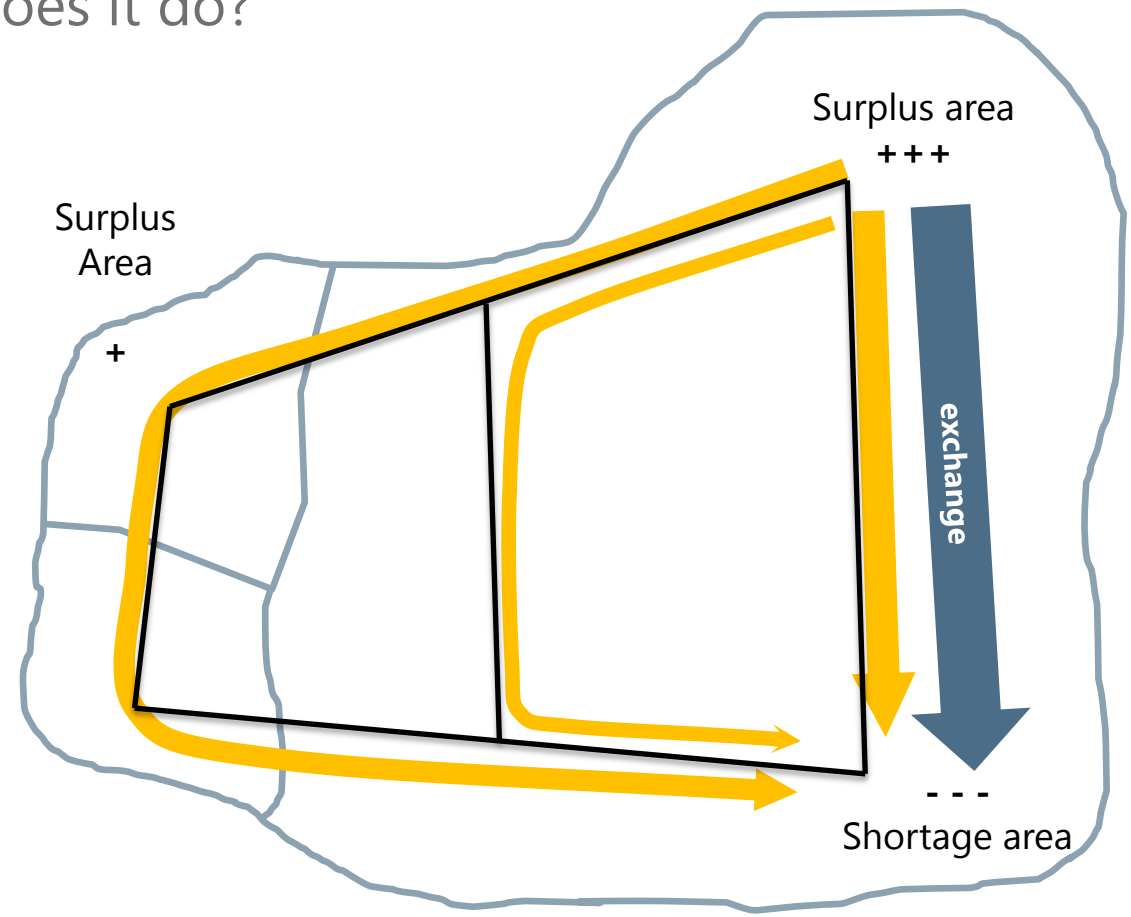
Zone delineation: what does it do?



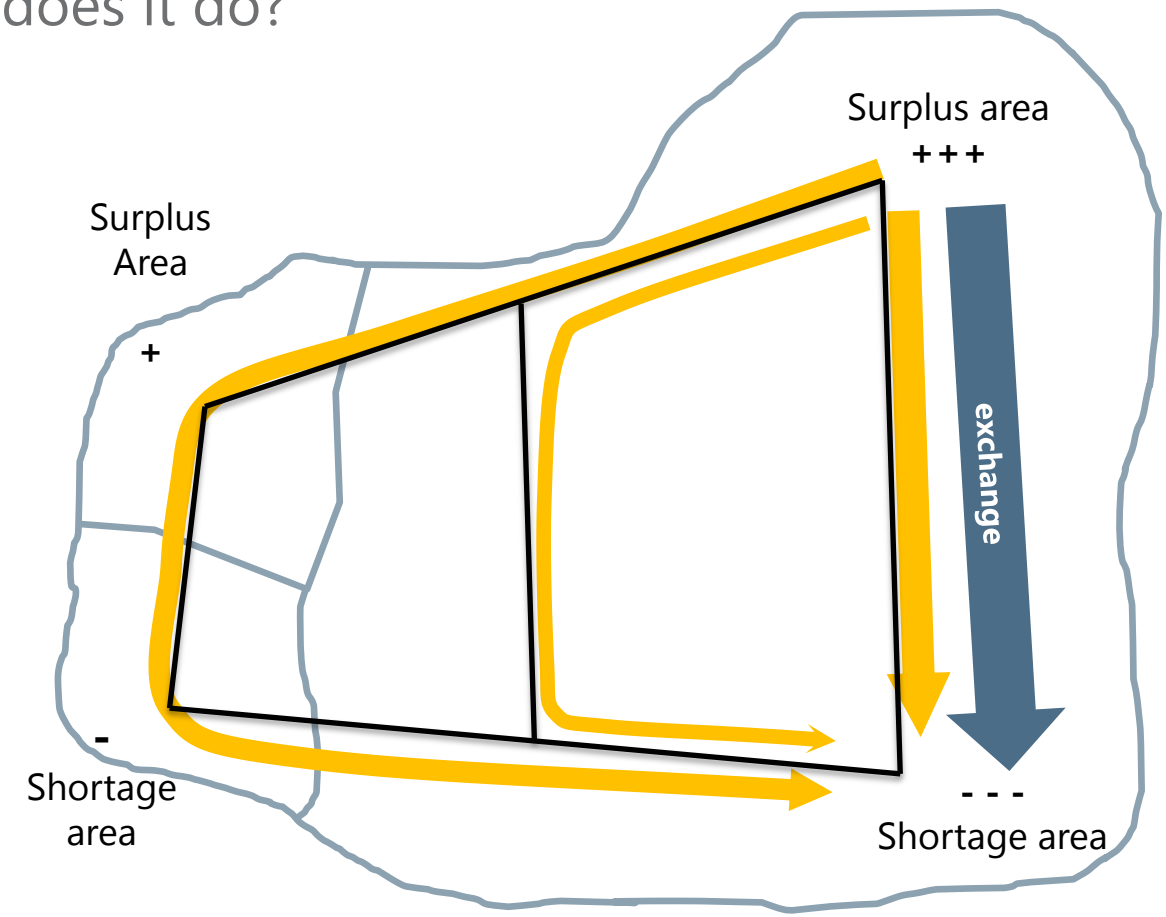
Zone delineation: what does it do?



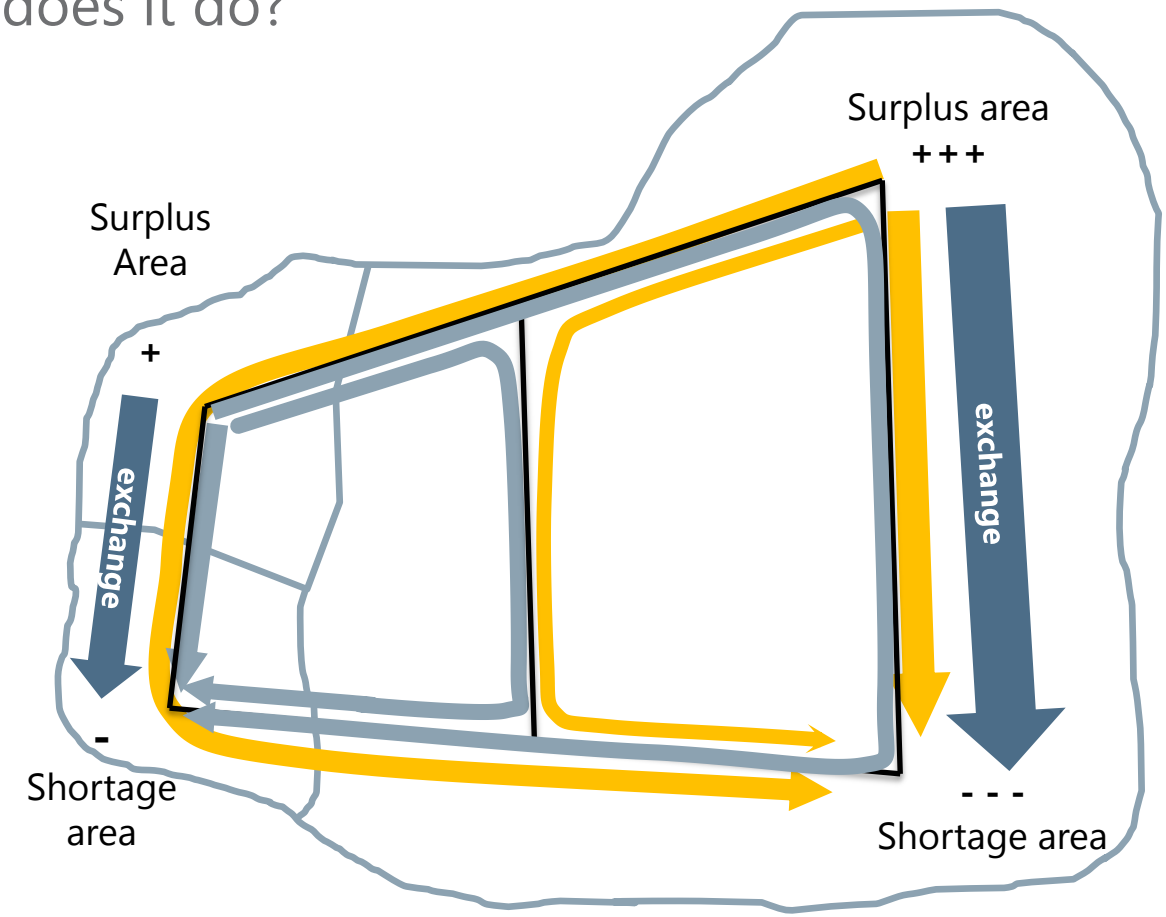
Zone delineation: what does it do?



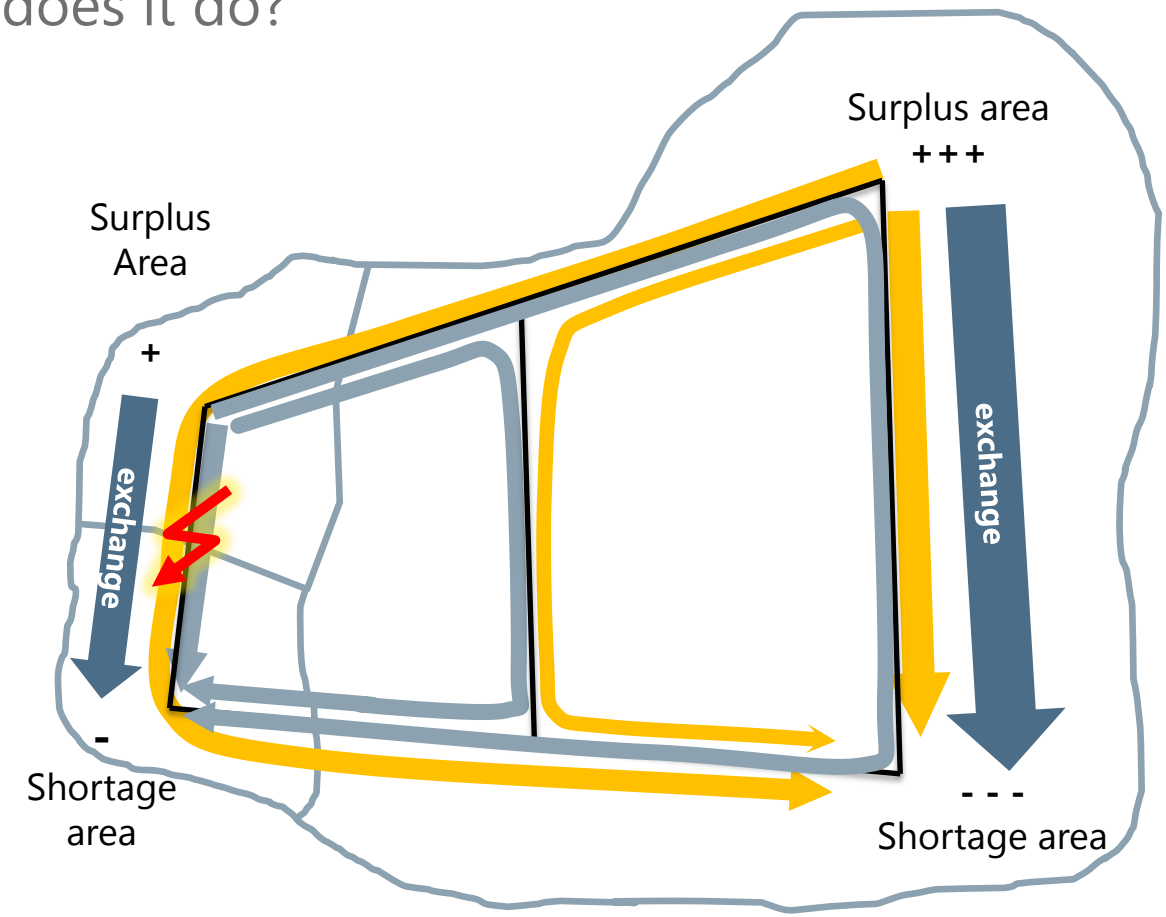
Zone delineation: what does it do?



Zone delineation: what does it do?

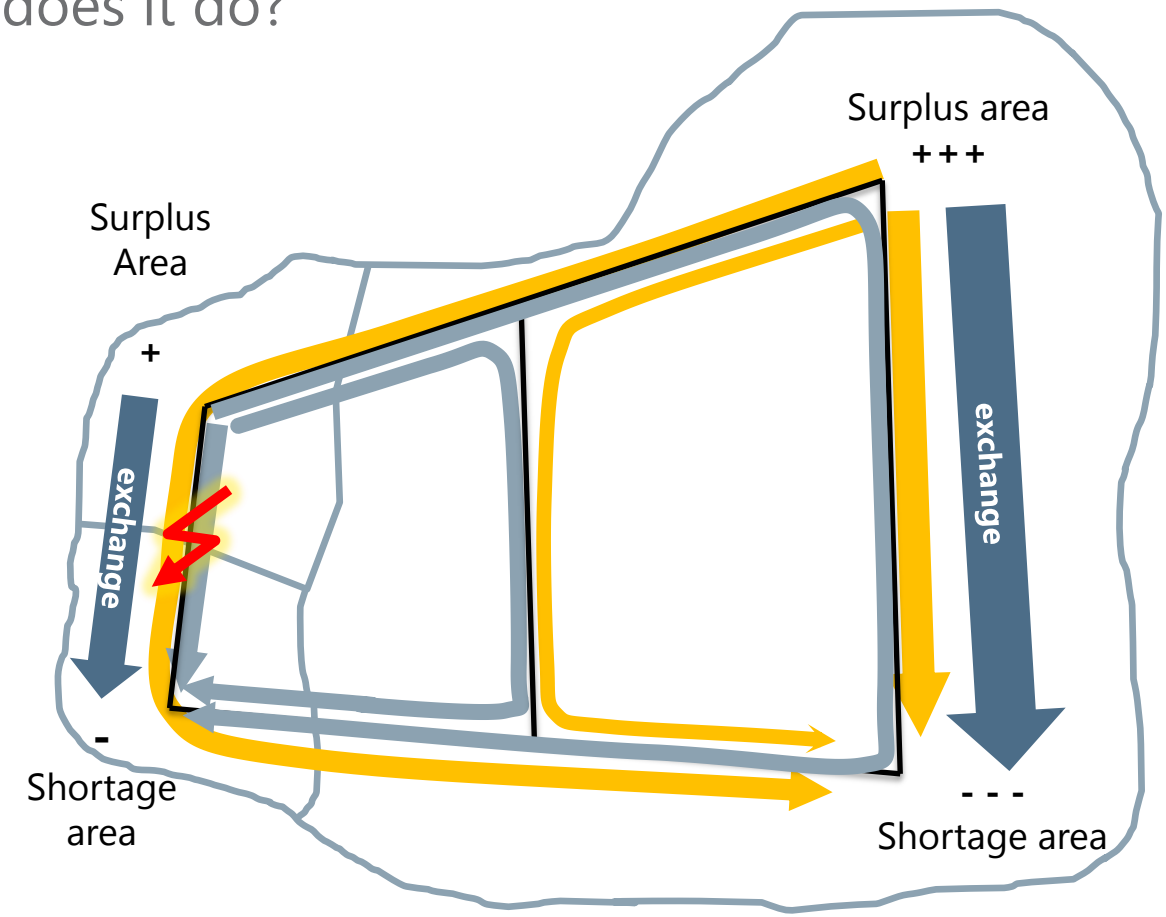


Zone delineation: what does it do?



Zone delineation: what does it do?

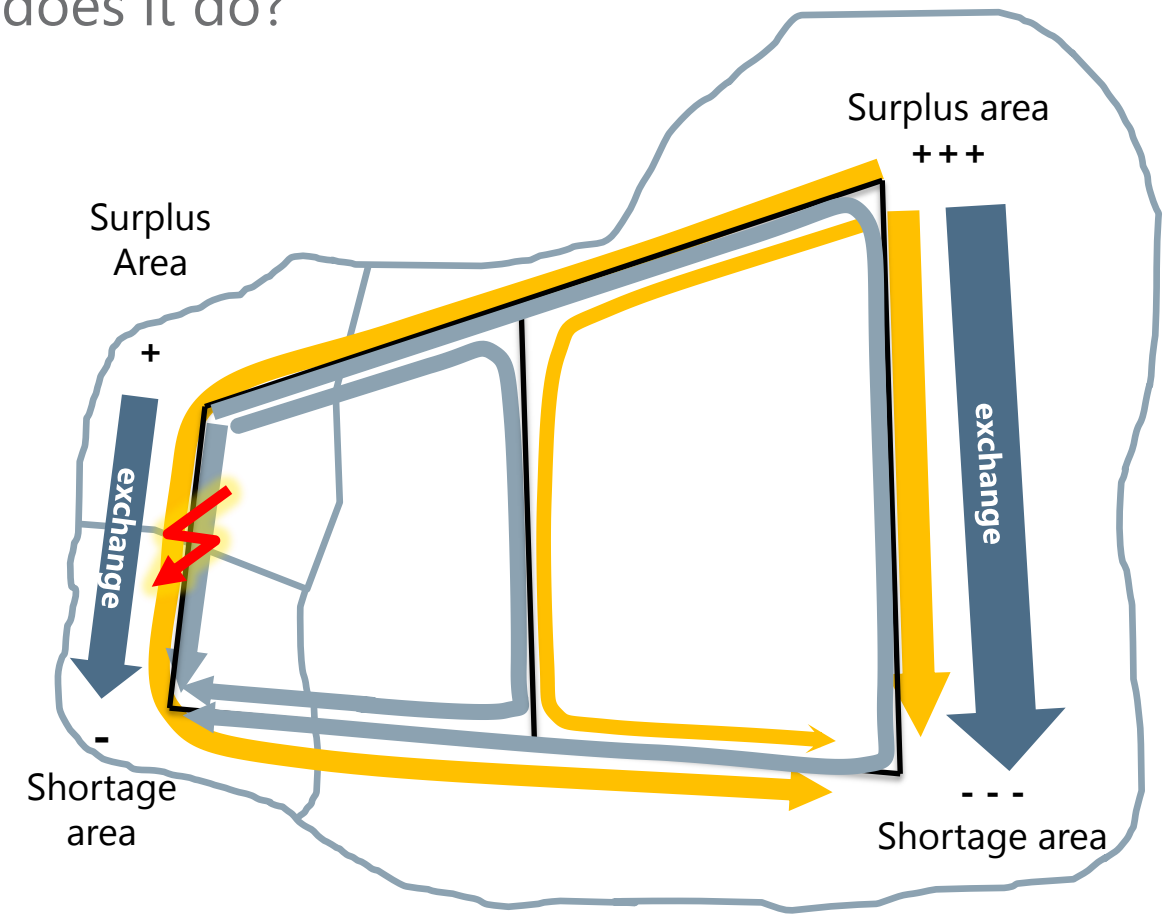
Which exchange is causing the congestion?



Zone delineation: what does it do?

Which exchange is causing the congestion?

- Flow caused by exchange not under allocation
- Flow caused by exchange under allocation

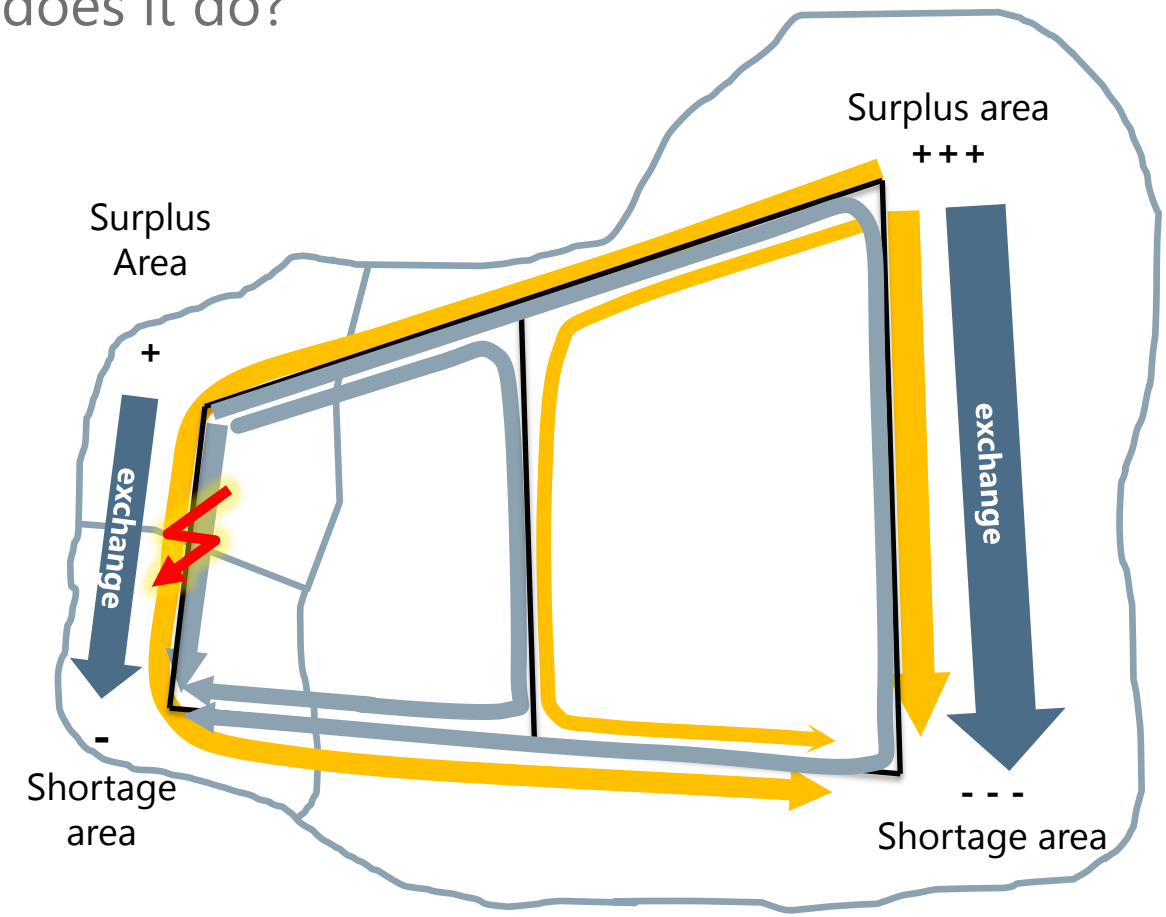


Zone delineation: what does it do?

Which exchange is causing the congestion?

- Flow caused by exchange not under allocation
- Flow caused by exchange under allocation

(Both are, but only one falls under allocation due to the current zone delineation)

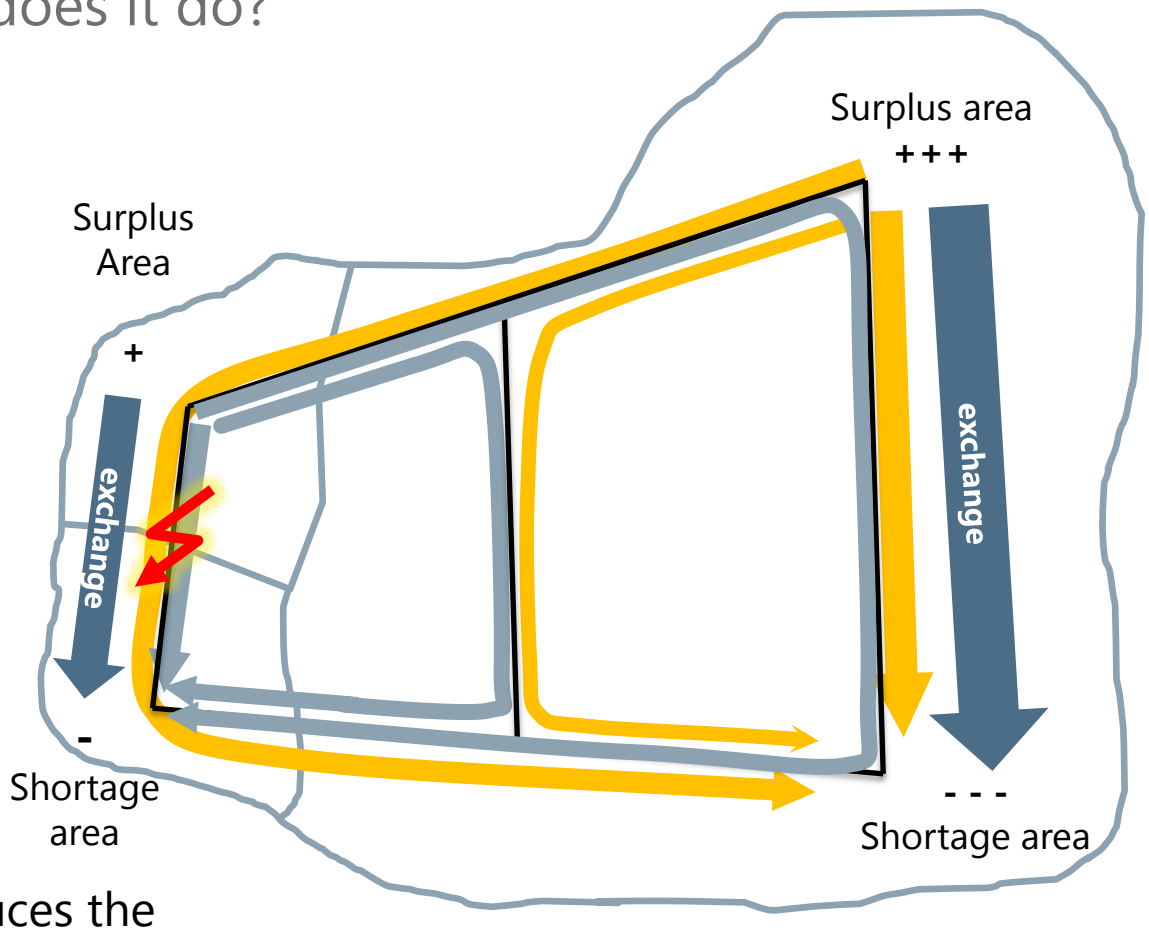


Zone delineation: what does it do?

Which exchange is causing the congestion?

- Flow caused by exchange not under allocation
- Flow caused by exchange under allocation

(Both are, but only one falls under allocation due to the current zone delineation)



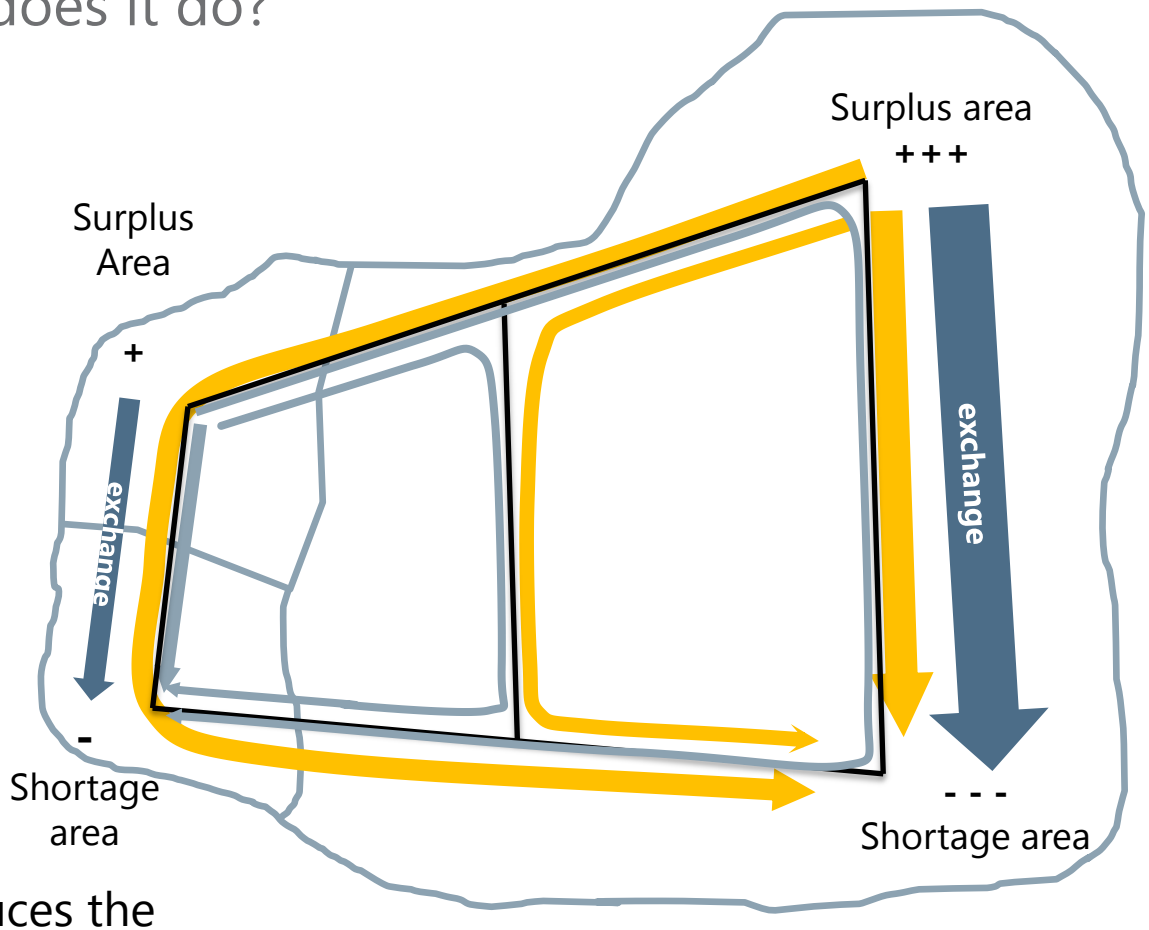
The allocation mechanism reduces the exchange under allocation until the congestion is relieved

Zone delineation: what does it do?

Which exchange is causing the congestion?

- Flow caused by exchange not under allocation
- Flow caused by exchange under allocation

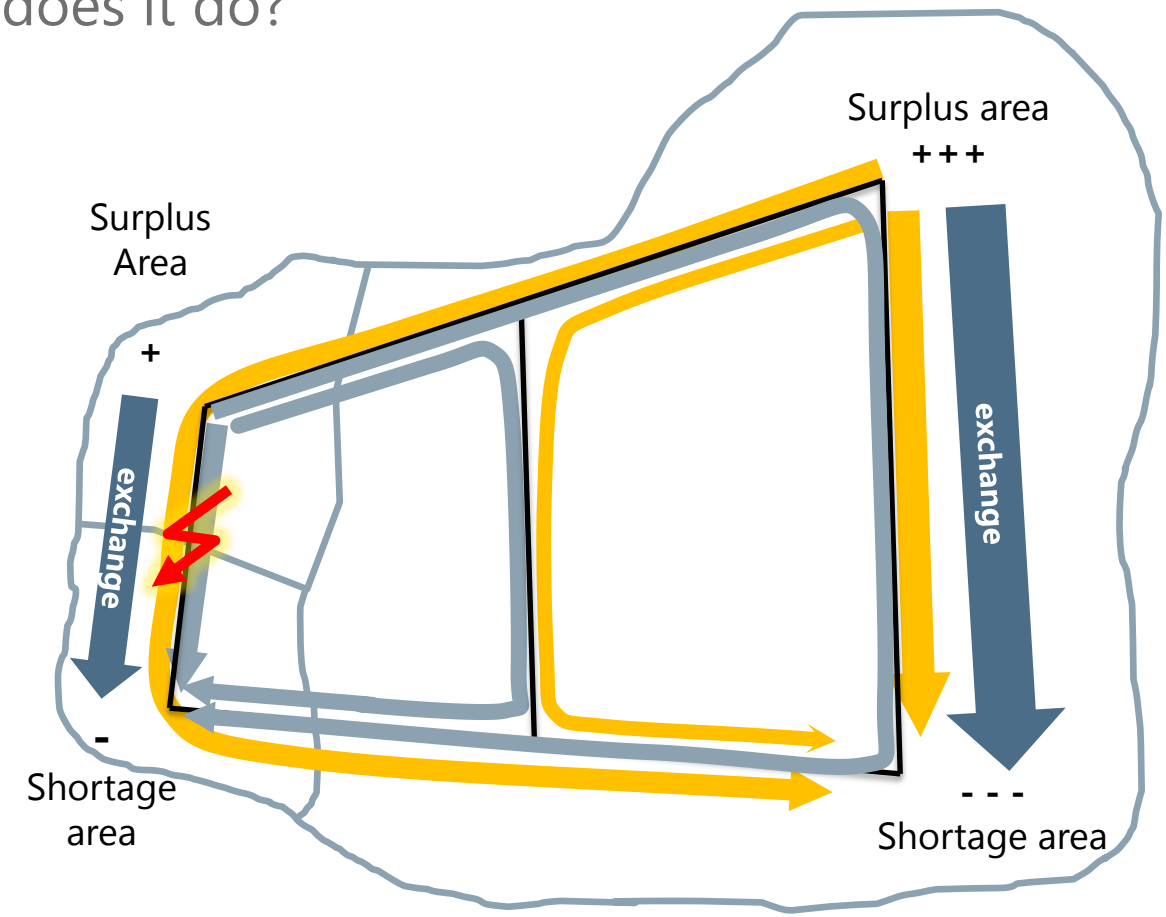
(Both are, but only one falls under allocation due to the current zone delineation)



The allocation mechanism reduces the exchange under allocation until the congestion is relieved

Zone delineation: what does it do?

- Flow caused by exchange not under allocation
- Flow caused by exchange under allocation

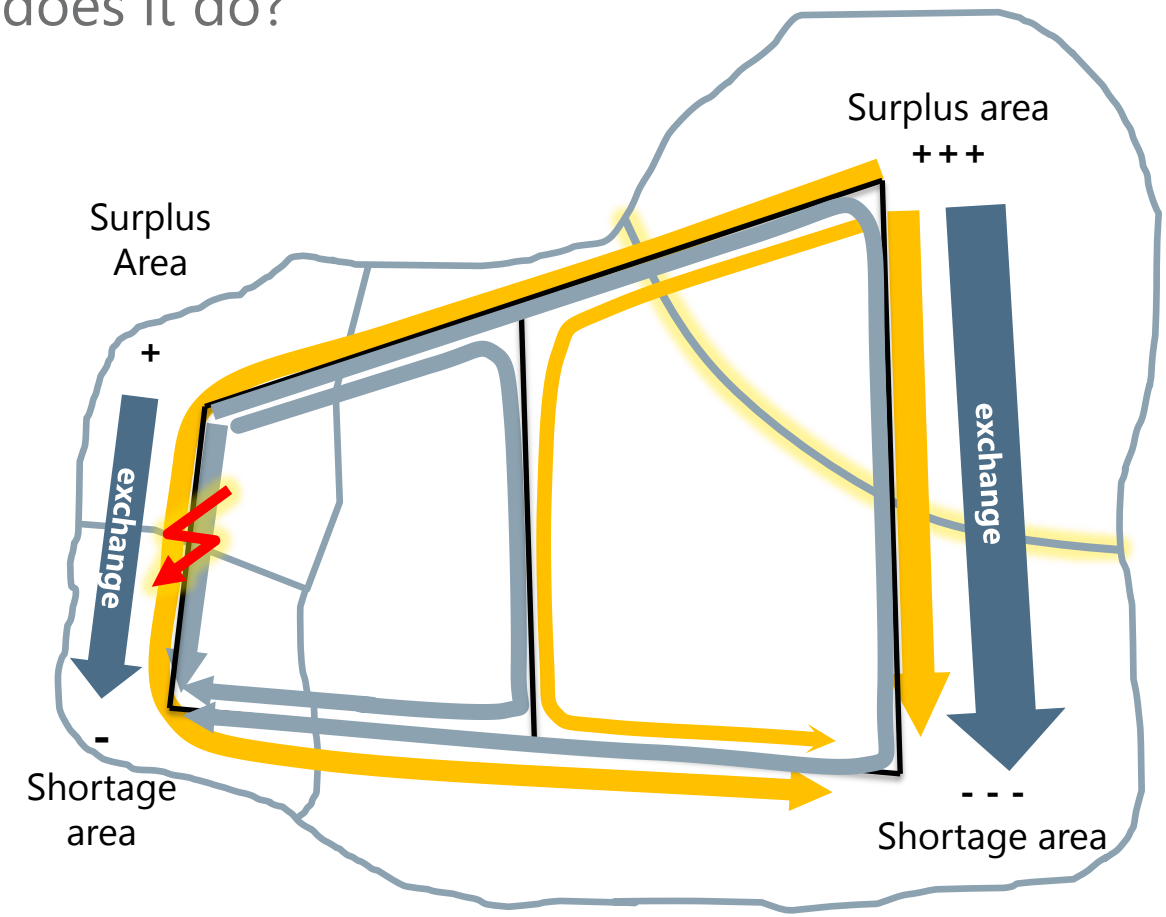


Zone delineation: what does it do?

Flow caused by exchange not under allocation

Flow caused by exchange under allocation

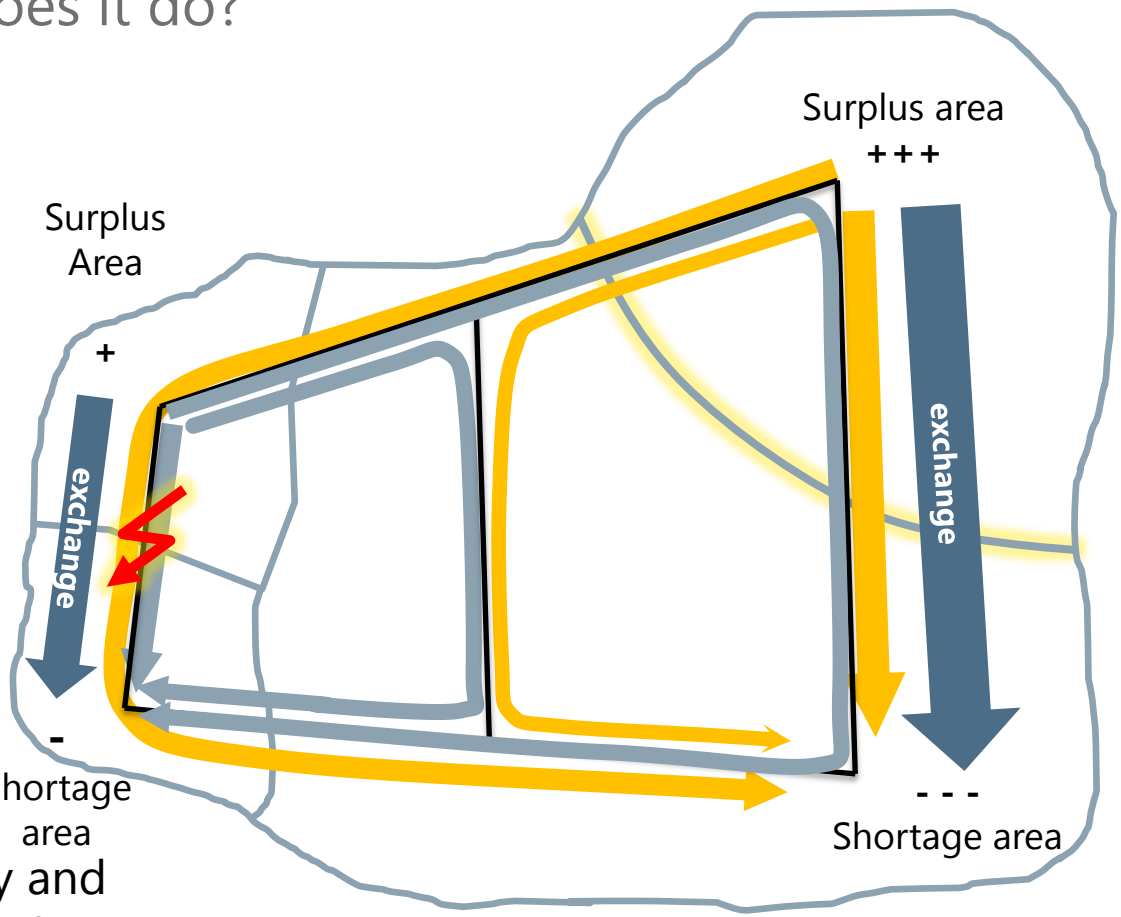
A new bidding zone brings the other exchange also under allocation



Zone delineation: what does it do?

Flow caused by exchange not under allocation

Flow caused by exchange under allocation



A new bidding zone brings the other exchange also under allocation

Both exchanges now compete for the scarce capacity and the price differences determine the capacity distribution between the two exchanges

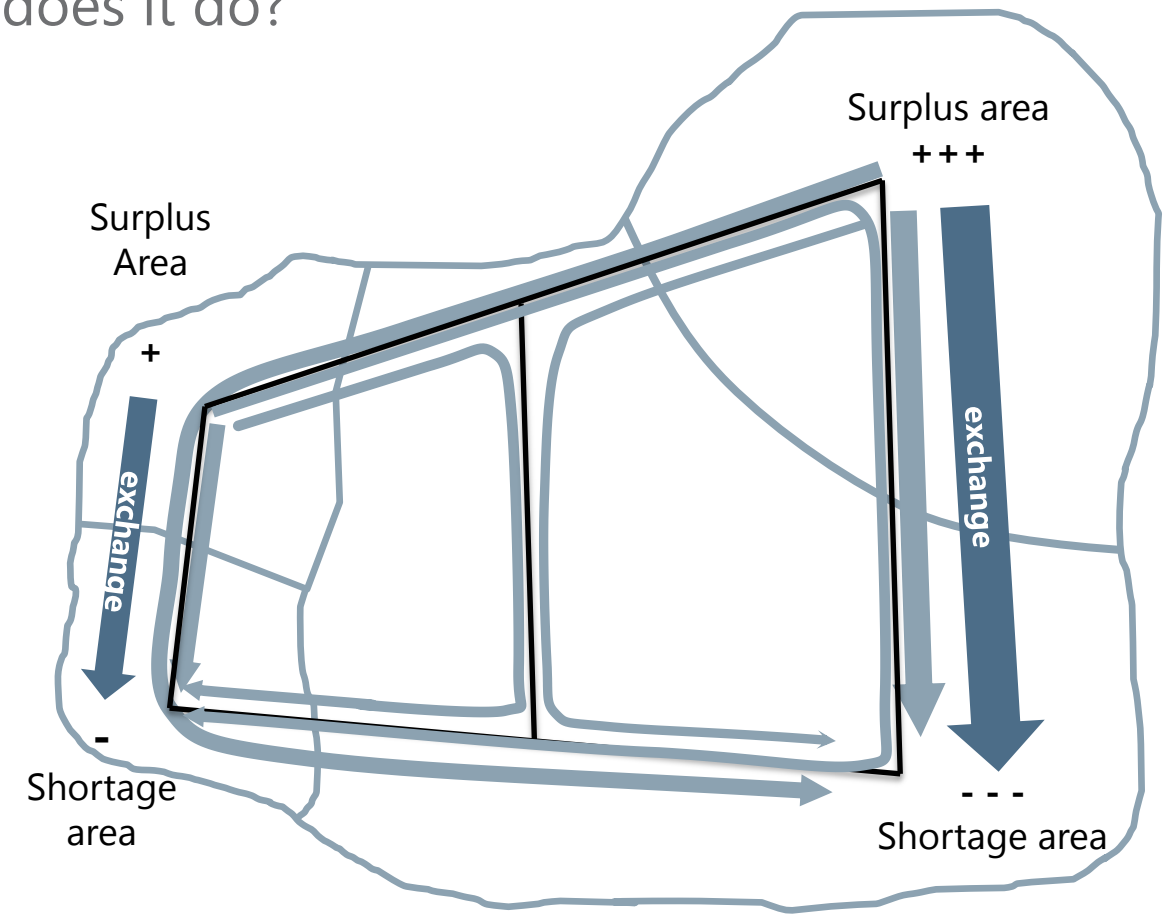
Zone delineation: what does it do?

Flow caused by exchange not under allocation

Flow caused by exchange under allocation

Both exchanges now fall under allocation

The congestion is efficiently managed through the allocation



Questions?

For further reading. . .

- Public CWE materials on market coupling, flow-based, and price zones can be found on: http://www.tennet.org/english/projects/Marketcoupling/downloads.aspx

- Schavemaker, P., Croes, A., Otmani, R., Bourmaud, J., Zimmermann, U., Wolpert, J., Reyer, F., Weis, O., and Druet, C.: Flow-based allocation in the central western Euro¬pean region, paper C5-307, CIGRE 2008, Paris.

- M. Aguado, R. Bourgeois, J.Y. Bourmaud, J. Van Casteren, M.A. Ceratto, M. Jäkel, B. Malfliet, C. Mestdag, P. Noury, M. Pool, W. Van Den Reek, M. Rohleder, P.H. Schavemaker, S. Scolari, O. Weis, J. Wolpert: Flow-based market coupling in the Central Western European region - on the eve of implementation -, paper C5- 204, CIGRE 2012, Paris.

E-Bridge Consulting B.V.
Utrechtseweg 159a
6862 AH Oosterbeek, the Netherlands

Phone +31 (0)26 700 9797
Fax +31 (0)26 700 9799
E-mail info@e-bridge.nl

For more information about our projects, customers and consultants please visit our web site at

www.e-bridge.com