Enduring Auction Capability

Market Design Explainer

Locational Procurement

November 2026

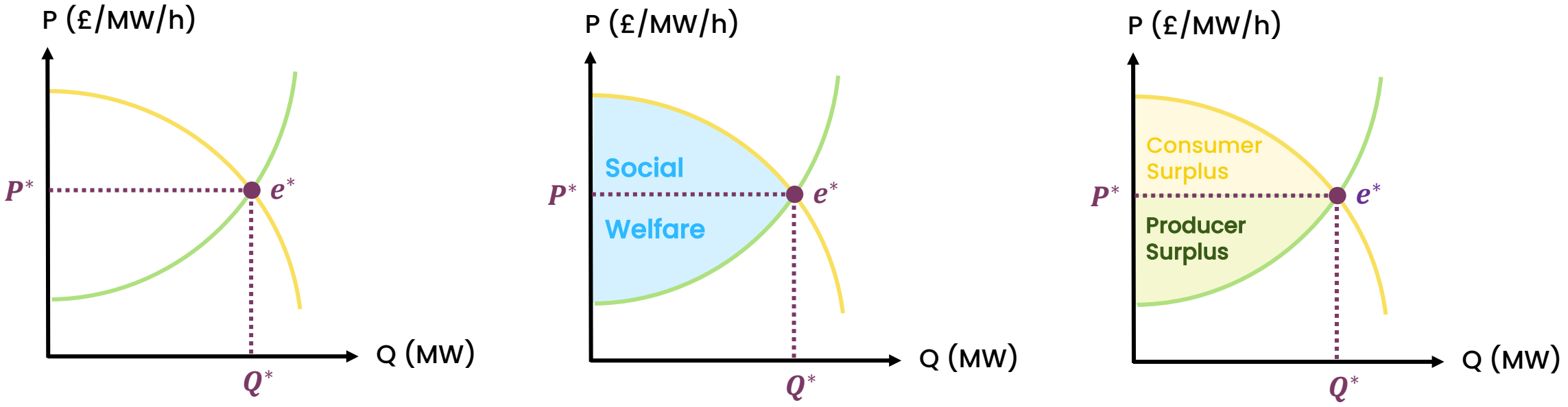
Market Fundamentals

- Market Welfare, Consumer Surplus and Producer Surplus
- Market Welfare Example

Market Welfare, Consumer Surplus and Producer Surplus

In its simplest case, the market clears at the intersection point of the demand and the supply curves.

- **Social / market welfare**
  - is defined as the sum of consumer surplus (CS) and producer surplus (PS)
  - is a function of order acceptance therefore does not depend on the market clearing price
- **Consumer surplus and producer surplus** depend on the market clearing price.
- The **objective function** finds the order selection that maximises the market welfare and the clearing prices that minimise total procurement costs, subject to network constraints.



Market Welfare Example

Consider the following example:

- NESO would like to procure $50MW$ of Product X. The maximum price NESO is willing to pay is $£100/MW/h$.
- Provider A offers $20MW$ at $£40/MW/h$.
- Provider B offers $30MW$ at $£80/MW/h$.

→ The market clears $50MW$ at $£80/MW/h$.

Type	Order ID	Participant	Product	Volume	Price
Buy	a	NESO	X	50	100
Sell	1	A	X	20	40
Sell	2	B	X	30	80

The market welfare and surpluses are calculated as follows:

Consumer Surplus (CS)

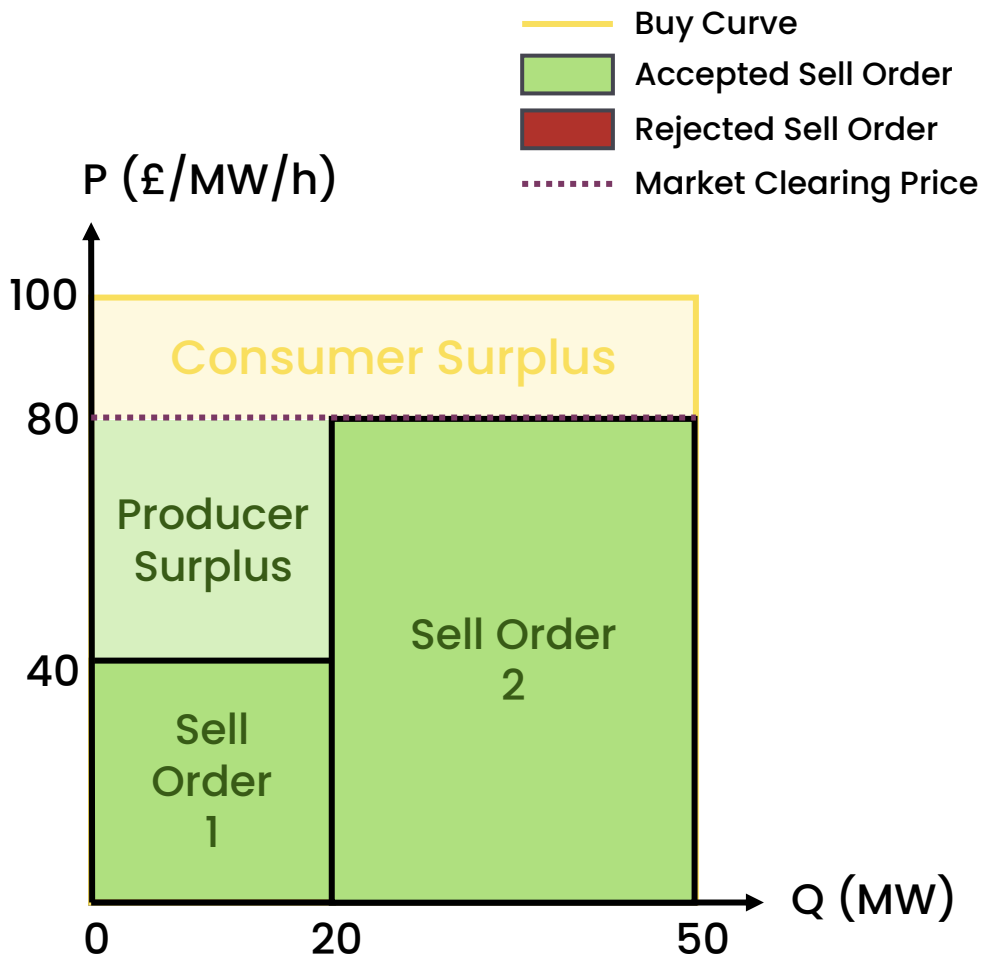
- $Consumer\ Surplus = (£100 - £80) \times 50MW = £1000/h.$

Producer Surplus (PS)

- $Producer\ Surplus_A = (£80 - £40) \times 20MW = £800/h,$
- $Producer\ Surplus_B = (£80 - £80) \times 30MW = £0/h,$
- $Total\ Producer\ Surplus = £800/h + £0/h = £800/h.$

Market Welfare

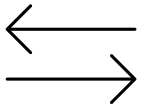
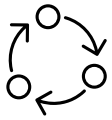
- $Market\ Welfare = CS + PS = £1800/h.$



Fundamental Features

- Global & local service requirements
- Transfer limits
- Multi-zone transfer rules

Fundamental Features

		Response	Reserve
Service requirements		Global requirements represented as global demand	Global requirements represented as global demand
		Local requirements represented as minimum and maximum constraints cleared quantities	Local requirements represented as inelastic (unpriced) local demand
Transfer limit		None	Thermal limits represented as Available Transfer Capacity (ATC) constraints
Multi-zone transfer rules		Not applicable	Sharing arrangement

Reserve Examples I

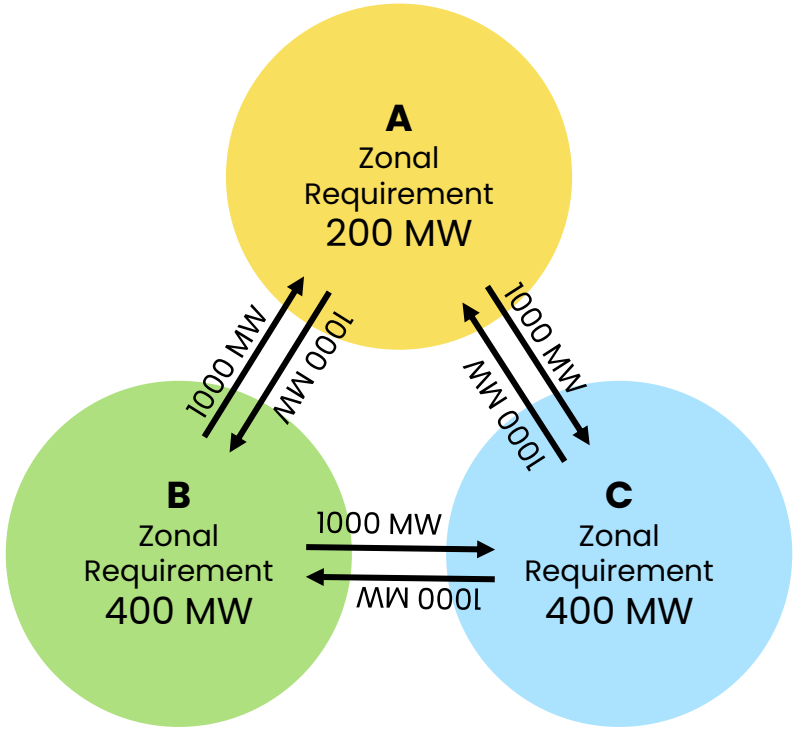
- Sufficient ATCs (Example 1)
- Binding ATCs (Example 2-3)

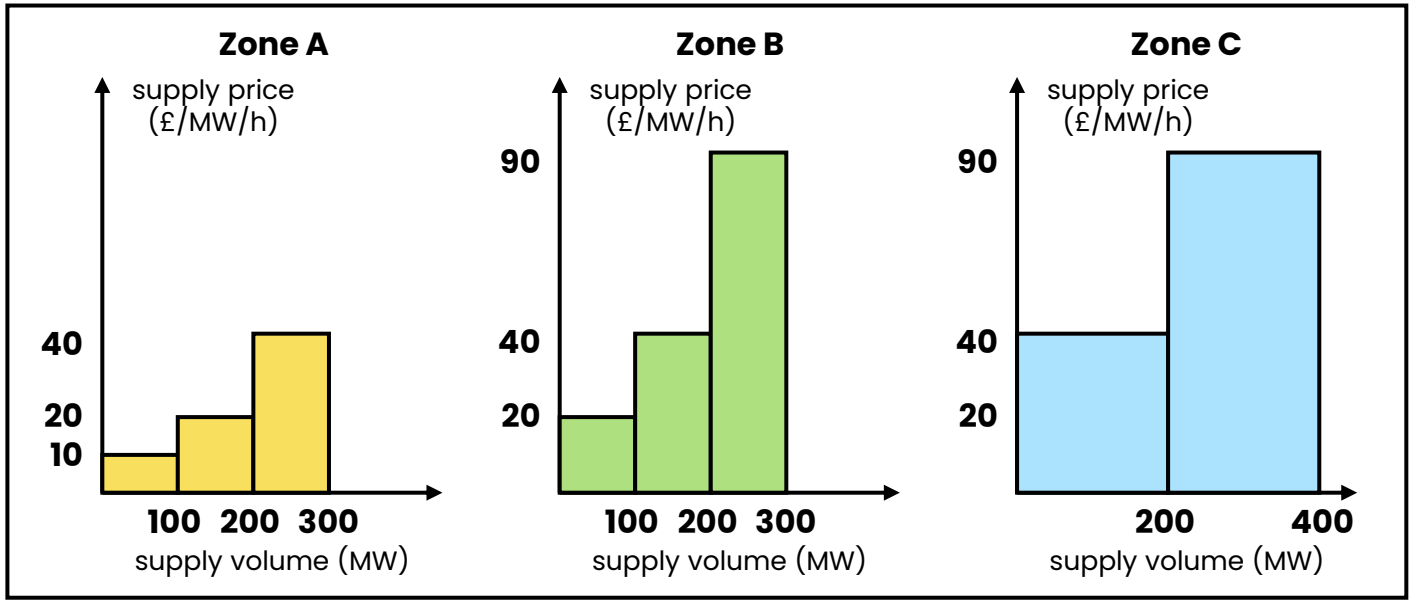
Note: *[1] Assume all supply orders are fully divisible and are fully independent from each other. [2] Available Transfer Capacity (ATC) represents how much Reserve can be transferred between interconnected zones without exceeding the relevant transmission boundary.*

NESO
National Energy System Operator

Example 1: Reserve Services [1/3]

When sufficient ATC exists, **all zones share the same price**



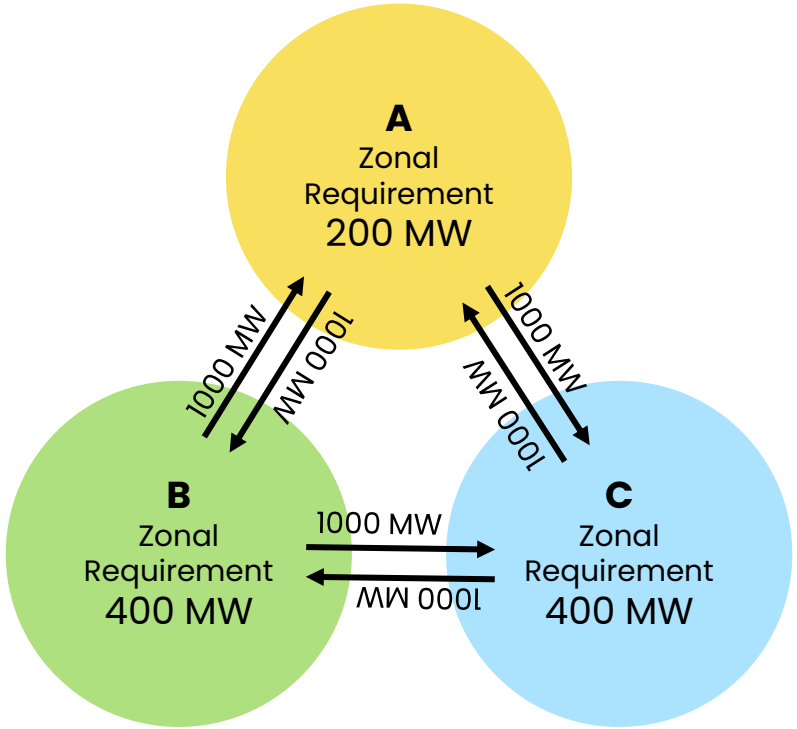


- **Each zonal requirement constitutes one scenario. The final dispatch must satisfy all scenarios simultaneously.**
- The ATC values are sufficiently large to supply any of the zonal requirements from any zone. Therefore, we can simply find the optimal dispatch by merging the supply orders into a single supply curve*, sorted in an ascending price order and selecting the cheapest first.

Note: *The aggregated supply curve is illustrated in Example 4.*

Example 1: Reserve Services [2/3]

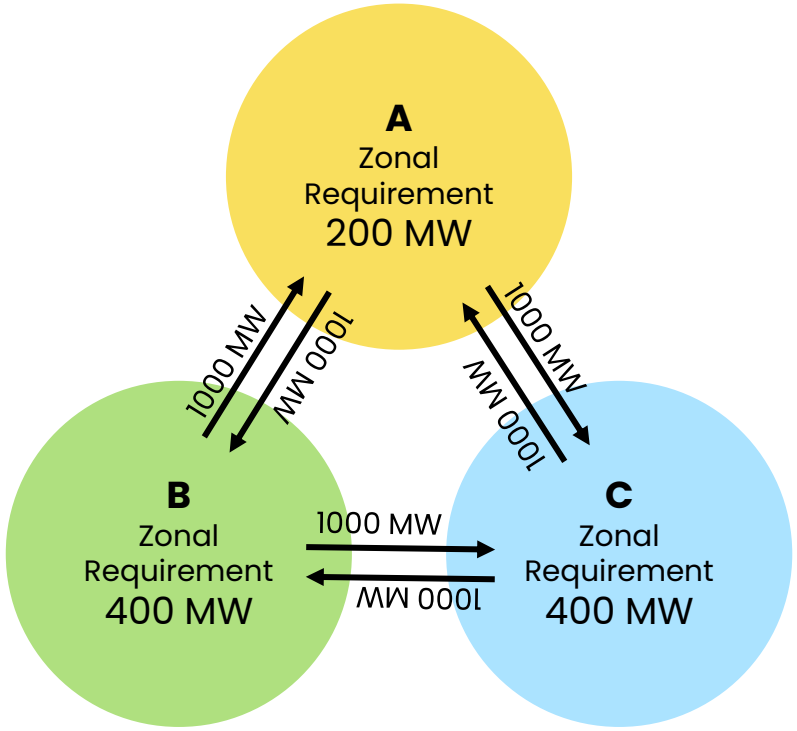
When sufficient ATC exists, **all zones share the same price**.

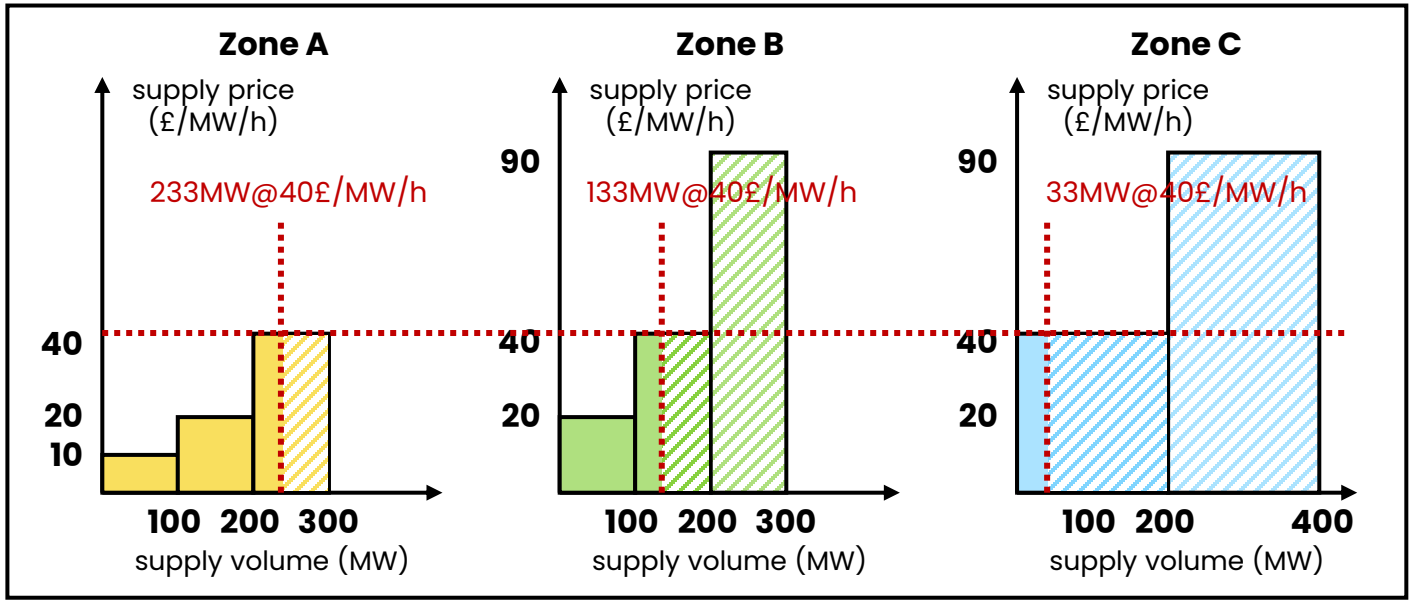


- Zonal requirement in zone A (Scenario A) is fulfilled by
  - accepting 100 MW in zone A (offered at 10 £/MW/h)
  - plus 100 MW from zones A and B (offered at 20 £/MW/h).
- Zonal requirement in zone B (Scenario B) is fulfilled by
  - accepting 100 MW in zone A (offered at 10 £/MW/h)
  - plus 200 MW from zones A and B (offered at 20 £/MW/h)
  - plus 100 MW from zones A, B, and C (offered 40 £/MW/h).
- Zonal requirement in zone C (Scenario C) is fulfilled by the same dispatch (same as zone B).
- Because all the zonal requirement scenarios can be respected with this dispatch, it clears as the optimal solution.
- No congestion means all zonal prices are equal, but it is also clear to see that all zones should have a price of 40 £/MW/h, which aligns with their marginal orders.

Example 1: Reserve Services [3/3]

When sufficient ATC exists, **all zones share the same price**.

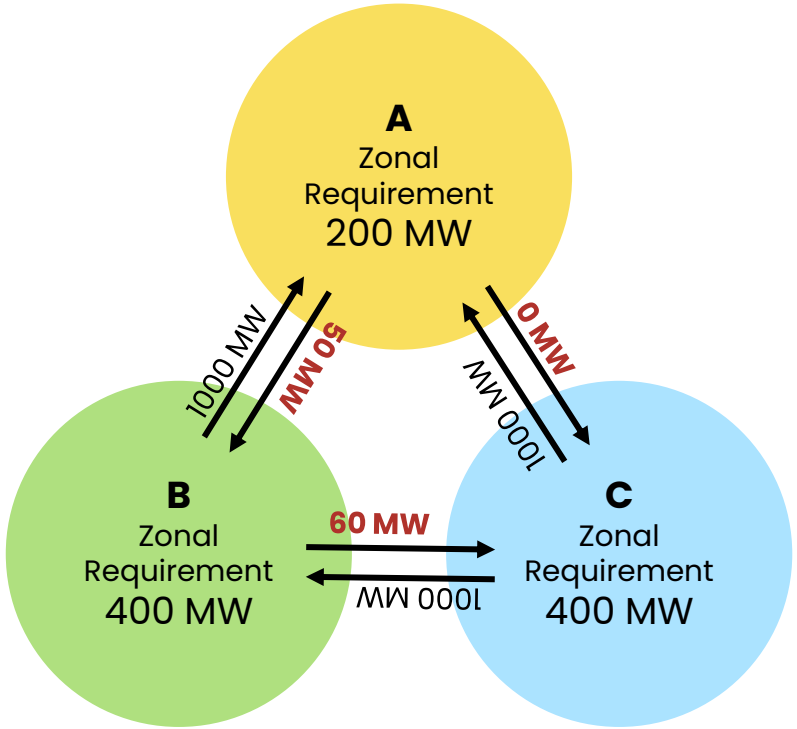




- **Supply Cost:** 9000 £/h (or 8960 £/h after volume rounding)
- **Procurement Cost**: 16000 £/h

Example 2: Reserve Services [1/2]

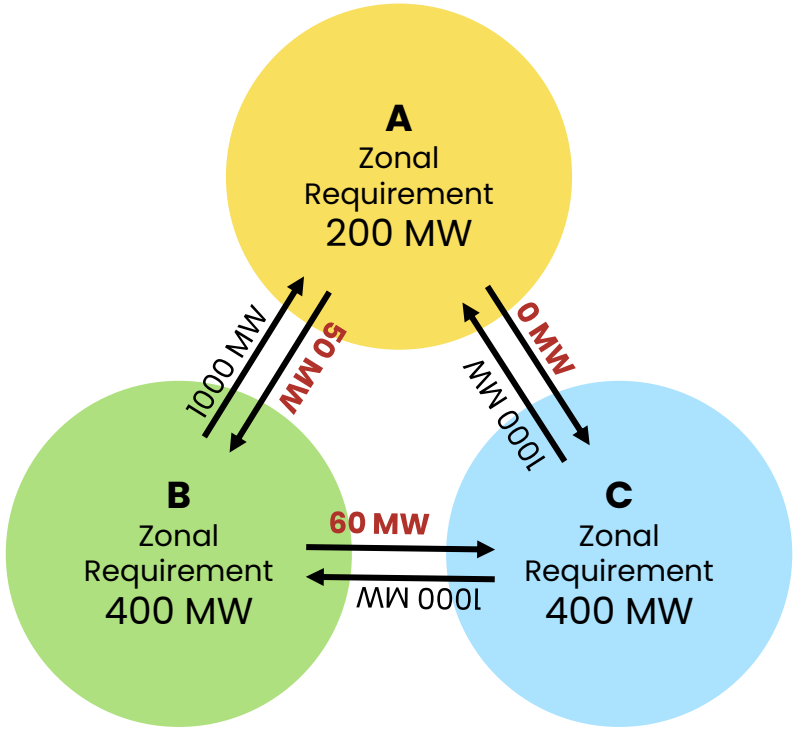
Binding ATCs, **allow price spreads between zones**.

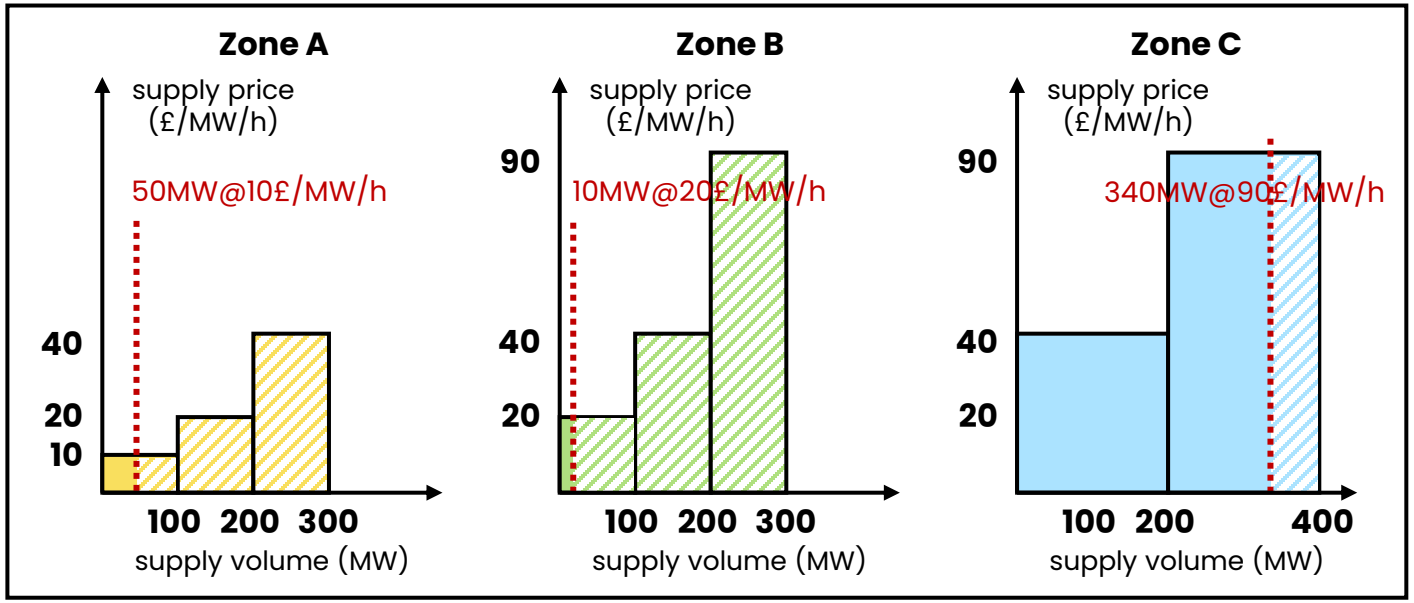


- Building from the previous example:
- Scenario A suffers no impact as it is the cheapest and most accessible zone for external supply.
- Scenario B is now limited in the amount it can import from zone A.
  - Zone B can only import 50 MW from A.
  - 100 MW can be supplied locally from the offer at 20 £/MW/h.
  - The other 250 MW are split between the orders offered at 40 £/MW/h in zones B and C.
- Scenario C is even more restricted.
  - It would require 50 MW of imports from A (passing through B).
  - 10 MW of imports from B.
  - and the rest needs to be supplied locally, reaching the order at 90 £/MW/h.
- Only the optimal dispatch for scenario C is feasible for the other scenarios as well. Because the ATCs A→B and B→C are binding, price spreads are allowed, creating the following price relationship: $price^A \leq price^B \leq price^C$ where prices would be:
  - $price^A = 10\ £/MW/h$
  - $price^B = 20\ £/MW/h$
  - $price^C = 90\ £/MW/h$

Example 2: Reserve Services [2/2]

Binding ATCs, **allow price spreads between zones**.



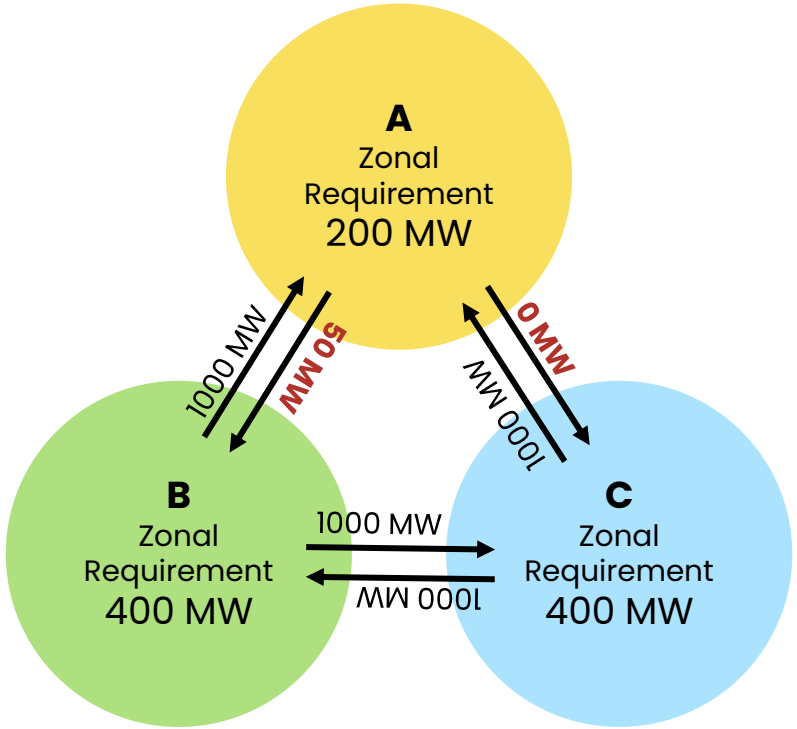


- **Supply Cost:** 21300 £/h
- **Procurement Cost**: 31300 £/h

Notably, limited ATCs increased the total procurement cost from 16000 £/h to 31300 £/h (almost doubling it). Supply cost increases from 9000 £/h to 21300 £/h (almost tripling it)

Example 3: Reserve Services [1/2]

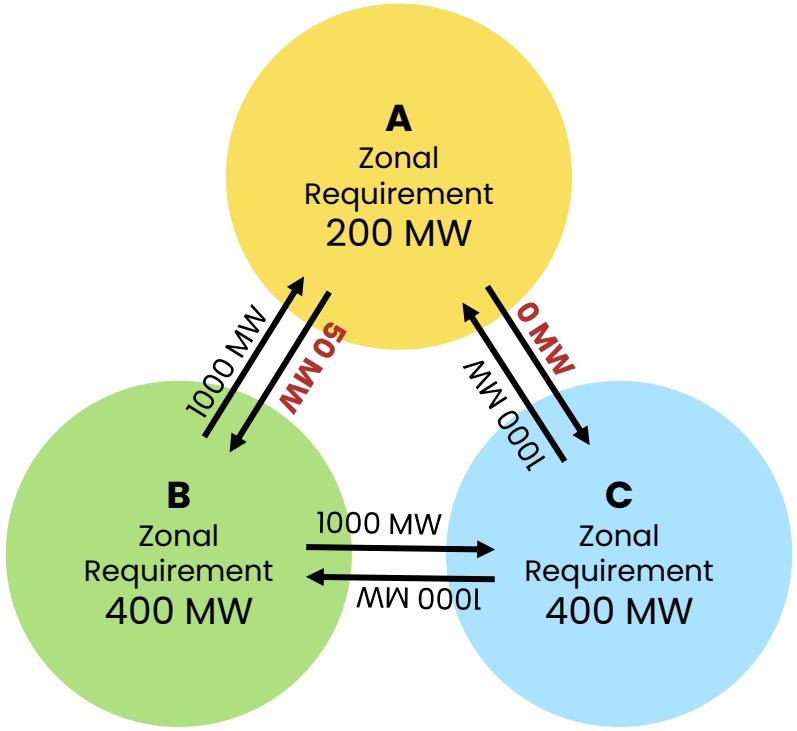
Well connected groups of zones share a single price.

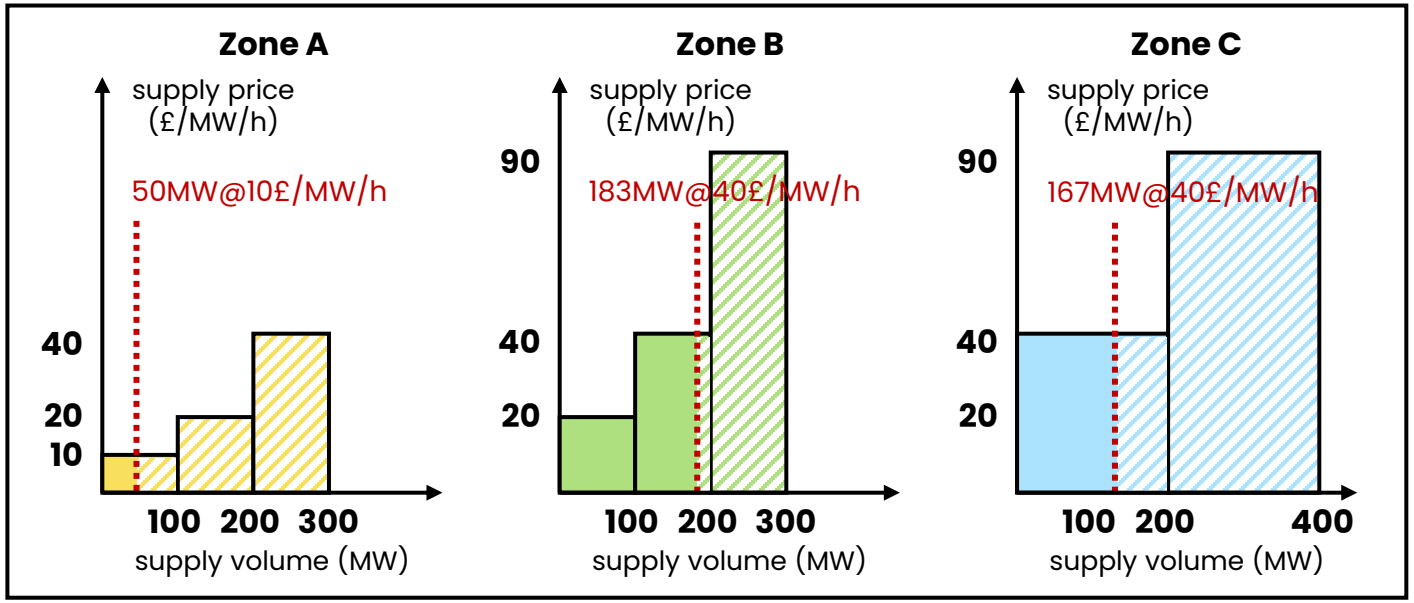


- If we reintroduce a large ATC from zone B to zone C, the dispatch and zonal prices will reflect the good connection between zones. Only scarce network capacity can create price differences between zones.
- Scenario C is still limited in the amount it can import from zone A.
  - Thus, it can only import 50 MW from A.
  - 100 MW can be supplied from zone B from the offer at 20 £/MW/h.
  - The other 250 MW are split between the orders offered at 40 £/MW/h in zones B and C.
- Only the optimal dispatch for scenario C is feasible for the other scenarios as well. Because the ATC A→B is binding, a price spread in that border is allowed.
- However, since there is no binding ATC between B and C, their price must be equal. $price^A \leq price^B = price^C$ where prices would be:
  - $price^A = 10\ £/MW/h$
  - $price^B = price^C = 40\ £/MW/h$
- Relaxing ATC B→C decreased the total procurement cost from 31300 £/h to 14500 £/h (even cheaper than the unconstrained scenario).

Example 3: Reserve Services [2/2]

Well connected groups of zones share a single price.





- **Supply Cost:** 12500 £/h
- **Procurement Cost**: 14500 £/h

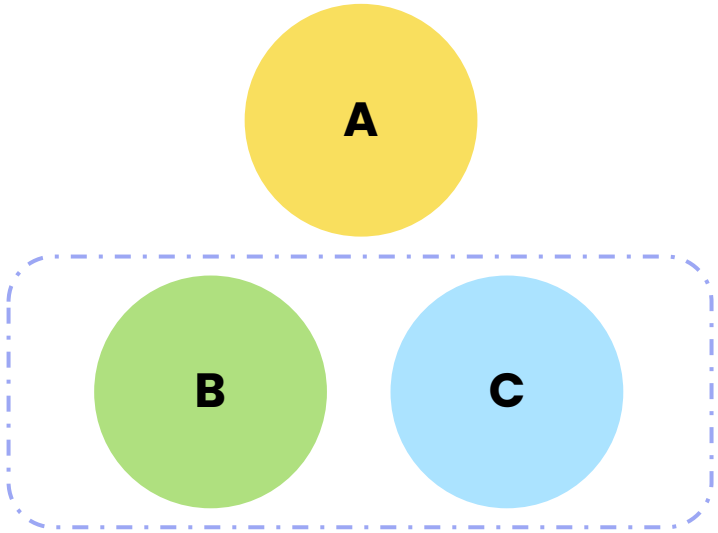
Response Examples I

- Unconstrained (Example 4)
- Binding constraints (Example 5-7)

Note: *Assume all supply orders are fully divisible and are fully independent from each other.*

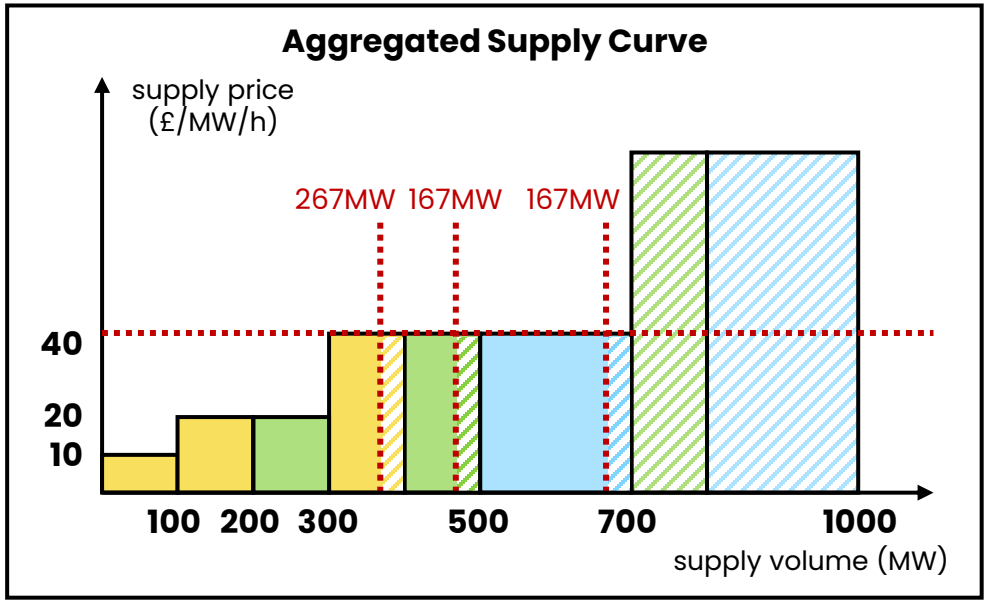
Example 4: Response Services (unconstrained) [1/2]

For response services, min/max constraints represent zonal requirements and transmission constraints.



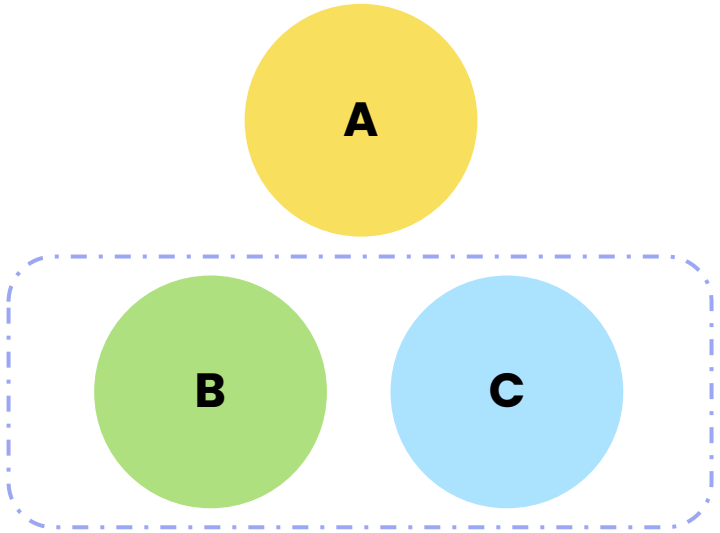
Zone / Zone Group	Min DRL (MW)	Max DRL (MW)
Zone A	0	600
Zone B	0	600
Zone C	0	600
Zone Group B & C	0	600
Global demand	**600 @1000 £/MW/h**	

- When constraints are sufficiently loose (no possible combination of accepted orders can violate the constraints), the auction clears like in Example 1.
  - No binding constraints produces equal prices everywhere.
  - Dispatch follows a merit order in the aggregate supply curve.
- Zone A clears 267 MW at 40 £/MW/h
- Zone B clears 167 MW at 40 £/MW/h
- Zone C clears 167 MW at 40 £/MW/h

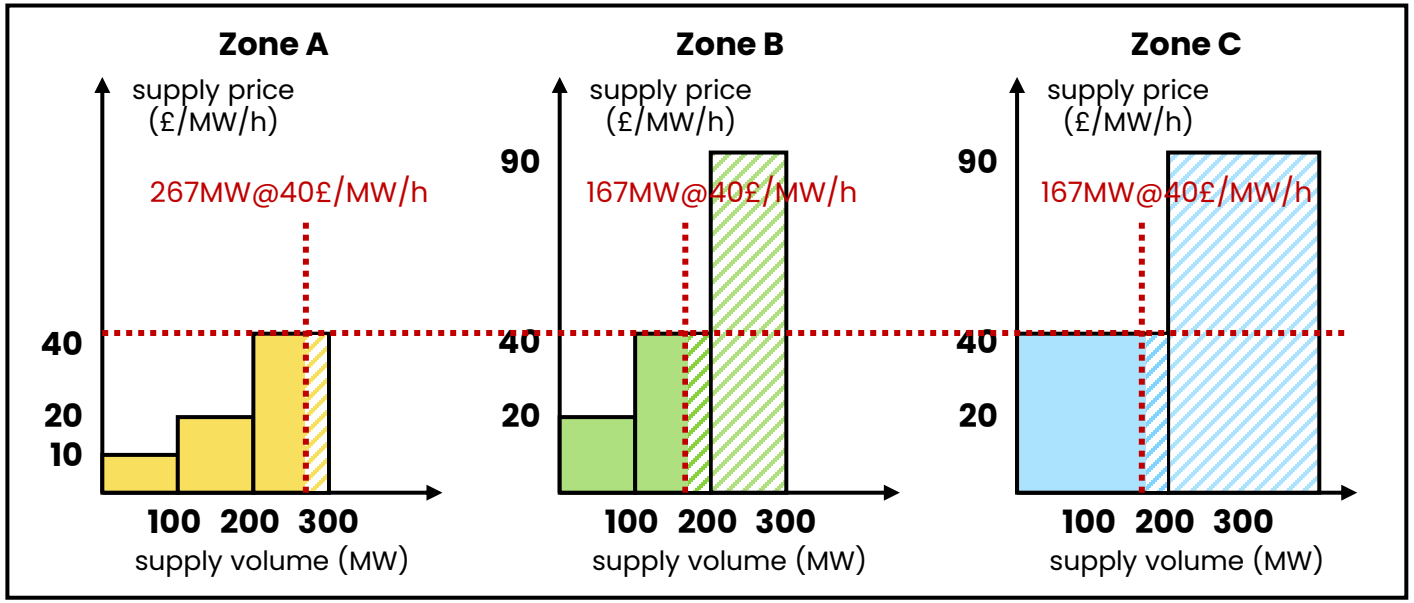


Example 4: Response Services (unconstrained) [2/2]

For response services, min/max constraints represent local demand and transmission constraints.



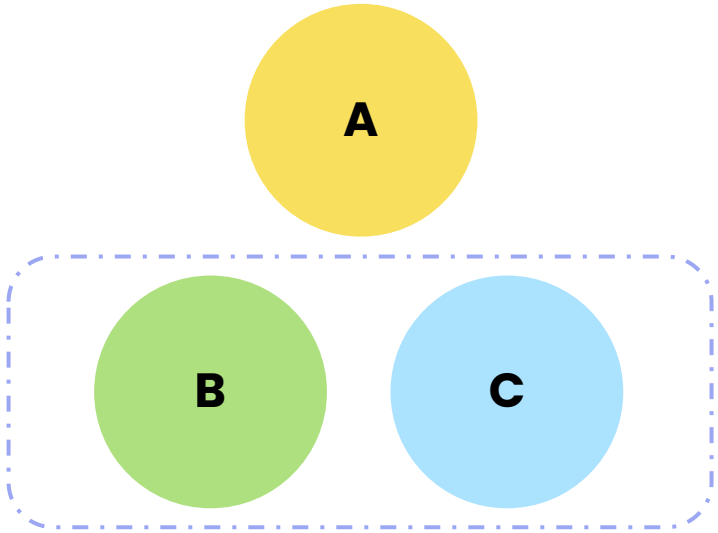
Zone / Zone Group	Min DRL (MW)	Max DRL (MW)
Zone A	0	600
Zone B	0	600
Zone C	0	600
Zone Group B & C	0	600
Global demand	**600 @1000 £/MW/h**	



- **Supply Cost:** 17000 £/h (or 17040 £/h after volume rounding)
- **Procurement Cost**: 24000 £/h (or 24040 £/h after volume rounding)
- **Welfare:** 576000 £/h

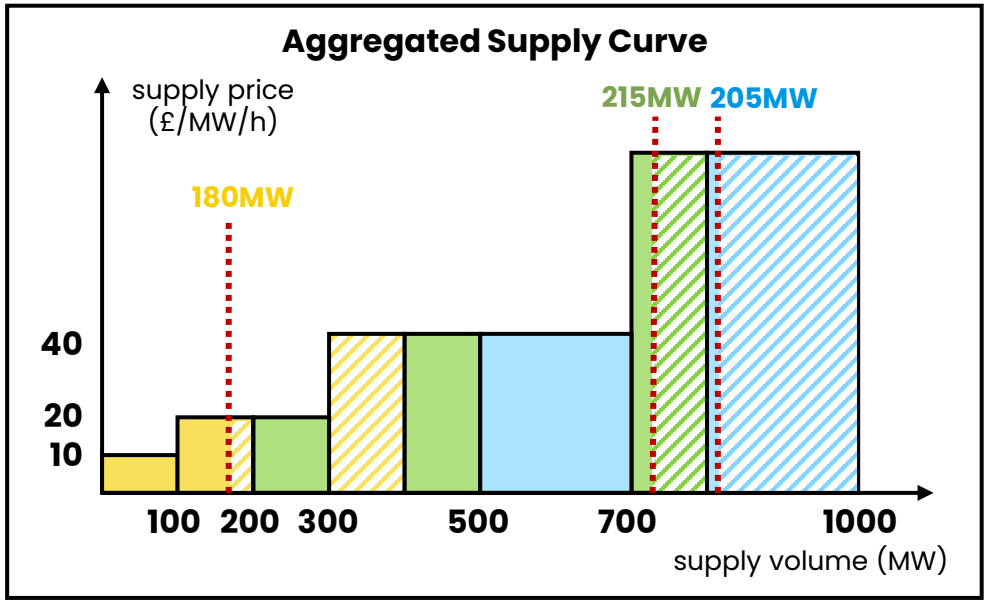
Example 5: Response Services (binding minimum accepted supply) [1/2]

Binding minimum accepted supply allows price spreads.



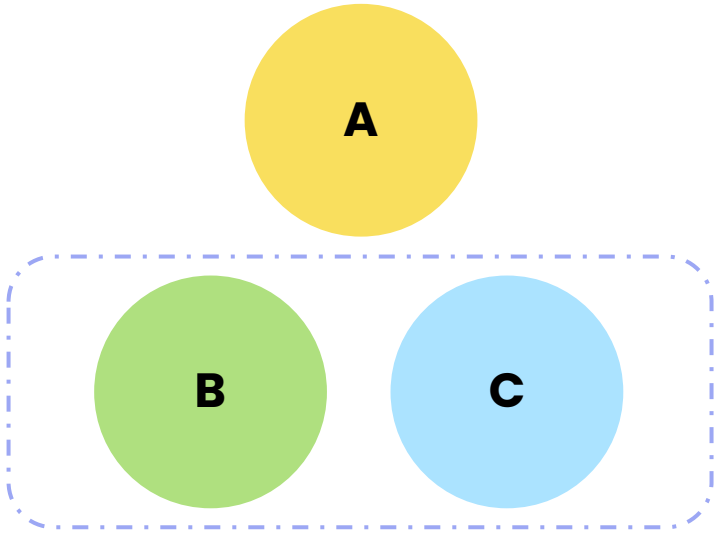
Zone / Zone Group	Min DRL (MW)	Max DRL (MW)
Zone A	0	600
Zone B	**210**	600
Zone C	0	600
Zone Group B & C	**420**	600
Global demand	**600 @1000 £/MW/h**	

- Starting from the unconstrained solution in Example 4:
  - The supply in zone B needs to increase to at least 210 MW. Most probably accepting more than that would be more expensive than needed.
  - To satisfy the minimum supply for group of zones B and C, supply in zone B or zone C should be increased until the constraint is binding as accepting more would unnecessarily increase costs.



Example 5: Response Services (binding minimum accepted supply) [2/2]

Binding minimum accepted supply allows price spreads.



Zone / Zone Group	Min DRL (MW)	Max DRL (MW)
Zone A	0	600
Zone B	**210**	600
Zone C	0	600
Zone Group B & C	**420**	600
Global demand	**600 @1000 £/MW/h**	

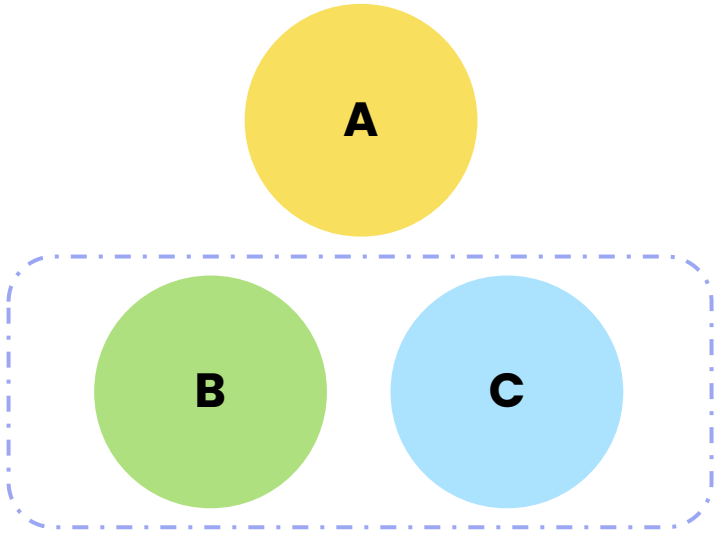
- Binding constraints create shadow prices (sp) equal or greater than zero, making the prices:
  - $price^A = x$
  - $price^B = x + sp^B_{min} + sp^{BC}_{min}$
  - $price^C = x + sp^{BC}_{min}$

  Note: zonal prices are equal to a common price plus/minus the shadow prices
- Therefore $price^A \leq price^C \leq price^B$:
  - Zone A clears 180 MW at 20 £/MW/h
  - Zone B clears 215 MW at 90 £/MW/h
  - Zone C clears 205 MW at 90 £/MW/h
- Only the minimum of group BC is binding, so a price spread is allowed between the group and its neighbours (zone A).

- **Supply Cost:** 18400 £/h
- **Procurement Cost**: 41400 £/h
- **Welfare:** 558600 £/h

Example 6: Response Services (binding maximum accepted supply) [1/2]

Binding maximum accepted supply allows price spreads.

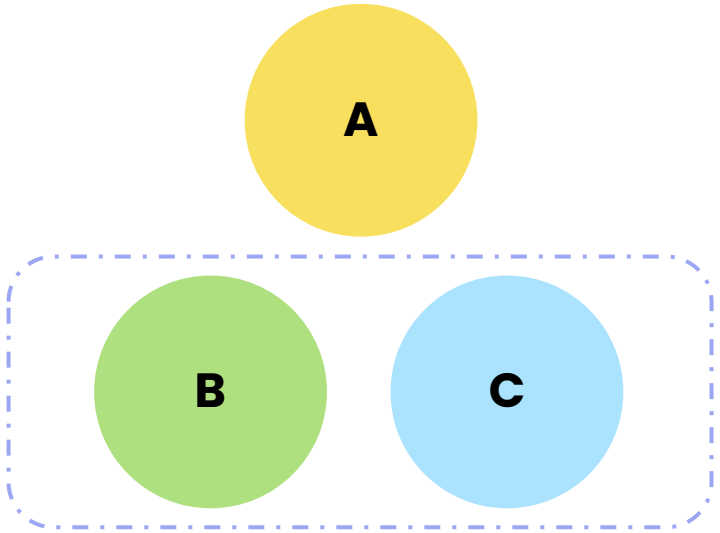


Zone / Zone Group	Min DRL (MW)	Max DRL (MW)
Zone A	0	600
Zone B	0	**150**
Zone C	0	600
Zone Group B & C	0	**310**
Global demand	**600 @1000 £/MW/h**	

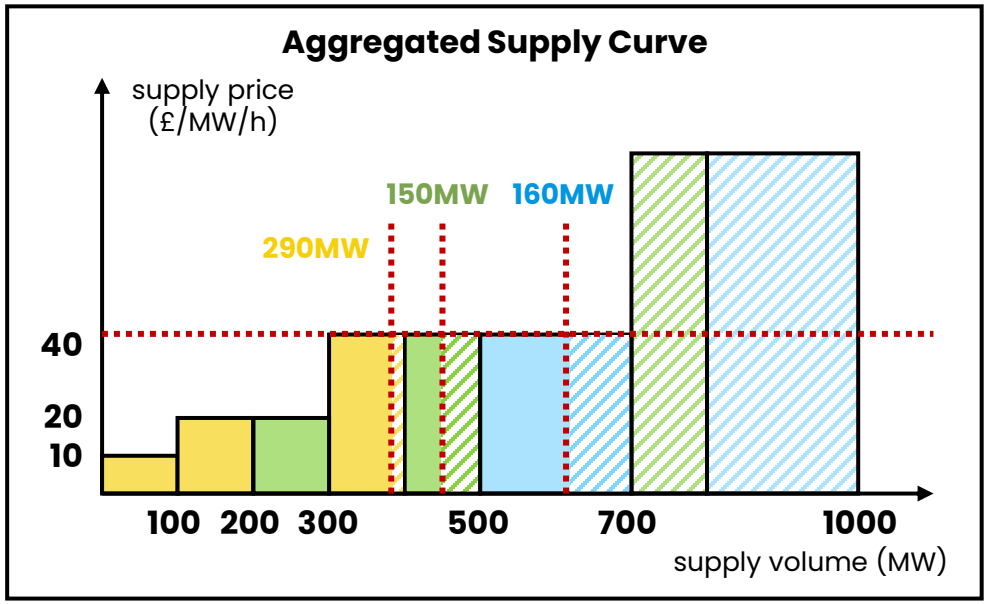
- Starting from the unconstrained solution in Example 4:
  - The supply in zone B needs to decrease to 150 MW at most. Most probably accepting less than that would leave useful inexpensive supply unaccepted.
  - To satisfy the maximum supply for group of zones B and C, supply in zone B or zone C should be increased until the constraint is binding as accepting more would unnecessarily increase costs.
- Binding constraints create shadow prices (sp) equal or greater than zero. Note that the sign of these shadow prices is opposite to the sign of those associated with minimum supply:
  - $price^A = x$
  - $price^B = x - sp^B_{max} - sp^{BC}_{max}$
  - $price^C = x - sp^{BC}_{max}$
- Therefore $price^B \leq price^C \leq price^A$:
  - Zone A clears 290 MW at 40 £/MW/h
  - Zone B clears 150 MW at 40 £/MW/h
  - Zone C clears 160 MW at 40 £/MW/h
- None of the constraints need to be binding (e.g., clearing 292, 149, 159 MW in A, B, C, resp.). This is reflected in shadow prices equal to zero.

Example 6: Response Services (binding maximum accepted supply) [2/2]

Binding maximum accepted supply allows price spreads.



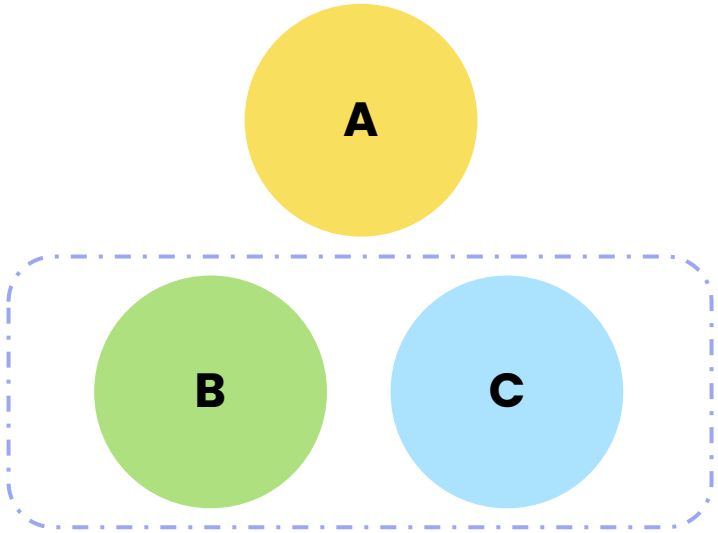
Zone / Zone Group	Min DRL (MW)	Max DRL (MW)
Zone A	0	600
Zone B	0	**150**
Zone C	0	600
Zone Group B & C	0	**310**
Global demand	**600 @1000 £/MW/h**	



- **Supply Cost:** 17000 £/h
- **Procurement Cost**: 24000 £/h
- **Welfare:** 576000 £/h

Example 7: Response Services (binding maximum accepted supply) [1/2]

Max supply constraints are especially relevant for cheap supply zones (and min for expensive ones).

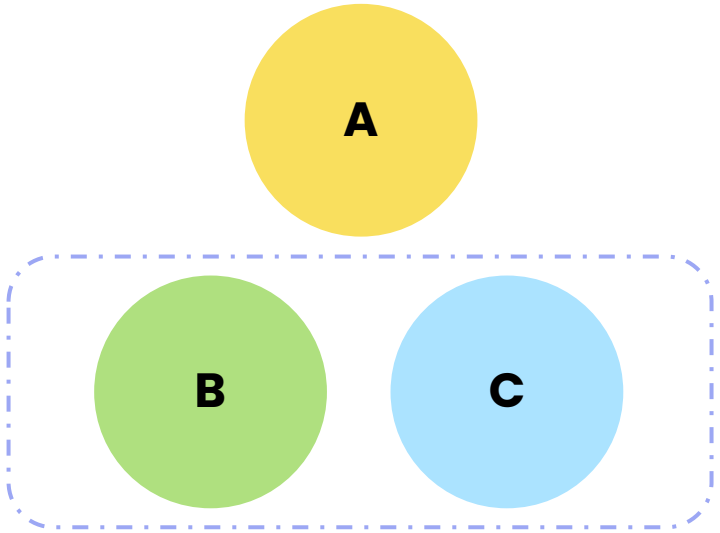


Zone / Zone Group	Min DRL (MW)	Max DRL (MW)
Zone A	0	**90**
Zone B	0	**120**
Zone C	0	600
Zone Group B & C	0	600
Global demand	**600 @1000 £/MW/h**	

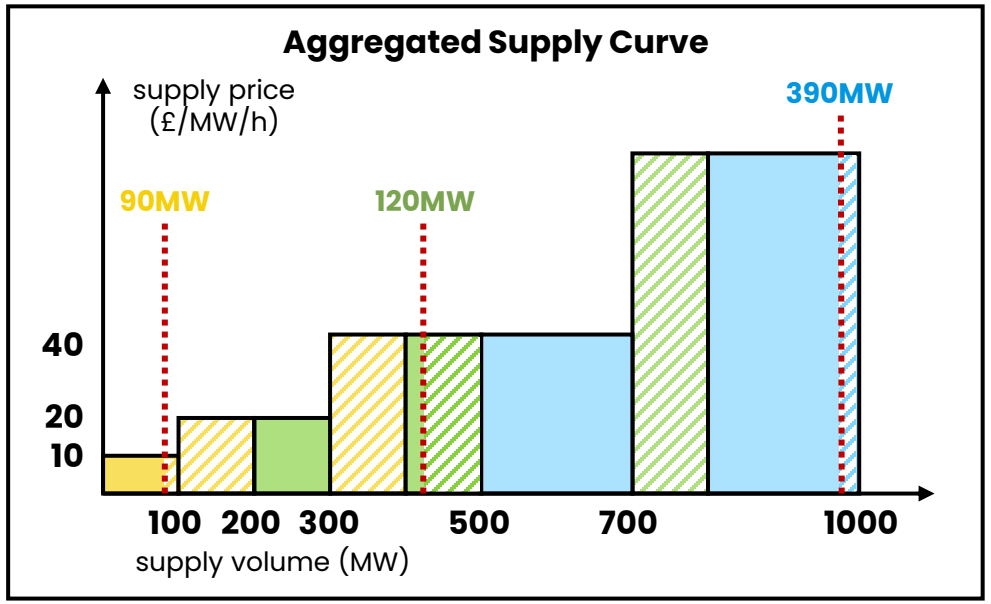
- Binding constraints create shadow prices (sp) equal or greater than zero. Note that the sign of these shadow prices is opposite to the sign of those associated with minimum supply:
  - $price^A = x - sp^A_{max}$
  - $price^B = x - sp^B_{max}$
  - $price^C = x$
- Therefore $price^C \leq price^A,\ price^C \leq price^B$:
  - Zone A clears 90 MW at 10 £/MW/h
  - Zone B clears 120 MW at 40 £/MW/h
  - Zone C clears 390 MW at 90 £/MW/h
- Shadow prices associated with max constraints in cheap (group of) zones and with min constraints in expensive (group of) zones are more prone to take values larger than zero.

Example 7: Response Services (binding maximum accepted supply) [2/2]

Max supply constraints are especially relevant for cheap supply zones (and min for expensive ones).



Zone / Zone Group	Min DRL (MW)	Max DRL (MW)
Zone A	0	**90**
Zone B	0	**120**
Zone C	0	600
Zone Group B & C	0	600
Global demand	**600 @1000 £/MW/h**	



- **Supply Cost:** 28800 £/h
- **Procurement Cost**: 40800 £/h
- **Welfare:** 559200 £/h

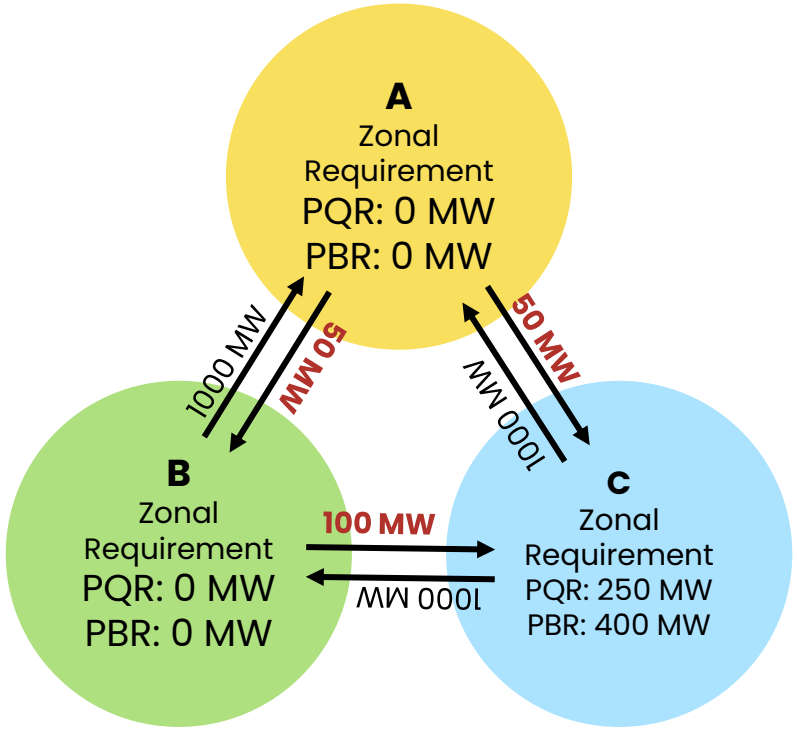
Reserve Examples II

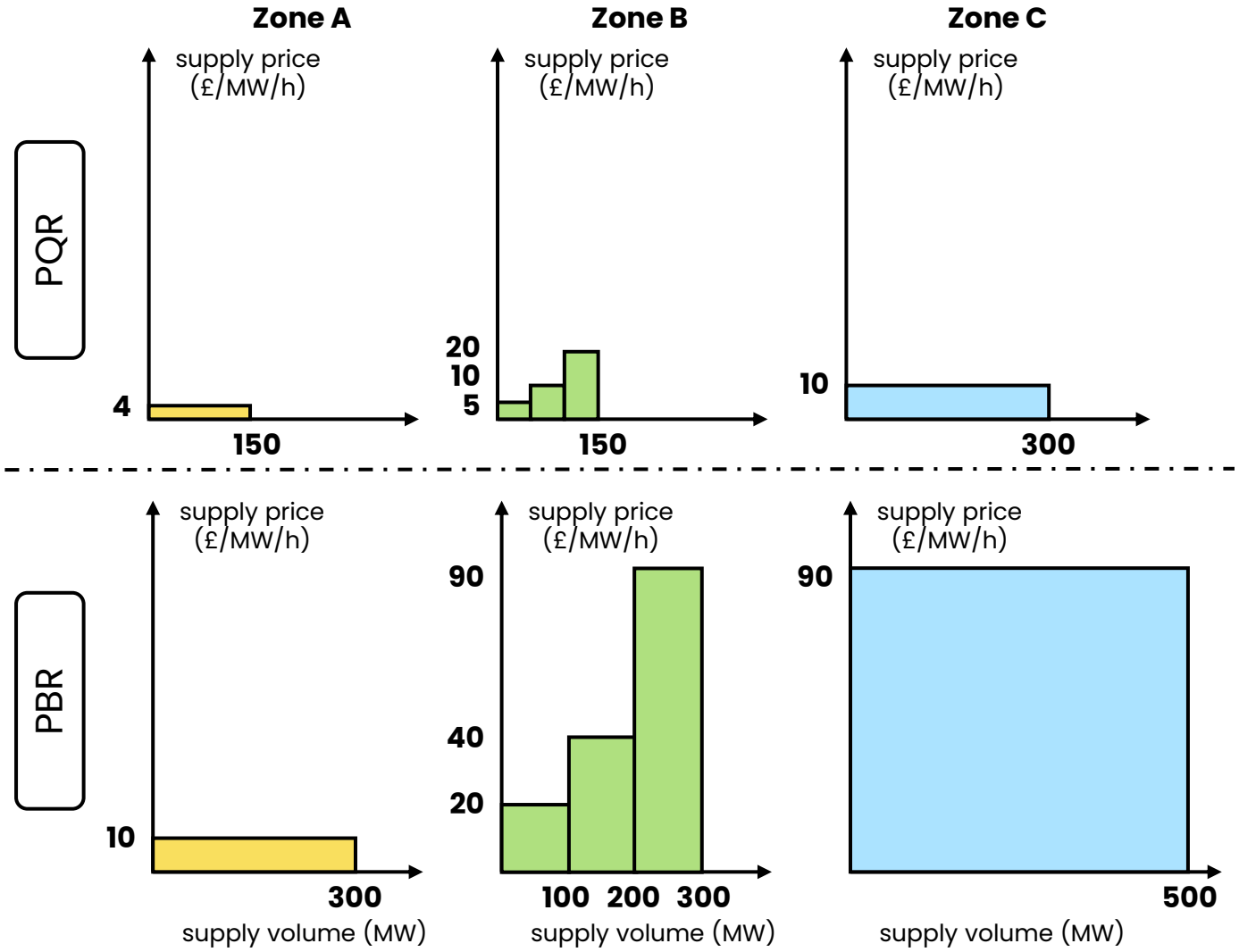
- Multiple Reserve Services (Example 8)
- Tie-breaks across zones (Example 9-10)

Note: *Assume all supply orders are fully divisible and are fully independent from each other.*

Example 8: Multiple Reserve Services [1/3]

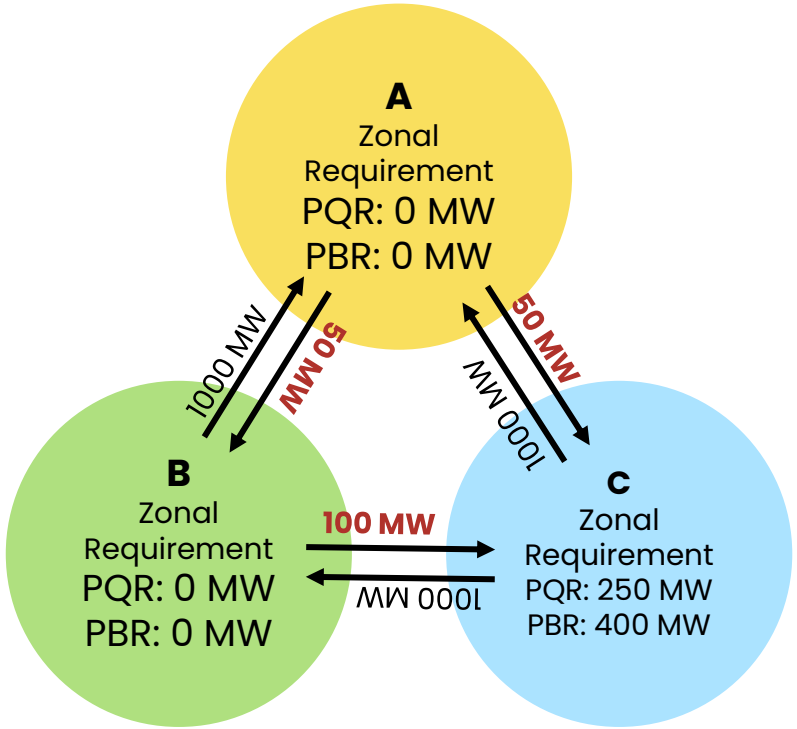
ATCs are booked for services that provide most value.





Example 8: Multiple Reserve Services [2/3]

ATCs are booked for services that provide most value.



In this example, there is limited transmission capacity towards zone C, where there is zonal requirement for PQR and PBR. In locational procurement, reserve services in the same direction (positive: PBR, PQR, and PSR; or negative: NBR, NQR, and NSR) compete against each other for the ATCs.

If we decided to use the ATCs for PQR:

PQR

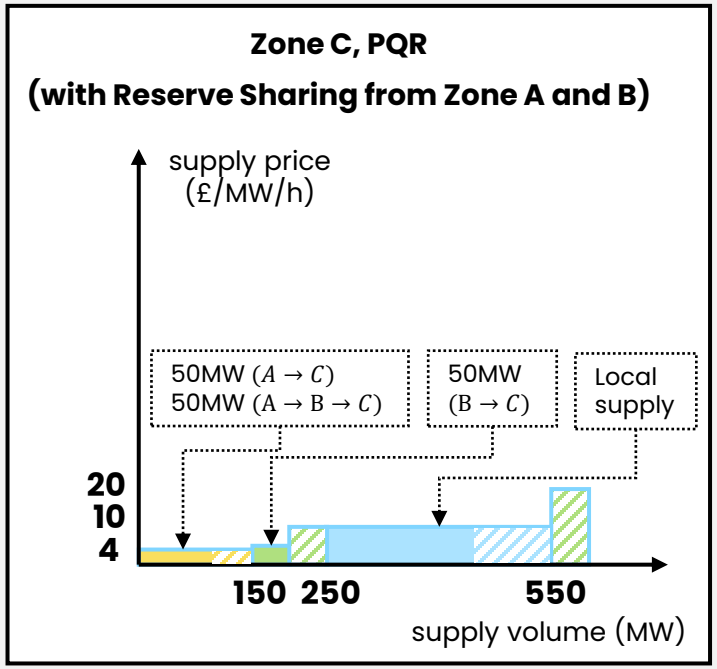
- Accept 100 MW/h of PQR in zone A
- Accept 50 MW/h of PQR in zone B
- Accept 100 MW/h of PQR in zone C

PBR

- Accept 0 MW/h of PBR in zone A
- Accept 0 MW/h of PBR in zone B
- Accept 400 MW/h of PBR in zone C

ATC needed

- A→C: 50 MW (50 PQR from A)
- A→B: 50 MW (50 PQR from A)
- B→C: 100 MW (50 PQR from A, 50 PQR from B)

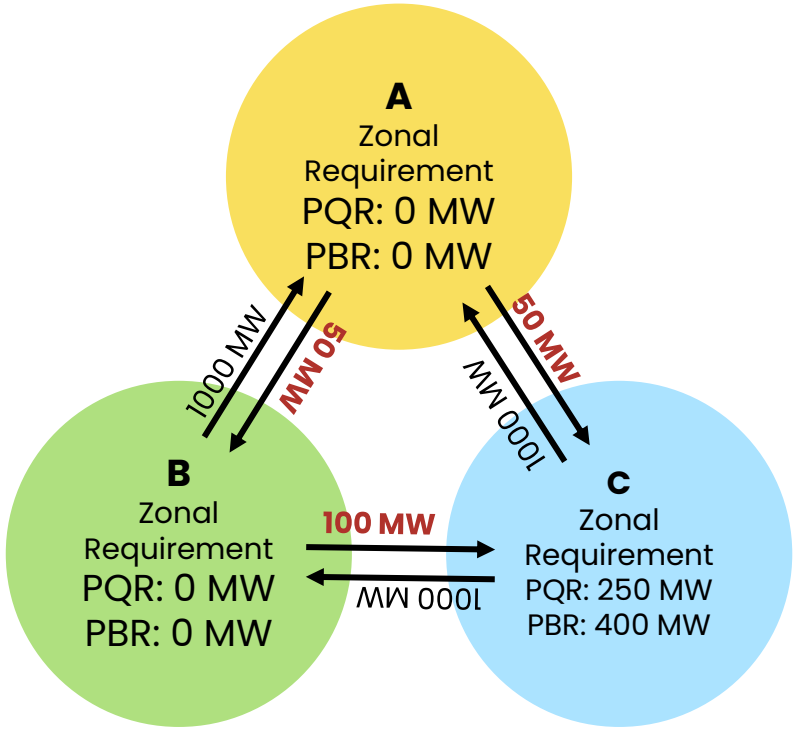


This leads to a total supply cost of

$$(100 \times 4 + 50 \times 5 + 100 \times 10) + (0 + 0 + 400 \times 90) = 37650\ £/h$$

Example 8: Multiple Reserve Services [3/3]

ATCs are booked for services that provide most value.



- **Supply Cost:** 27000 £/h
- **Procurement Cost**: 27000 £/h

If we decided to use the ATCs for PBR instead:

PQR

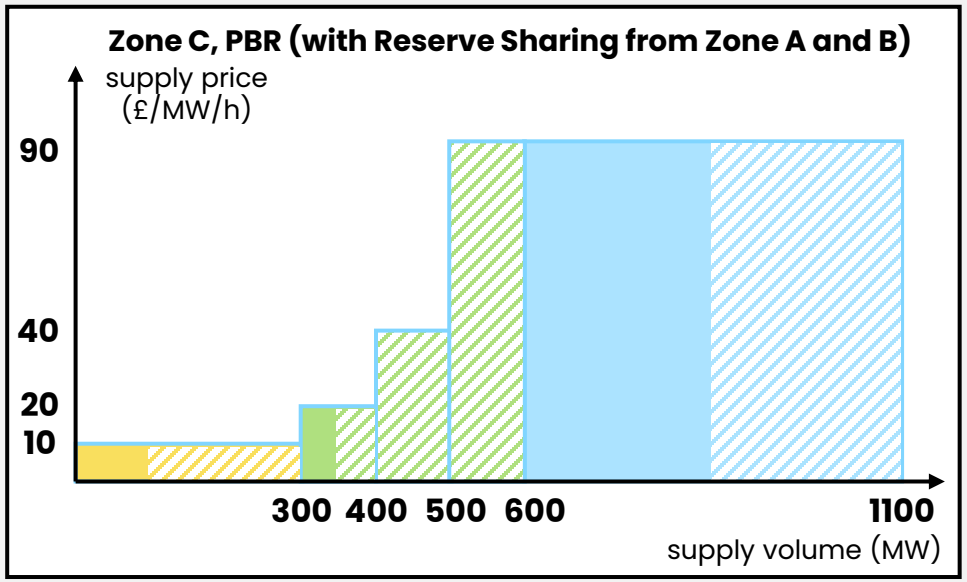
- Accept 0 MW/h in zone A
- Accept 0 MW/h in zone B
- Accept 250 MW/h in zone C

PBR

- Accept 100 MW/h in zone A
- Accept 50 MW/h in zone B
- Accept 250 MW/h in zone C

ATC needed

- A→C: 50 MW (50 PBR from A)
- A→B: 50 MW (50 PBR from A)
- B→C: 100 MW (50 PBR from A, 50 PBR from B)



This leads to a total supply cost of

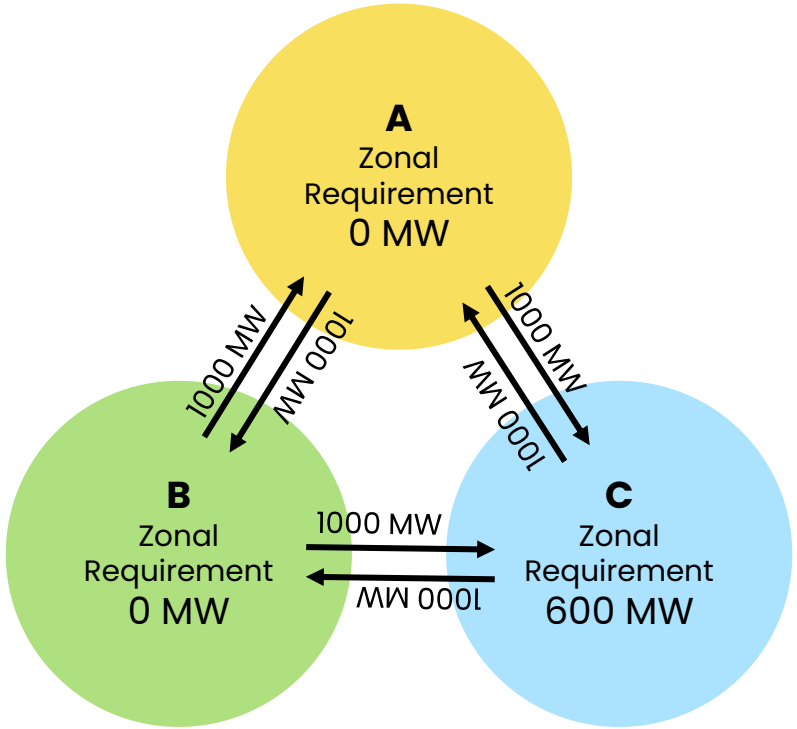
$$(0 + 0 + 250 \times 10) + (100 \times 10 + 50 \times 20 + 250 \times 90) = 26250\ £/h$$

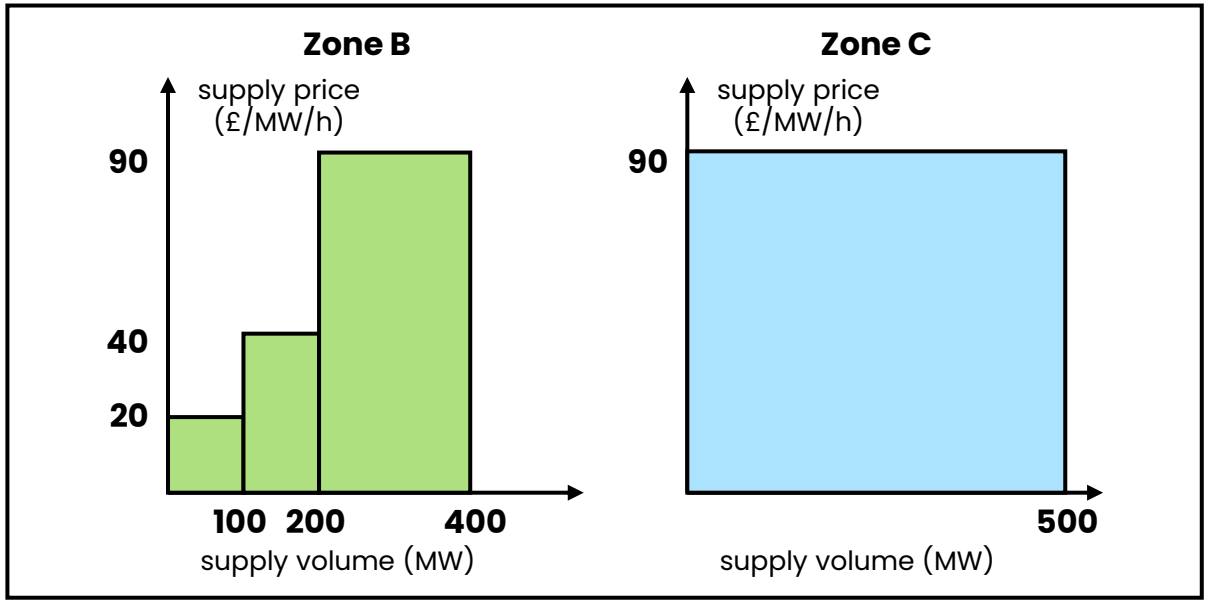
ATCs are more valuable for PBR than for PQR by achieving a supply cost that is 11400 £/h lower. For every MW of PBR that is imported to zone C, the supply cost decreases by at least 50 £/h and up to 80 £/h. The price difference in PQR orders between zone C and the rest are much smaller, making ATC more attractive for PBR. EAC selects this dispatch as it maximises welfare.

Congestion creates price spread for both reserve products with prices following this relationship: $price^A \leq price^B \leq price^C$

Example 9: Tie-breaks across zones [1/2]

In case of ties across zones, EAC minimised booked ATCs.



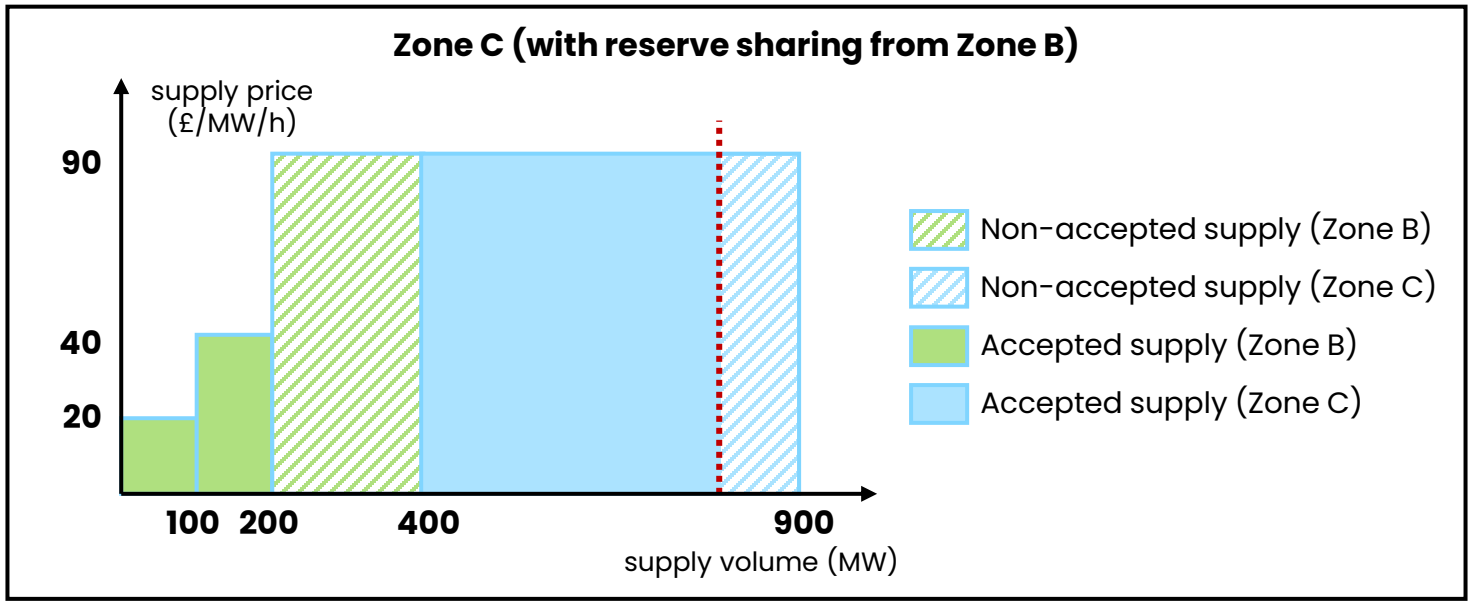


In this example:

- ATCs are not scarce
- There is only demand in zone C

Example 9: Tie-breaks across zones [2/2]

In case of ties across zones, EAC minimised booked ATCs.

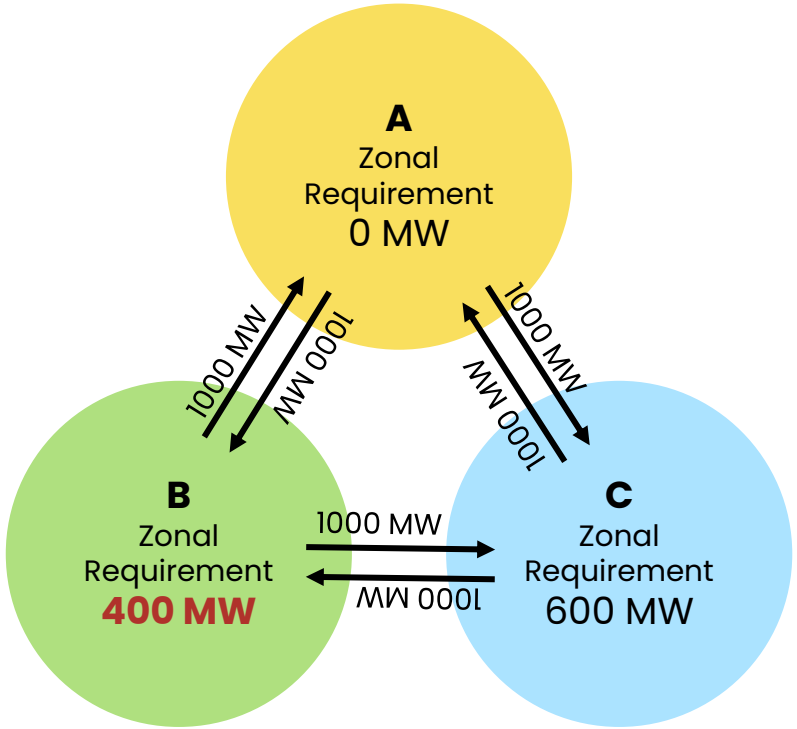


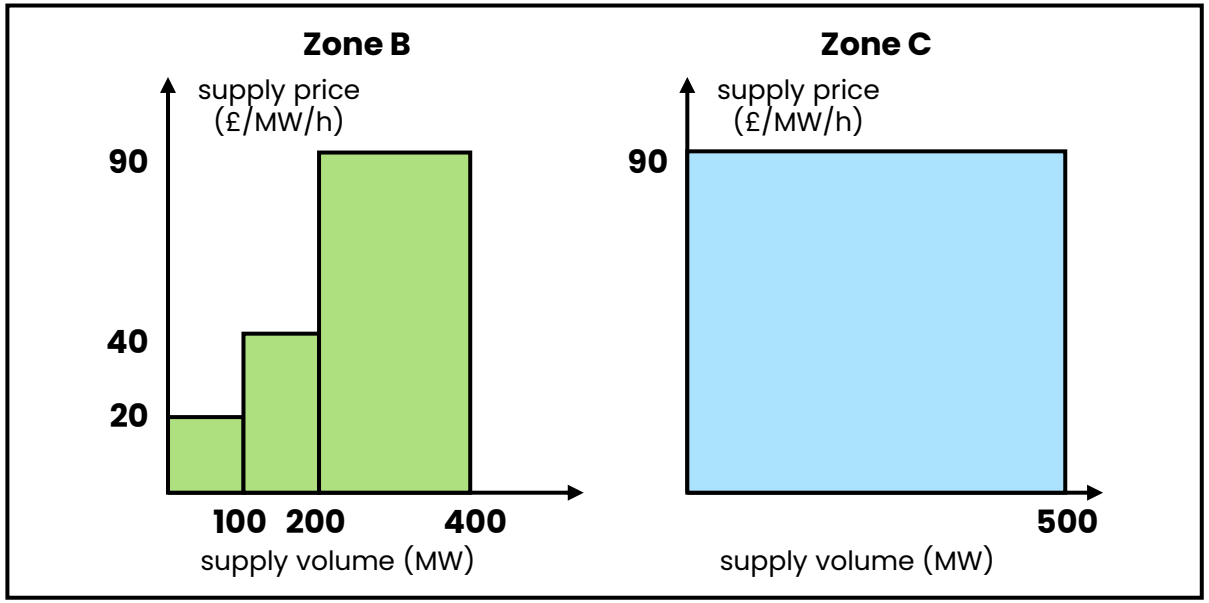
- **Supply Cost:** 42000 £/h
- **Procurement Cost**: 54000 £/h

- After accepting the first 200 MW from zone B, the other 400 MW are directly assigned to zone C.
- Since there are no binding constraints, the shadow prices are equal to zero. In other words, there cannot be price spreads.
  - Zone B clears 200 MW at 90 £/MW/h
  - Zone C clears 400 MW at 90 £/MW/h
- Booked ATCs:
  - $B \rightarrow C: 200\ MW$
- Splitting the unresolved volume differently would increase the necessary ATC. Therefore, to minimise booked ATCs, we give priority to supply that is closest to the demand.

Example 10: Tie-breaks across zones [1/2]

Booked ATCs must fulfill all demand scenarios

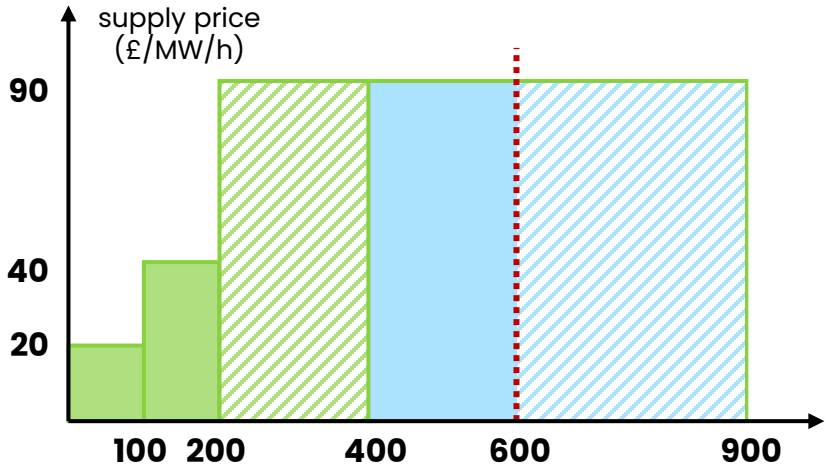




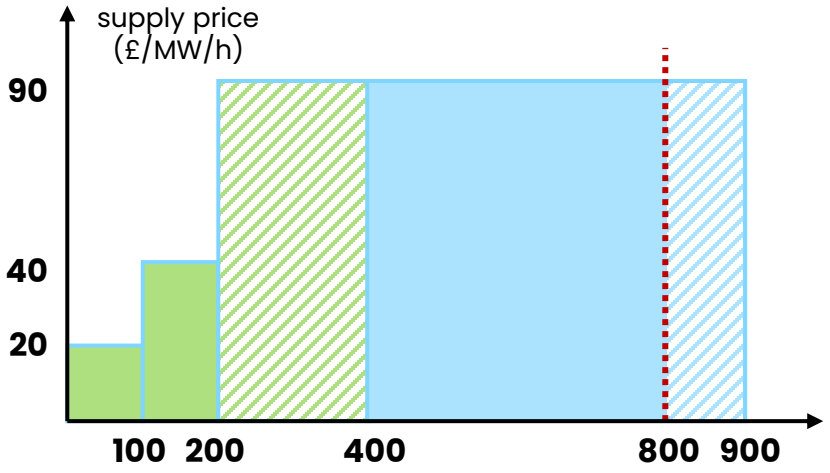
- Now, there is a local demand in zone B.
- The same solution satisfies both zonal requirements, but it is no longer a unique ATC-minimising solution to resolve the tie between the 90 £/MW/h orders.
  - **Supply Cost:** 42000 £/h
  - **Procurement Cost**: 54000 £/h

Example 10: Tie-breaks across zones [2/2]

Zone B (with reserve sharing from Zone C)



Zone C (with reserve sharing from Zone B)

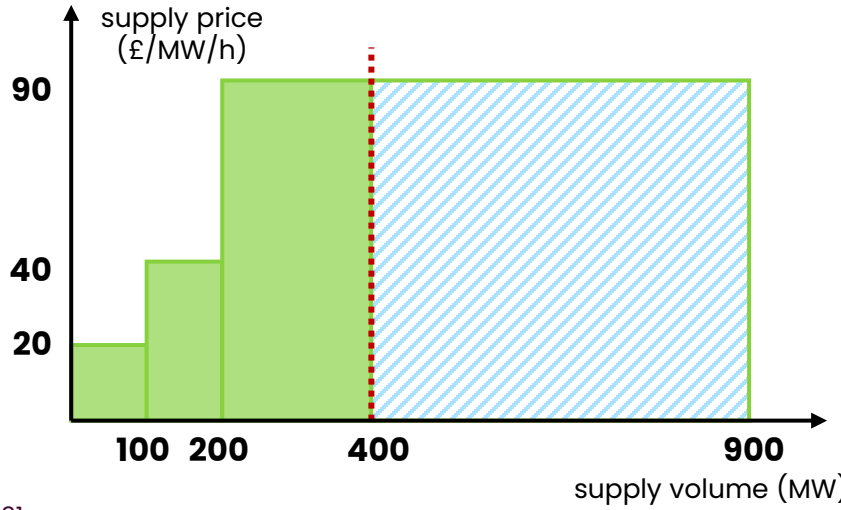


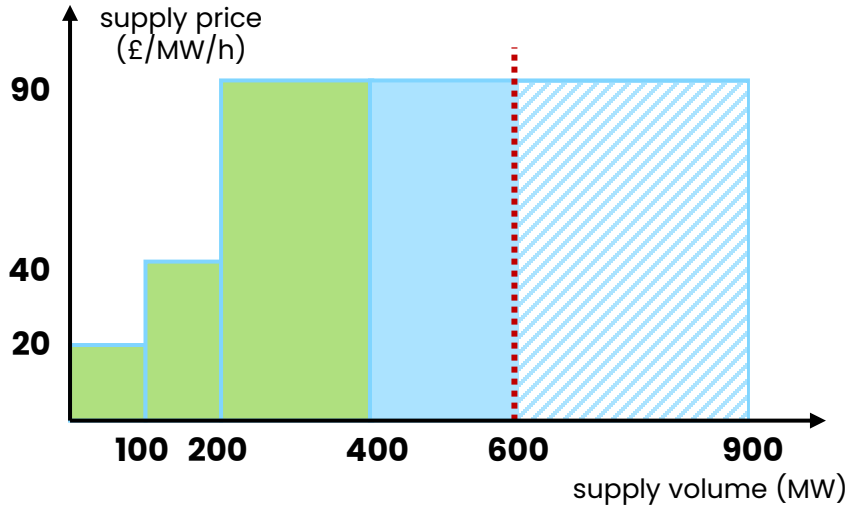
Dispatch from previous example:

- Zone B clears 200 MW at 90 £/MW/h
- Zone C clears 400 MW at 90 £/MW/h

The new booked ATCs (total 400 MW) are

- $B \rightarrow C: 200\ MW$
- $C \rightarrow B: 200\ MW$





Instead, if we accept more from zone B to fairly distribute the disputed (tie between sell orders) volume of (400 MW):

- Zone B clears 400 MW at 90 £/MW/h
- Zone C clears 200 MW at 90 £/MW/h

The new booked ATCs (total 400 MW) are:

- $B \rightarrow C: 400\ MW$
- $C \rightarrow B: 0\ MW$