Electricity Markets Training

Provided by CPPA-G

Centralized Trading of Energy

Module Layout

- **Centralized Trading of Energy:**
  i. **Energy Trading over an Exchange**
  ii. **Power Pools**
  iii. **Simple and Complex Bidding**
  iv. **Multi-Settlement Markets**

Module Layout

- **Centralized Trading of Energy:**

   v. **Interactions between Day-Ahead and Balancing Market**

   vi. **Pricing Systems**

   vii. **Locational Marginal Prices**

Introduction

Introduction

Evolution of Bilateral Markets

- Bilateral markets evolve gradually based on opportunities and needs.
- Centralized markets introduce structure and may be established within bilateral markets.
- Centralized markets include **exchanges** and **power pools**.
- Some are regulated or established by the government to address industry-specific challenges.
- Multi-settlement markets integrate various electricity market elements, including scheduling and balancing.

Electricity Market Exchanges

What is an Electricity Market Exchange?

- An electronic platform where buyers and sellers can submit bids and offers to buy and sell electricity.
- Exchange matches the bids and offers to establish trades.

Components of an Electricity Market Exchange

- Products
- Order types (e.g. Limit Orders)
- Matching engine
- Settlement

Electricity Market Exchanges

Limit Orders and the Order Book

- **Limit Orders** are the simplest type of order.
- A limit order specifies a **maximum price for a buyer** or a **minimum price for a seller**
- The **Order Book** is a list of all the limit orders that have been submitted to the exchange
- The order book is ranked by price, with the highest bids at the top and the lowest offers at the bottom.

Product: Firm Power Tartu, April 30, 9:00-10:00		
Offers to sell energy		
ID	**Price €/MWh**	**Quantity €/MWh**
659199	46.61	37
659254	45.12	42
659309	43.4	12
659364	43.4	27
659419	43.34	17
659474	43.33	22
Bids to buy energy		
ID	**Price €/MWh**	**Quantity M W**
656301	43.3	12
656400	42.95	1
656499	42.9	3
656598	39.35	52
656697	38.65	27

An Illustrative Limit Order Book for One Product on an Exchange.

Electricity Market Exchanges

- The Matching Engine ranks the bids and offers and establish trades.
- Use of multiple criteria
- Unsuccessful bids and offers
- Submission of matching bids
- Information revealed by an Exchange
- Fluctuations in exchange activities- Liquid and Non-Liquid windows
- Trading over the exchange is typically bilateral

Product: Firm Power Amesterdam, April 30, 9:00-10:00		
Offers to sell energy		
ID	**Price €/MWh**	**Quantity MW**
659199	46.61	37
657399	45.12	42
660889	43.4	12
660886	43.4	27
659159	43.34	17
663010	43.33	22
Bids to buy energy		
ID	**Price €/MWh**	**Quantity MW**
656301	43.3	12
664505	42.95	17
661388	42.9	37
660848	39.35	52
664113	38.65	27

Electricity Market Exchanges

What is Central Counterparty Clearing?

- A process in which the exchange acts as the counterparty to all trades
- The Exchange becomes the **Seller** to the Original Buyer and the **Buyer** to the Original Seller.

Benefits of Central Counterparty Clearing:

- Central counterparty clearing reduces credit risk for buyers and sellers
- The exchange is responsible for ensuring that trades are settled, even if one of the original counterparties defaults

Electricity Market Exchanges

Exchange Trading as a Source of Price Information

- Exchange trading is a good source of price information for electricity.
- The prices that are established on an exchange are typically more reliable than price assessments based on voluntary reporting..

Limitations of Exchange Trading Data:

- Only a subset of trades occurs on an exchange.
- The vast majority of bilateral trading may continue to take place off-exchange

Power Pool

Power Pools

What is a Power Pool?

- A power pool is a regional electricity market where participants, including generators, distributors, and large consumers, can buy and sell electricity.
- The pool establishes a set of rules that govern the market as a whole, including how much energy is needed, how it is priced, and how it is dispatched to consumers.
- Pools can be Single Side Bidding or Double Side Bidding
- Price or Cost Based

Benefits of Power Pools

- Increased efficiency
- Improved reliability
- Enhanced competition

Operation of Power Pools

Repeated Auctions?

- Series of auctions for each trading window
- Sellers submit offers and Buyer submit bids (in case of double side bidding).
- Demand and Supply intersection determines the Clearing Prices for each trading window.
- Generators below the Market Price are dispatched
- Buyers with Bids higher than the Market Clearing Price purchase electricity in the pool

Simple Bids

Simple Bids

What are Simple Bids?

- A simple set of rules treats each hour independently
- A type of bid that specifies a single price and quantity for a particular hour of electricity
- A simple bid is just a price and quantity pair, (p,q), for that hour's auction.
- Each generator can submit multiple offers.

Simple Bids

An Illustrative Set of Supply Offers Into a Pool From Four Generators.

Generator	Supply Offers	
	Price $/MWh	Quantity MW
Abbeville	27.6	70
Abbeville	40.2	155
Adrian	36.5	55
Adrian	60.4	105
Adrian	26.2	55
Blakely	30.5	205
Bostwick	27.6	60

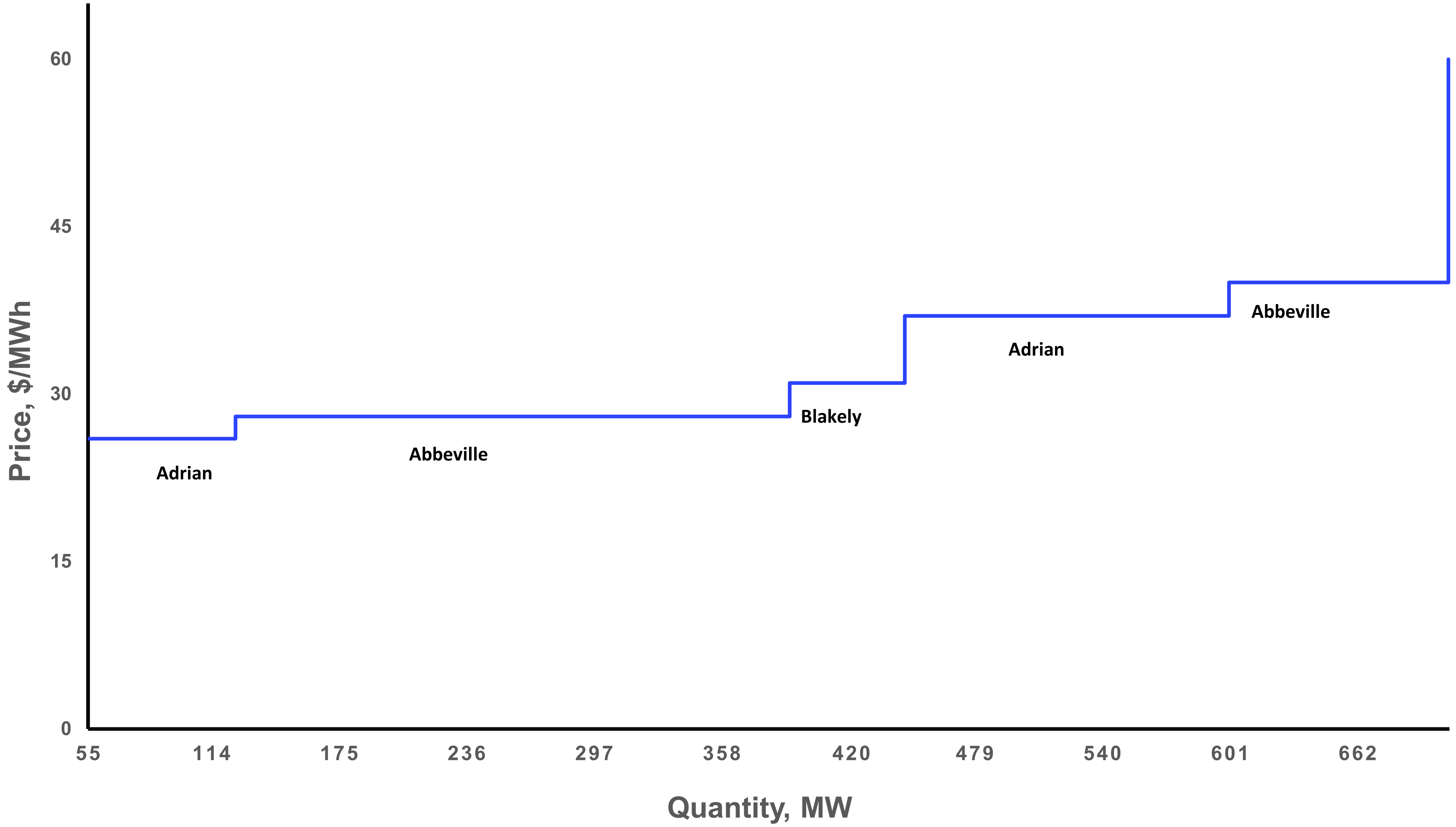
Simple Bids

Pool Supply Curve

- The Pool Operator collects all of the offers and constructs a pool supply curve.
- The individual generator offers are ranked according to price, with the lowest price representing the start of the supply curve, and the highest price representing the end of the supply curve.

Pool Demand Curve

Simple Bids



Price, $/MWh
60
45
30
15
0
Adrian
Abbeville
Blakely
Adrian
Abbeville
55
114
175
236
297
358
420
479
540
601
662
Quantity, MW

Simple Bids

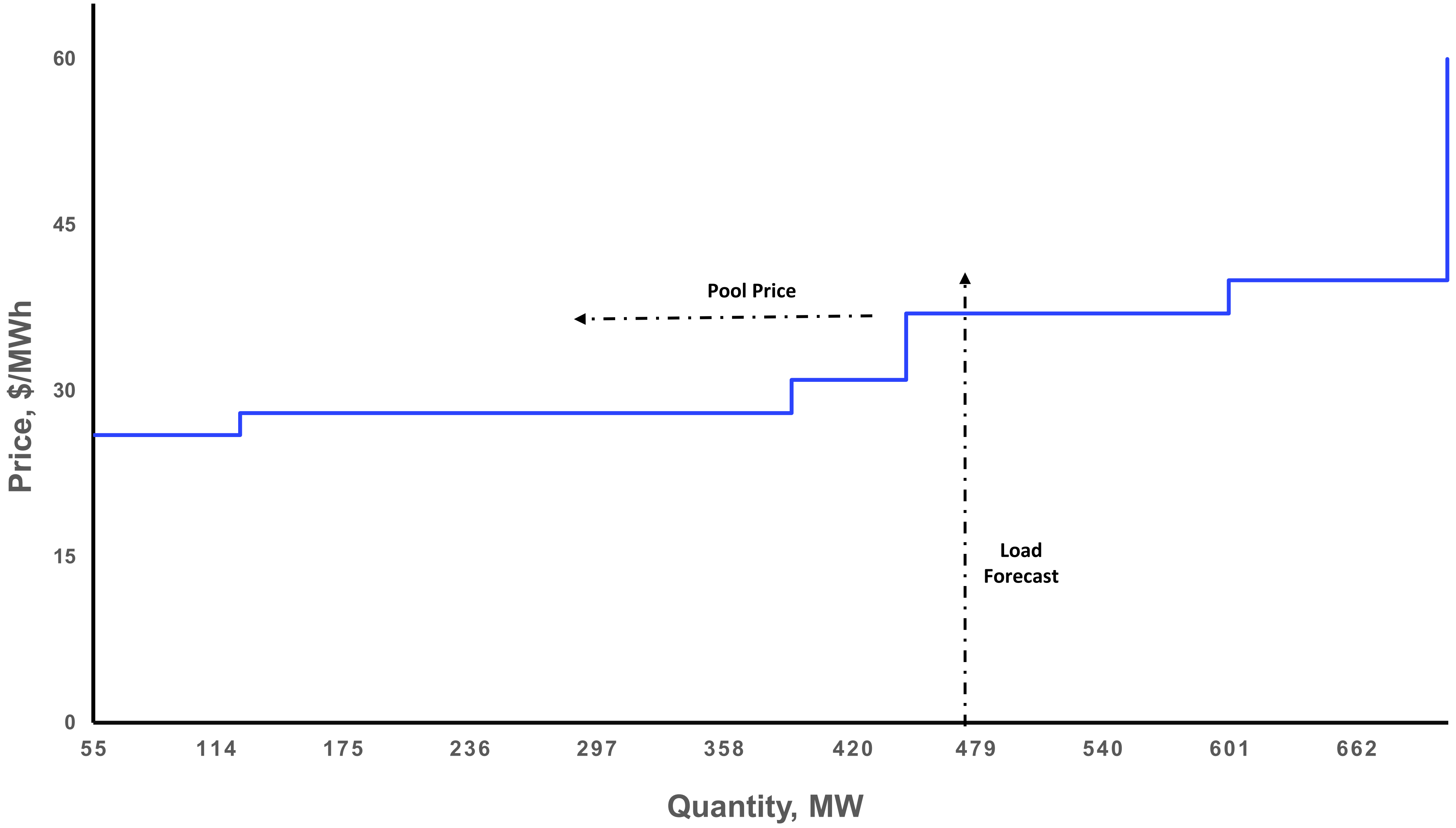
Pool Supply Curve

- The Pool Operator collects all of the offers and constructs a pool supply curve.
- The individual generator offers are ranked according to price, with the lowest price representing the start of the supply curve, and the highest price representing the end of the supply curve.

Pool Demand Curve

- There are two main ways to construct a pool demand curve.
- One is to have the pool operator insert a forecast of the demand.

Simple Bids



Price, $/MWh
60
45
30
15
0
Pool Price
Load
Forecast
55
114
175
236
297
358
420
479
540
601
662
Quantity, MW

Simple Bids

Pool Supply Curve

- The Pool Operator collects all of the offers and constructs a pool supply curve.
- The individual generator offers are ranked according to price, with the lowest price representing the start of the supply curve, and the highest price representing the end of the supply curve.

Pool Demand Curve

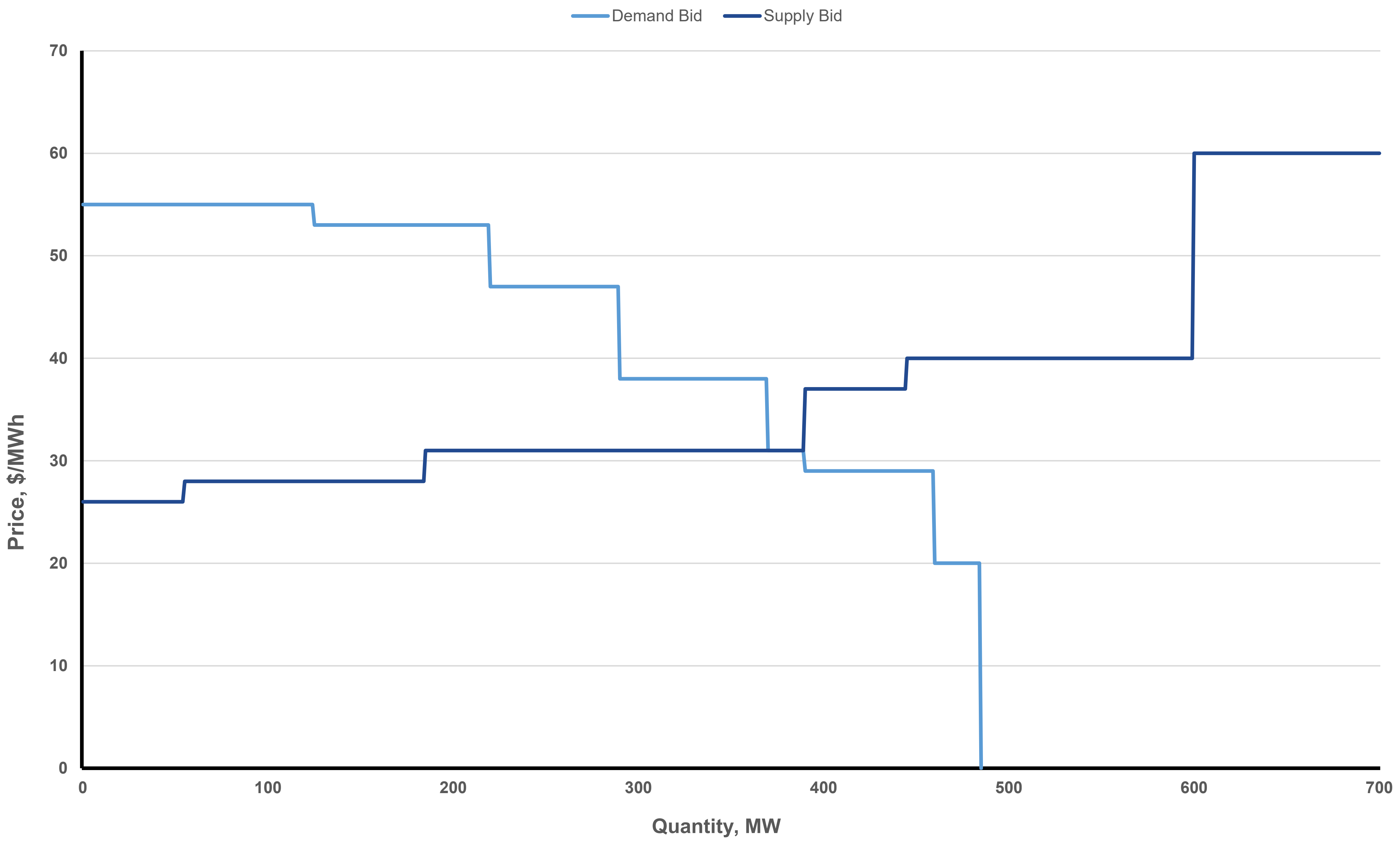
- There are two main ways to construct a pool demand curve.
- One is to have the pool operator insert a forecast of the demand.
- A second way is to allow LSEs to bid their demand.

Simple Bids

An Illustrative Set of Demand Bids Into a Pool From Four LSEs.

Load Serving Entity	Demand Bids	
	Price $/MWh	Quantity MW
Minsk	55	125
Minsk	29	70
Minsk	53	95
Minsk	31	20
Fanipal	38	80
Fanipal	20	25
Uzda	47	70

Simple Bids



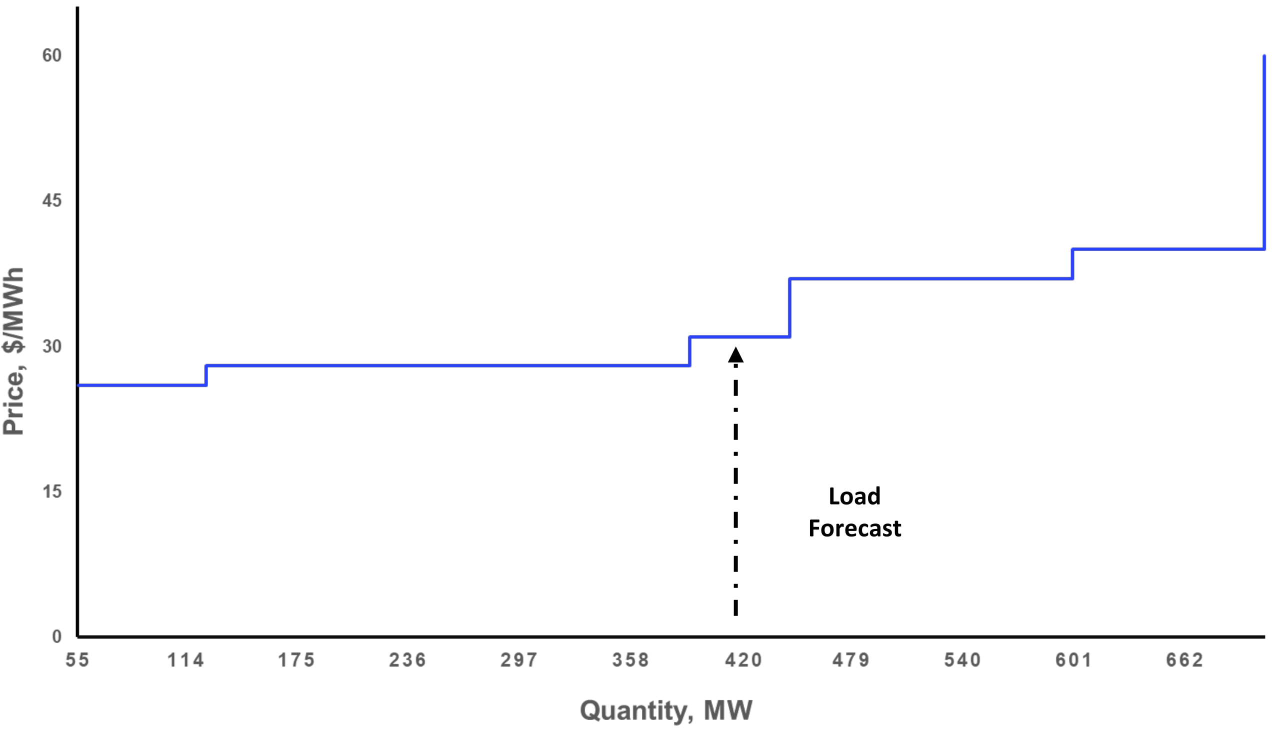
Demand Bid
Supply Bid
Price, $/MWh
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
Quantity, MW

Simple Bids

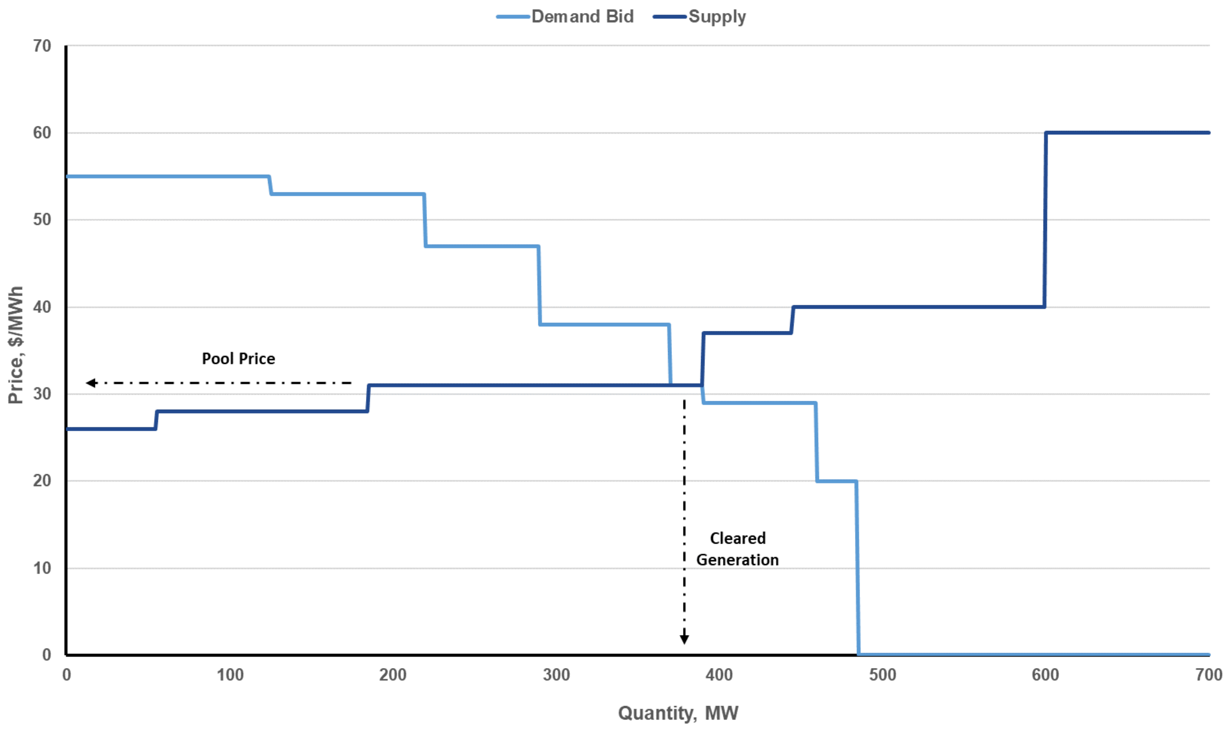
Pool Price

- The pool price is determined by the intersection of the supply and demand curves.
- The lowest price at which supply is greater than demand is the pool price.

Simple Bids



Price, $/MWh
60
45
30
15
0
55
114
175
236
297
358
420
479
540
601
662
Load Forecast
Quantity, MW

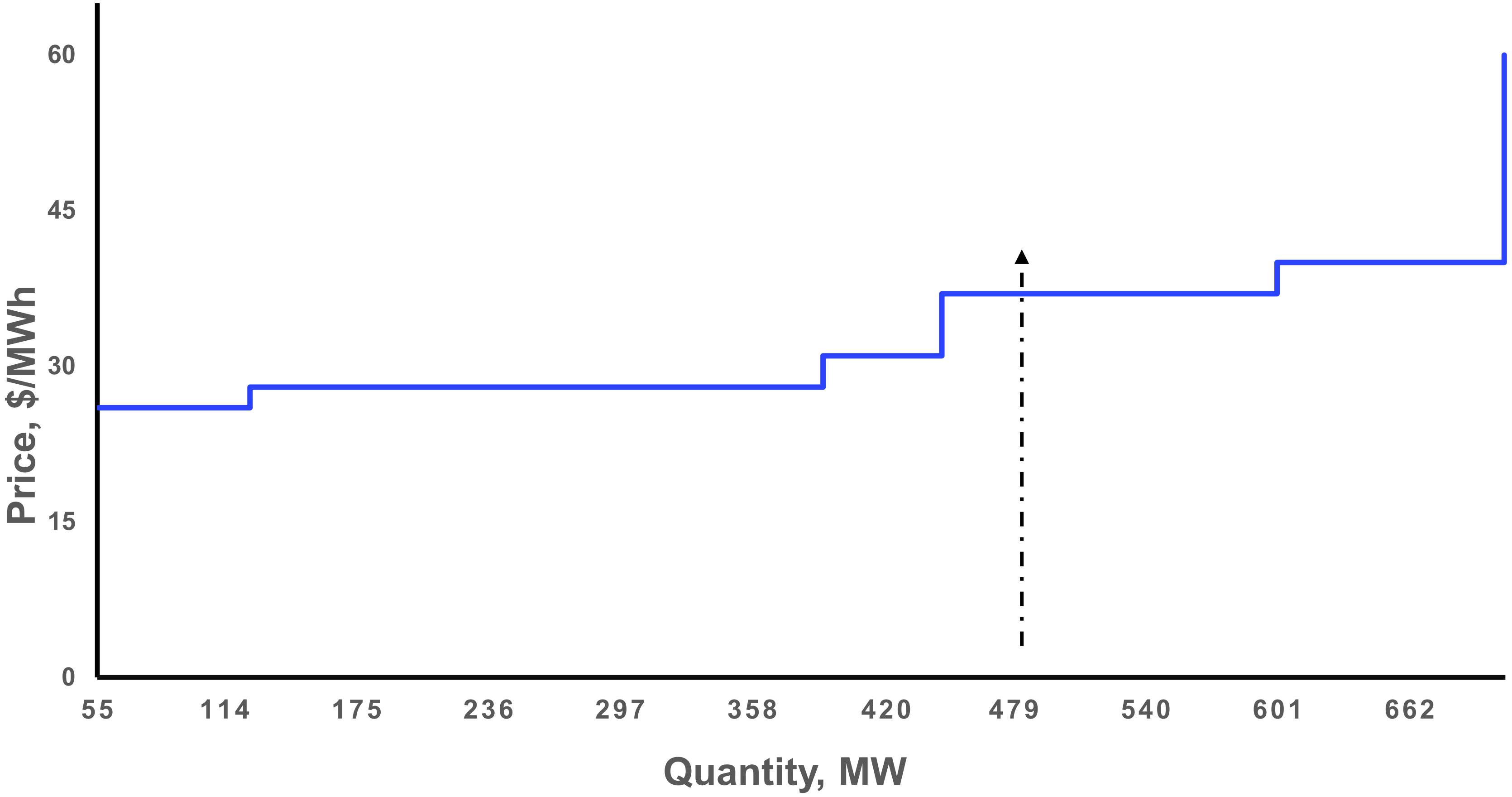


Demand Bid
Supply
Price, $/MWh
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
Pool Price
Cleared Generation
Quantity, MW

Simple Bids

Generator Dispatch

- All of the offers that are less than the pool price are cleared.
- Treatment of Offers equal to the Pool Price.



Simple Bids

Generator Payment

- All of the generators with cleared bids are paid the pool price for the power they offered, even when they had offered the power at a lower price.

Marginal Generator

- The marginal generator is the generator with the highest accepted bid, the one exactly equal to the pool price.

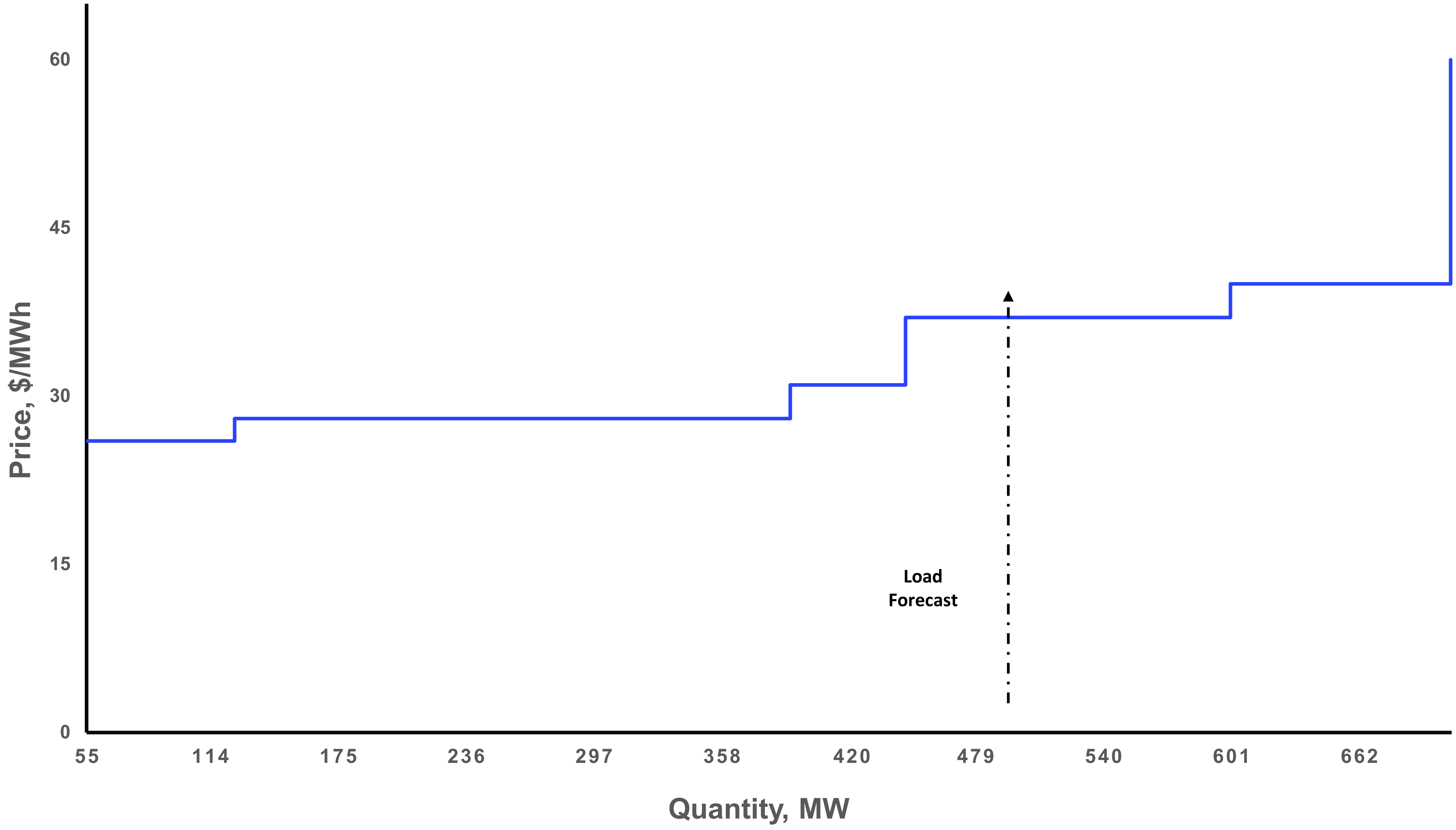
Infra-marginal Generators

- All other generators with prices below the pool price the infra-marginal generators-will receive awards for their full offers that were below the pool price.

System Marginal Price

- The pool price is the system's marginal cost of an additional unit of power in the pool. In some systems it is also called the system marginal price (SMP).

Simple Bids


60
45
30
15
0
Price, $/MWh
55
114
175
236
297
358
420
479
540
601
662
Quantity, MW
Load
Forecast

Simple Bids

Competition in Pool Auctions

- Under certain conditions, most importantly including competition among the generators, each generator maximizes its expected profit by setting its offers equal to its marginal cost.
- However, there is often inadequate competition among generators, meaning that each generator has some market power.
- A generator with market power maximizes its expected profit by setting its offers above its marginal cost. This results in a system marginal price that is above the efficient system lambda.
- Pools and other market systems regularly monitor bidding to determine whether or not it is competitive-i.e., whether offers are close to marginal cost. They have measures in place to manage the exercise of market power in generator bidding.

Complex Bids

Complex Bids

Complex Bids

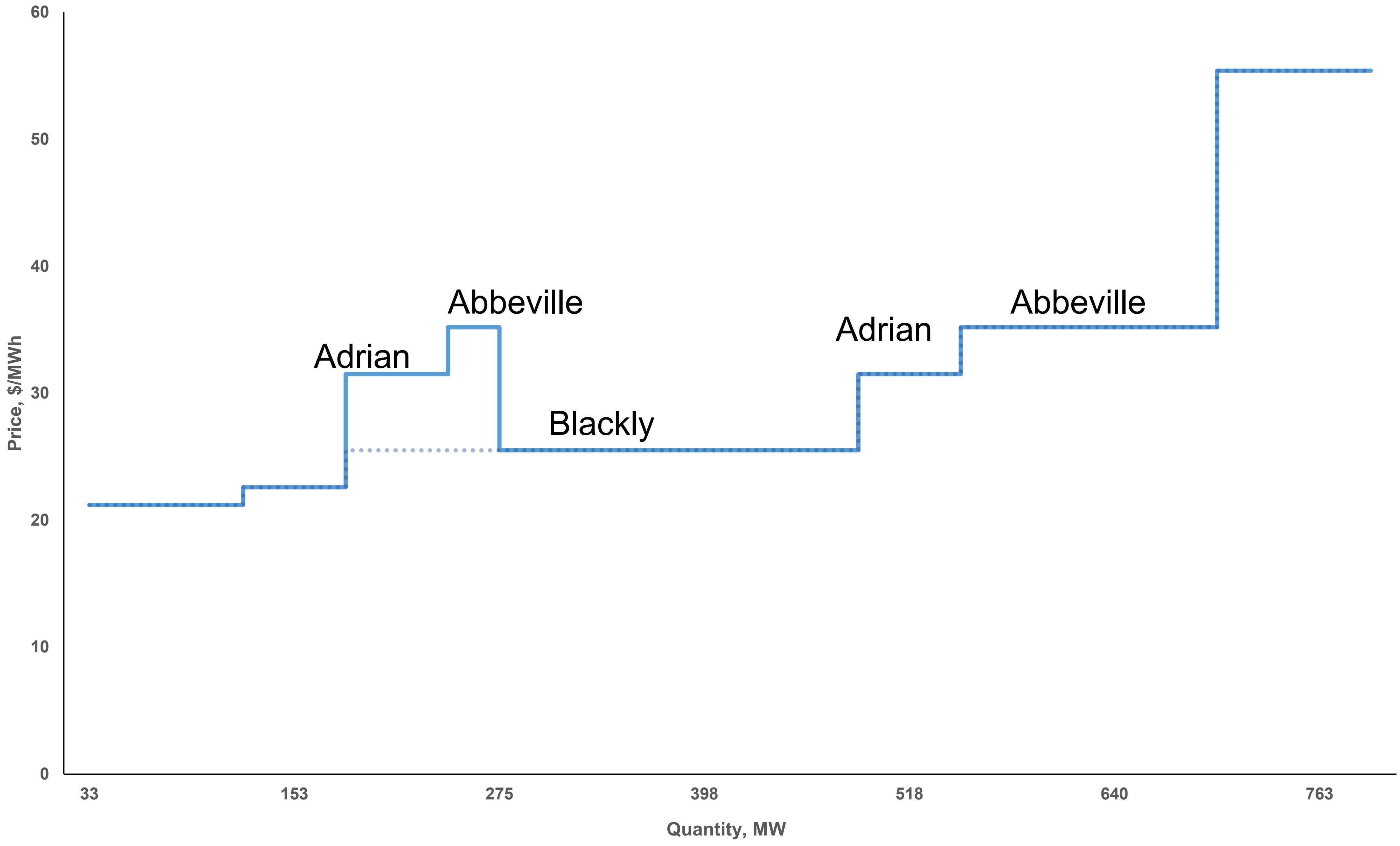
- Allow sellers to reflect the actual operation of their plants.

Complex Bids

An Illustrative Set of Complex Supply Offers Into a Pool From Four Generators

Generator	Complex Supply Offers		
	Price $/MWh	Quantity MW	Min Gen MW
Abbeville	27.6	70	0
Abbeville	40.2	155	0
Adrian	36.5	55	0
Adrian	60.4	105	0
Adrian	26.2	55	0
Blakely	30.5	205	100
Bostwick	26.2	45	0

Complex Bids



Complex Bids

Complex Bids

- Allow sellers to reflect the actual operation of their plants.
- Can help to encourage generator bids to be a simple reflection of their marginal cost
- Can make it more difficult to analyze the strategic impact of moving from one set of auction rules to another

Benefits of Complex Bidding

- **Encourages Efficiency:** Sellers are incentivized to bid their true marginal cost.
- **Improves Price Signals:** More accurate price signals guide investment and resource allocation.
- **Reduces Market Power:** Makes it harder for individual generators to manipulate the market.

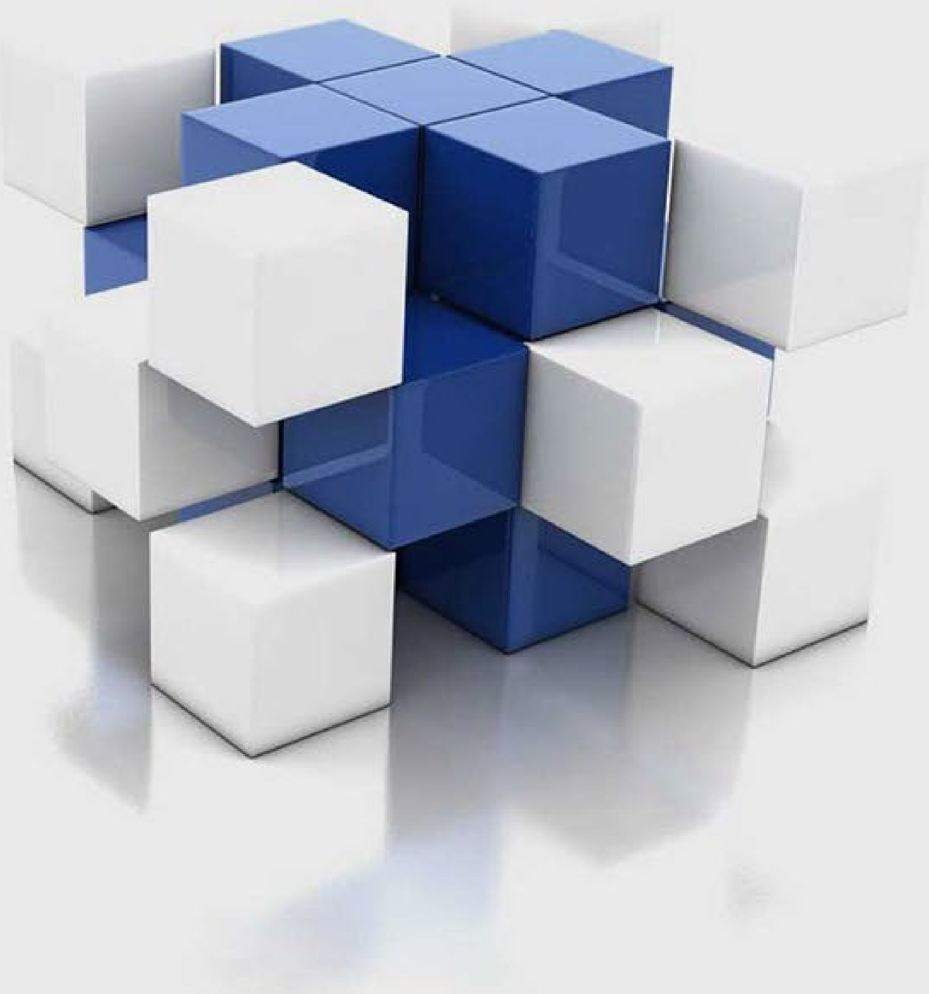
Complex Bids

Challenges of Complex Bidding

- **Increased Complexity:** Requires sophisticated auction mechanisms and market design.
- **Computational Demands:** Clearing auctions with complex bids can be computationally intensive.
- **Strategic Bidding:** Potential for strategic behavior by market participants.

Conclusion

- Complex bidding offers a promising solution to overcome the limitations of simple bidding in power markets.
- While challenges exist, the potential benefits of improved efficiency, transparency, and reduced costs make complex bidding a worthwhile solution for implementation.



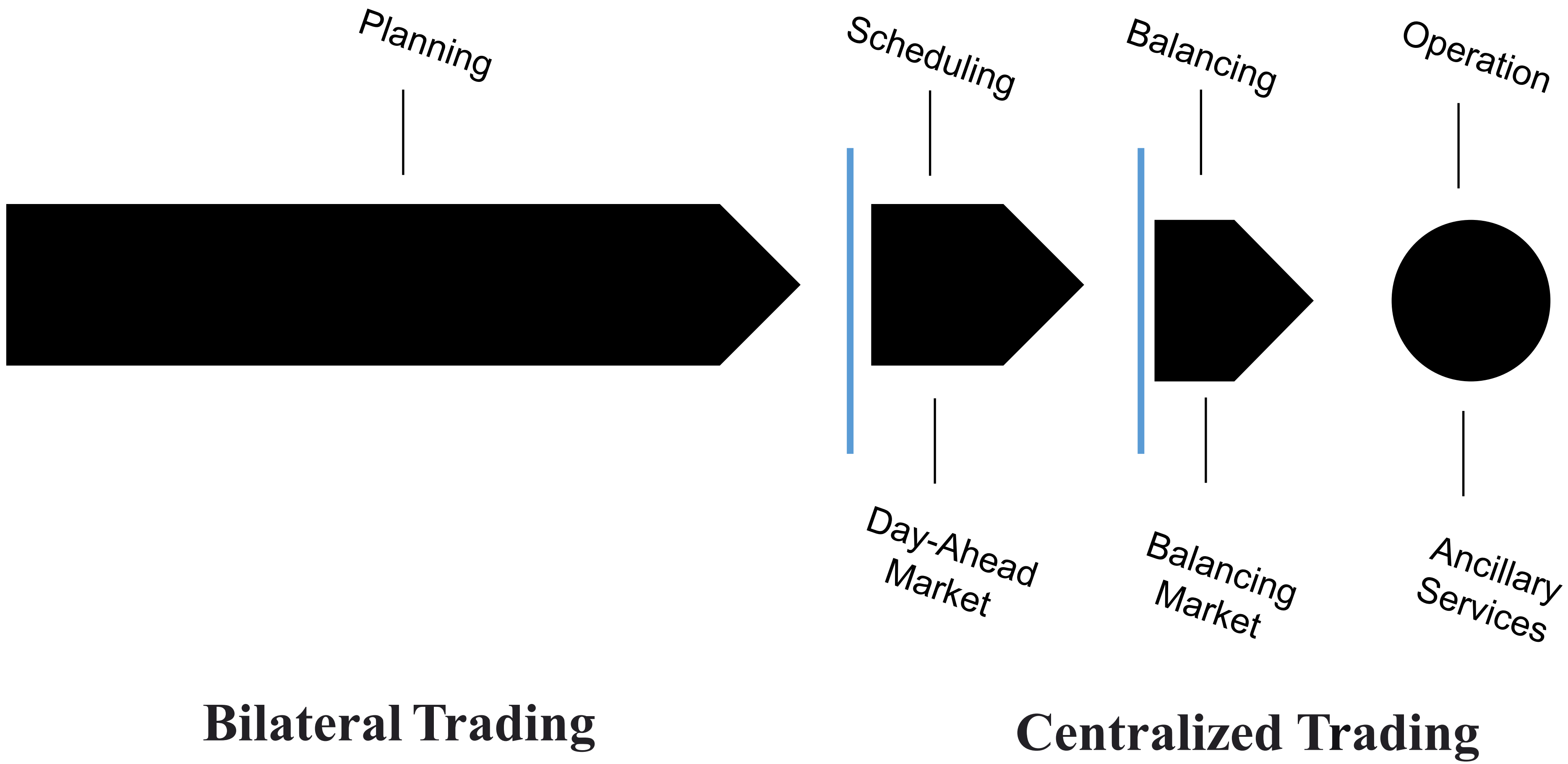
Multi-Settlement Markets

Multi-Settlement Markets

- Electricity systems involve a sequence of iterative decisions made about the power to be delivered in a given hour or set of hours.
- Power Supply Planning and Dispatch Process involves the following stages:
  - Years in Advance
  - As the Year and Season Progress
  - Approaching the Actual Day
  - Actual Day
  - Moment of Generation

Multi-Settlement Markets

- Centralized markets have been adapted to this iterative decision making using multi-settlement markets.



Integrated Settlement

Integrated Settlement

- Integration of Market Stages:
  - Bilateral trading results feed into day-ahead market.
  - Day-ahead market results inform balancing market.
  - Each stage balances generation and load, with adjustments.
  - Balancing market sets terms for adjustments due to updated load or generator information.
  - Shortfalls in balancing market awards are covered by reserve resources and ancillary services.
  - These Ancillary Services are pre-contracted to ensure preparedness for potential shortfalls.

Integrated Settlement

- **Bilateral Contracts in Day-Ahead Market:**
  - GENCO's and LSEs submit balanced schedules based on contracts.
  - Example: New York market with 50% bilateral + 50% competitive offers.
  - Bilateral contracts guarantee generation/load awards at contract price.
- **Financial Settlement Options:**
  - Direct: LSE pays Genco contract price, regardless of day-ahead price.
  - Integrated: System operator buys/sells at day-ahead price, creating secondary payment between Genco and LSE to match contract price.

Integrated Settlement

Alternative Settlements of a Bilateral Contract Integrated Into a Centralized Market.

Bilateral Contract Terms		
Quantity	(MW)	200
Price	($/MWh)	30
Payment	($)	6,000
Centralized Market		
Clearing Price	($/MWh)	32
Alternative #1: All Settlement is External (Direct Approach)		
Central Market Payment	($)	0
Bilateral Payment	($)	6,000
Total Payment	(9	6,000
Alternative #2: Centralized Market Settlement with Sidepayments		
Central Market Payment	($)	6,400
Bilateral Payment	($)	-400
Total Payment	($)	6,000

Integrated Settlement

Integrated Settlement Across the Day Ahead and Balancing Market

Day-ahead Market		
Quantity	MW	400
Clearing price	$/MWh	48
Total payment awarded	$	19,200
Revised deliverable quantity	MW	325
Balancing Market		
Quantity	MW	-75
Clearing price	$/MWh	55
Total payment awarded	$	-4,125
Net Settlement		
Total quantity		325
Total payment awarded	$	15,075

Integrated Settlement

- **Market Variations:**
  - Different countries/regions have diverse market structures.
  - Some regions lack dedicated ancillary services markets.
  - Gradual market development: balancing/bilateral first, then scheduling/ancillary services.
  - U.S. Standard design: Single Balancing Market ("real-time market").
  - Europe: multiple balancing markets ("intraday markets").
  - US: potential for integrating reserve market with day-ahead and real-time markets.

Location, Congestion and Prices

Location, Congestion and Prices

Congestion Management

- **Displacement Mechanism:** Higher offers downstream of constraints displace lower offers upstream.
- **Priority by Price:** Offers remain prioritized by price within and outside congested areas.

Decentralized System Challenges

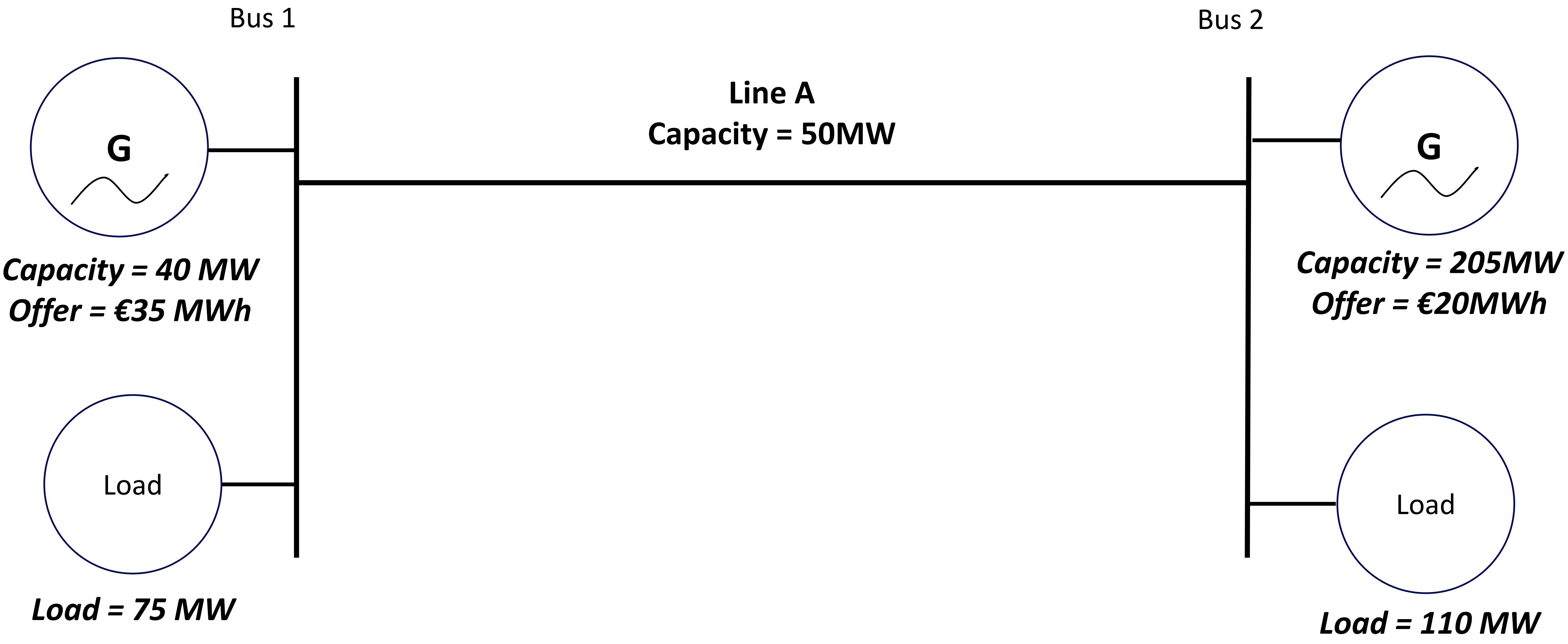
- **Iterative Redispatch:** In a decentralized system, optimization relies on an iterative process of redispatch.
- **Suboptimal Solutions:** Decentralized systems are less likely to arrive at the most optimal constrained dispatch solution.

Location, Congestion and Prices

Final Dispatch Awards

- **Transmission Constraint Consistency:** Final dispatch awards aim to be the lowest cost option consistent with transmission constraints.
- **Single Algorithm Advantage:** Centralized markets achieve this seamlessly within a single algorithm.

Location, Congestion and Prices

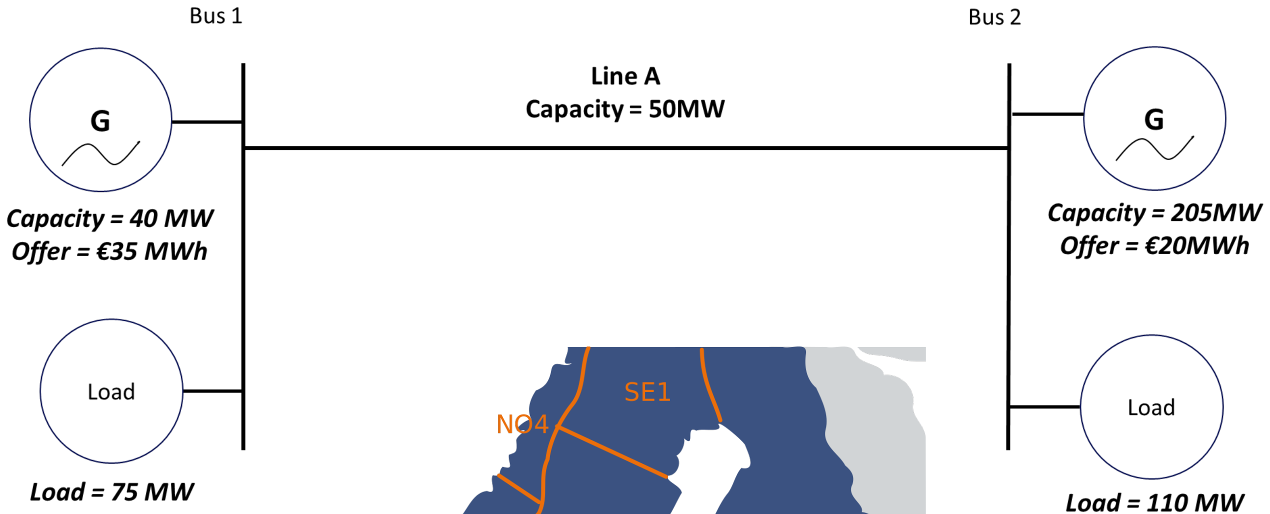


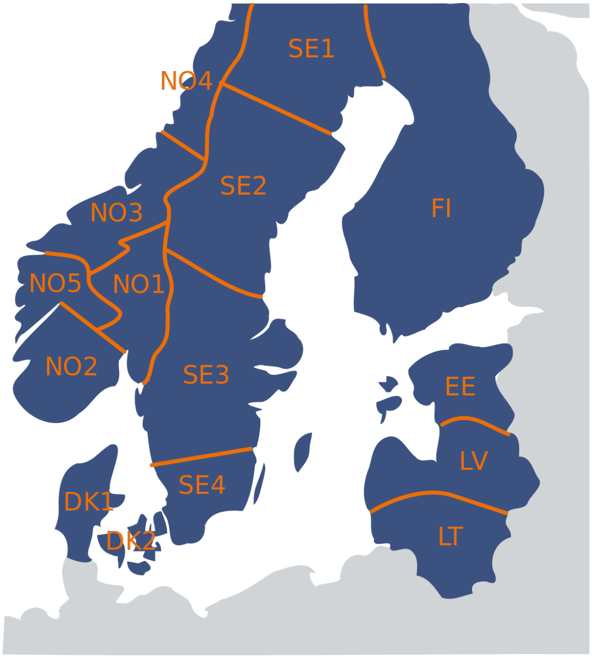
Location, Congestion and Prices

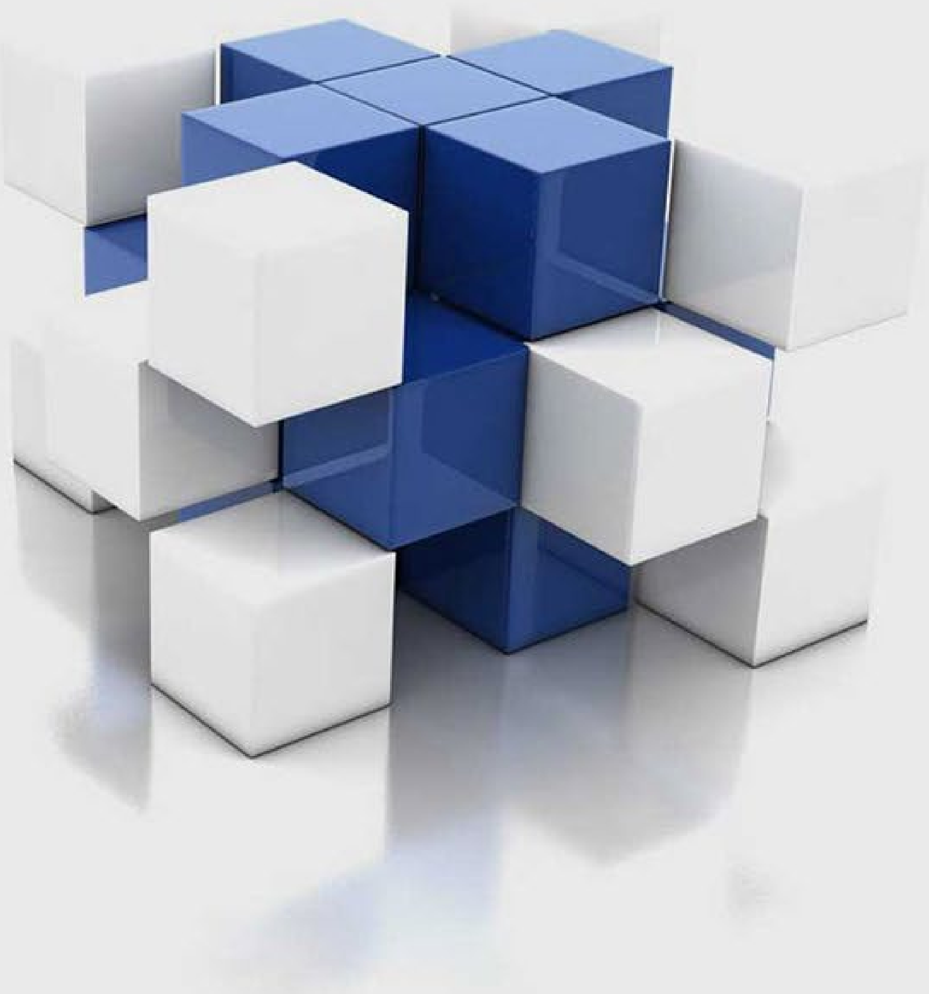
Adaptation in Pricing: Exploring Alternatives

Pricing Mechanisms in Markets:

1. Uniform Price System
2. Price Zones- Market Splitting and Congestion Pricing
3. Nodal Market







Nodal Markets

Nodal Markets

Nodal Market Design

- A nodal market design assigns a different locational marginal price (LMP) to each individual node on the transmission system.
- Generators and load bid into the auction, and their bids are cleared in the usual way, respecting the constraints of the transmission network.
- The result of the auction is not one single pool price, but a list of Prices at different nodes.
- This list of prices is the lowest cost way to serve the load given the constraints of the transmission network.
- Nodal markets take congestion pricing to the limit, reflecting the constraint in delivering power from one region to another.

Nodal Markets

Nodal Market Design

- Generators in different regions receiving day-ahead generation awards will be paid different prices for their power.
- A nodal market also incorporates losses into prices.
- The LMP at each location reflects the marginal value of an additional unit of generation at that location.
- Nodal markets can be advantageous for incentives.

Nodal Markets

Components of LMP

LMP = energy + congestion + losses

- **Energy component:** The marginal cost of an additional unit of power in the system as a whole, not including the cost of congestion or losses.
- **Congestion component:** Positive for nodes downstream of congestion, and zero for all nodes if there is no congestion.
- **Loss component:** Equal to the marginal value of systemwide losses from an incremental unit of generation at that node.

Nodal Markets

Passing Along LMP Cost to Individual Consumers

- Most systems that use LMP pricing pay individual generators the LMP at the node where they are located but have a slightly different policy for passing along the LMP cost to individual consumers.
- Retail customers across large sub-regions usually pay a single wholesale price undifferentiated by the particular LMP where the customer is located.
- However, the aggregated load is paying an amount determined by the load's location and the LMPs across the sub-region.

Location, Congestion and Prices

Annual Load-Weighted Average Day-Ahead LMP Components in PJM and Selected Sub-Regions

	LMP ($/MWh)	Energy Component ($/MWh)	Congestion Component ($/MWh)	Loss Component ($/MWh)
Vianden	29.68	29.55	0.14	0.01
Zone				
Creos	28	29.5	-0.72	-0.79
Sudstroum	29.12	29.57	-0.06	-0.39
Frères	34.95	29.65	4.77	0.53
+Diekirch	26.83	29.75	-3.3	0.38

Congestion Surplus

Congestion Surplus

What is congestion surplus?

- The difference between the price at which energy is bought and the price at which it is sold at a point of congestion.

How is congestion surplus calculated?

- The congestion surplus is calculated by multiplying the difference in price by the amount of energy flowing across the point of congestion.

Who collects the congestion surplus?

- The congestion surplus is typically collected by the system operator.

Location, Congestion and Prices

Calculation of the Congestion Surplus with LMPs.

		Bus #1	Bus #2	Total
Load	(MWh)	75	110	185
Generation	(MWh)	25	160	185
LMP	($/MWh)	35	20	
Gen Revenue	($)	875	3,200	4,075
Load Payment	($)	2,625	2,200	4,825
Congestion Surplus	($)	1,750	- 1,000	750

Congestion Surplus

What is the role of the congestion surplus?

- The congestion surplus can be used to incentivize investments in transmission, or it can be returned to customers as an offset to the charges levied for building and operating the transmission system.

Conclusion

- The congestion surplus is a complex issue with no easy answers.
- The way in which the congestion surplus is distributed can have a significant impact on the efficiency and fairness of the electricity market.

Integrating Bilateral Contracts With Congestion Pricing

Integrating Bilateral Contracts With Congestion Pricing

Introduction

- Bilateral contracts are agreements between two parties to buy or sell electricity at an agreed price.
- In a nodal pricing system, the price of electricity is determined by the location of the buyer and seller.
- This can create congestion risk for parties to bilateral contracts.
- There are two alternative ways to settle the contract using the centralized market prices.

Integrating Bilateral Contracts With Congestion Pricing

Alternative Settlements of a Bilateral Contract Integrated Into a Centralized Market With Congestion Pricing			
Bilateral Contract Terms			
Quantity	(MW)		200
Price	($/MWh)		30
Payment	($)		6,000
Centralized Market — nodal prices			
Price at Buyer	($/MWh)		32
Price at seller	($/MWh)		29
Difference	($/MWh)		3
System Energy price			3
Congestion Price at Buyer			1
Congestion Price at Seller		-	2

Integrating Bilateral Contracts With Congestion Pricing

Alternative #1: Energy Settled Congestion Centrally

Central Payment with Buyer	($)	200
Central payment with seller	($)	- 400
Difference	($)	600
External Payment	($)	6,000
Total Payment from Buyer	($)	6,200
Total Payment to Seller	($)	5,600
Difference	($)	600

Alternative #2: Centralized Market Settlement with Sidepayments

Central Payment with Buyer	($)	6,400
Central Payment with Seller	($)	5,800
Difference	($)	600
External Payment	($)	- 200
Total Payment from Buyer	($)	6,200
Total Payment to Seller	($)	5,600
Difference	($)	600

Integrating Bilateral Contracts With Congestion Pricing

Two Alternatives for Settling Bilateral Contracts

- **Alternative 1: Leave financial settlement for the sale of energy to the two parties to the contract.**
  - The system operator still collects the congestion charge.
  - The buyer pays the seller the contract price for energy.
  - The buyer and seller make payments to the system operator based on the congestion charge at their respective locations.

Integrating Bilateral Contracts With Congestion Pricing

Two Alternatives for Settling Bilateral Contracts

- **Alternative 2: Treat the scheduled power as if it is a part of the day-ahead centralized market clearing and collect both the energy and congestion components.**
  - The buyer and seller make payments to the system operator based on the LMP at their respective locations.
  - The buyer and seller make a side payment to each other to adjust for the difference between the system energy price and the contract price.

Integrating Bilateral Contracts With Congestion Pricing

Congestion Price Risk

- Parties to bilateral contracts still face congestion price risk, even in a nodal pricing system.
- This is because they cannot lock in the congestion price.
- The division of congestion price risk between the buyer and seller depends on the congestion price at their locations.

Hedging Congestion Price Risk

- The LMP system allows parties to bilateral contracts to take all of the congestion risk in the form of congestion price risk.
- In coming modules, we will study how a market in transmission rights creates an opportunity to hedge this risk.

Integrating Bilateral Contracts With Congestion Pricing

Conclusion

- The LMP system does not create congestion risk.
- Congestion risk is embedded in all uniform price systems.
- The LMP system allows parties to bilateral contracts to take all of the congestion risk in the form of congestion price risk.