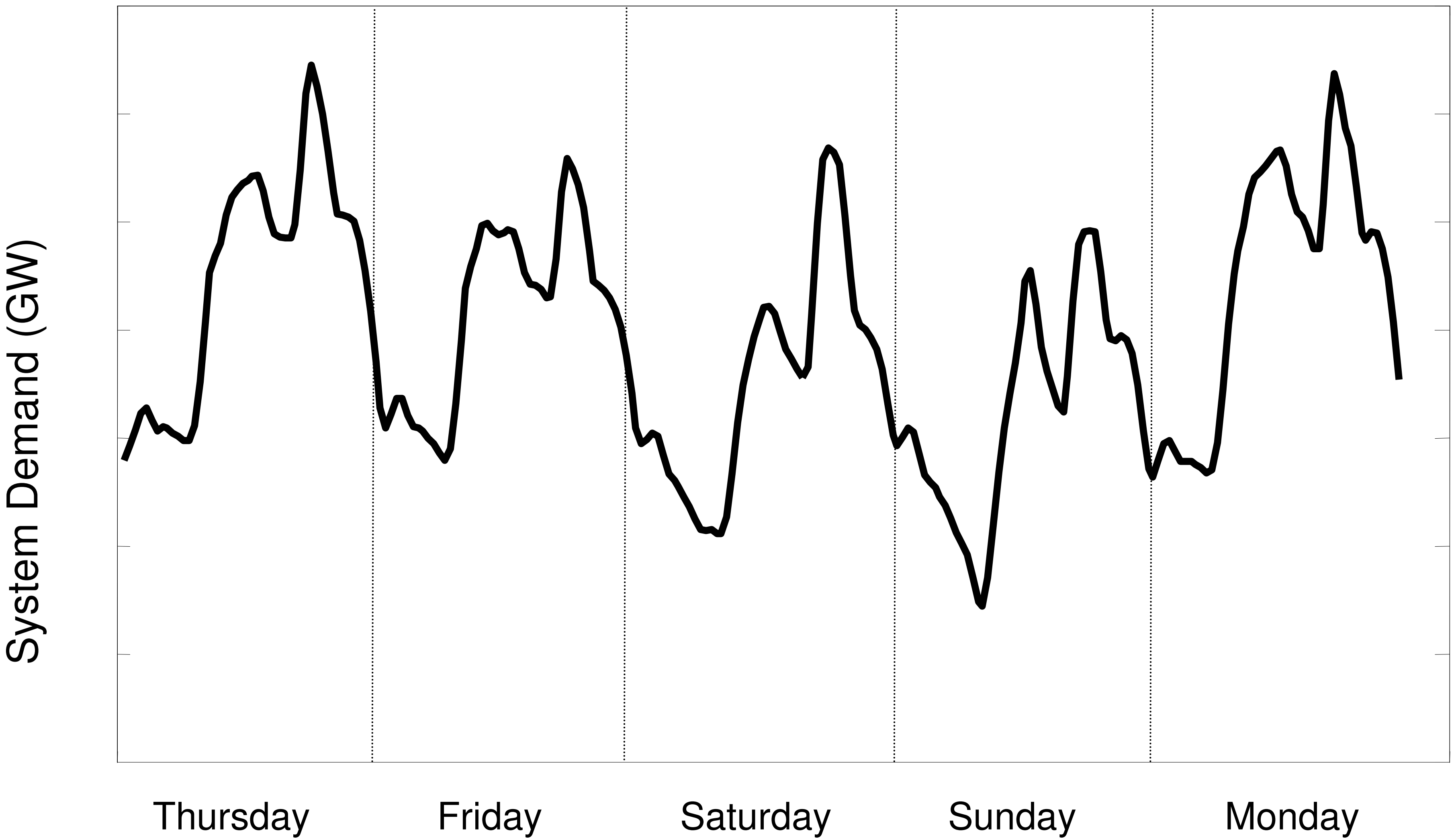
Power System Operation

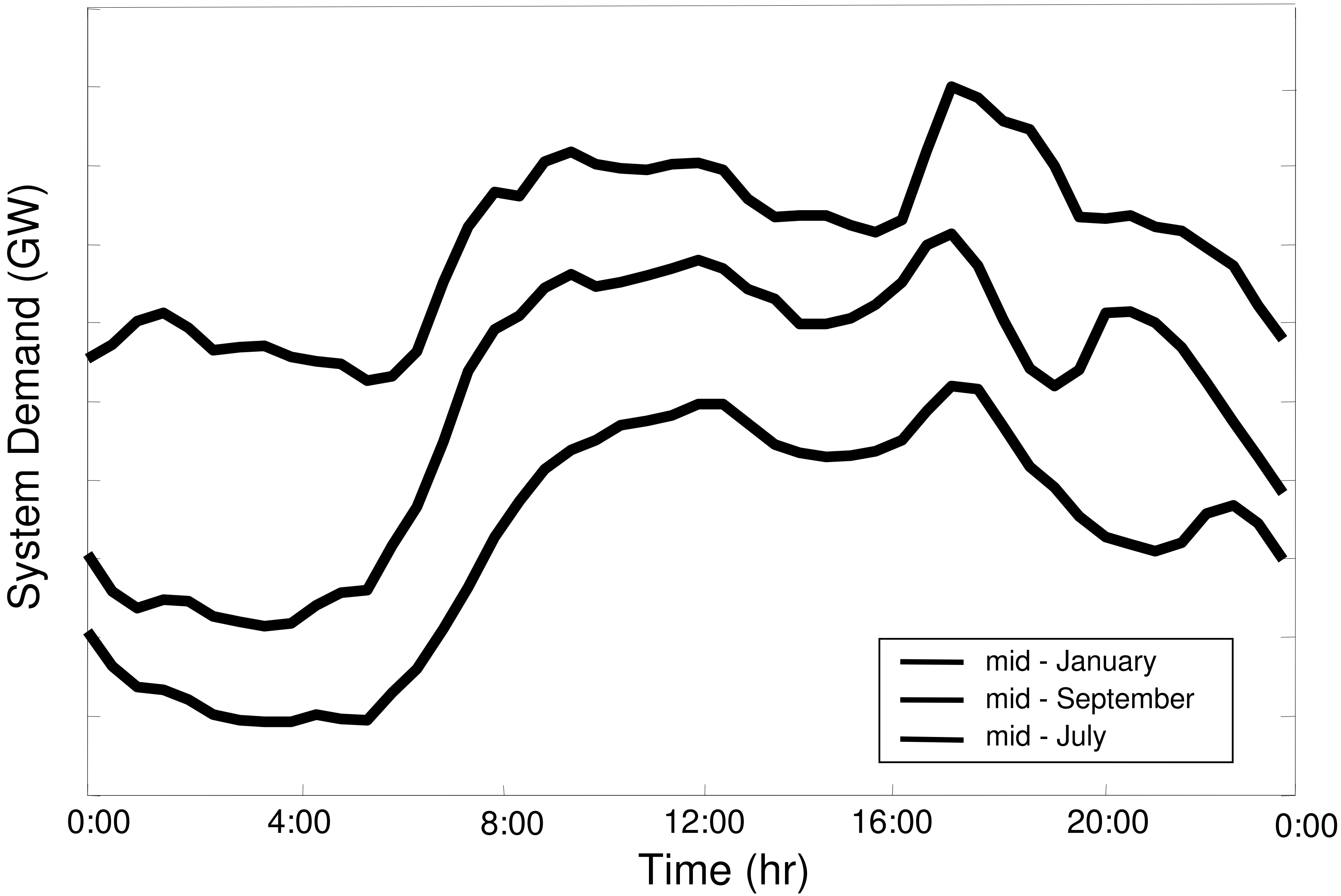
Electricity Cannot be conveniently Stored

- Cost effective means of storing large amounts of electrical power does not currently exist
- Instantaneous balance required between generation and demand
- System voltage and frequency to be maintained within statutory limits
- Electrical demand fluctuates between wide (daily / seasonal) limits
- Must have sufficient generation capacity available to supply maximum yearly demand

5-Day Demand Pattern



Seasonal Demand Variation

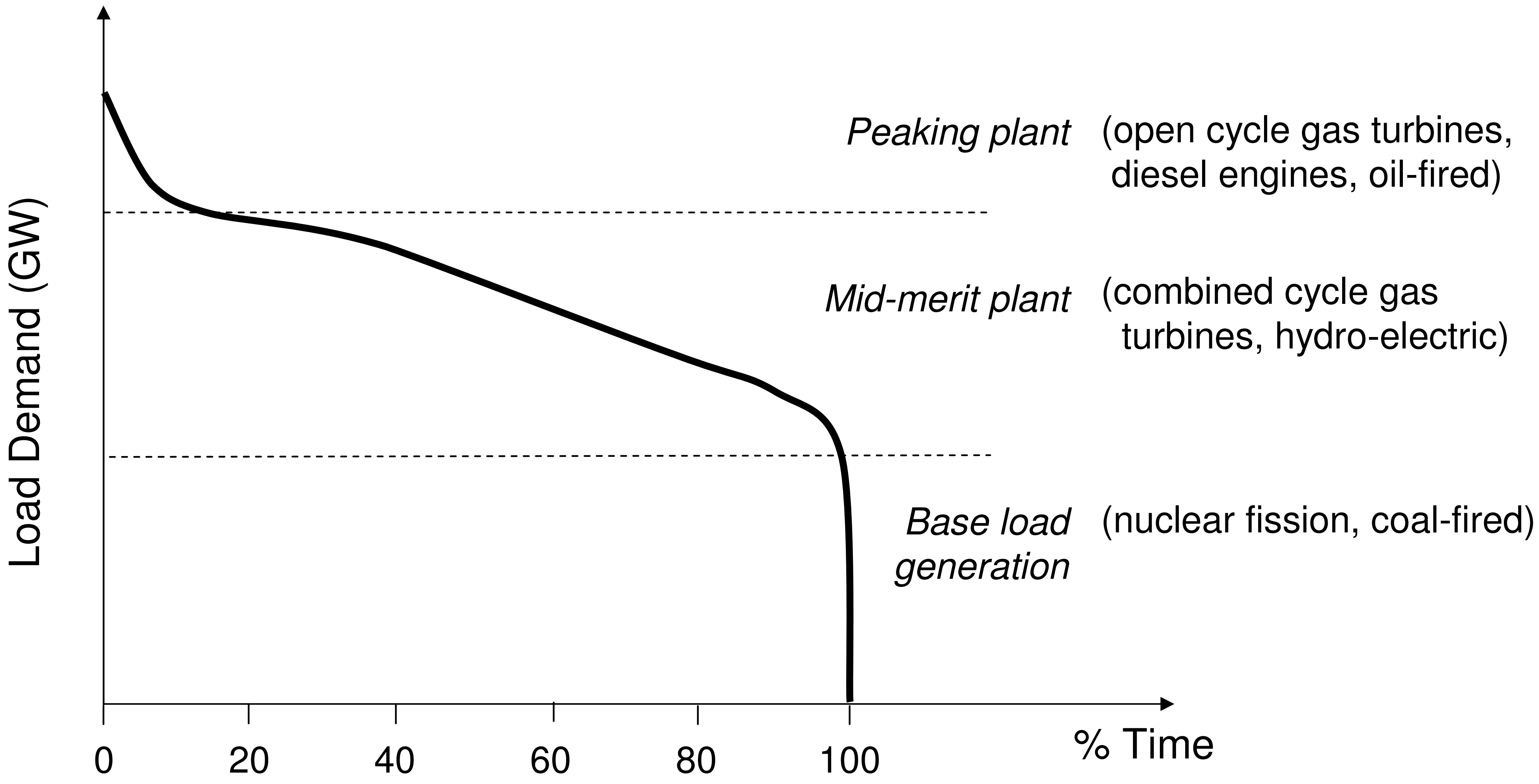


Merit Order Operation

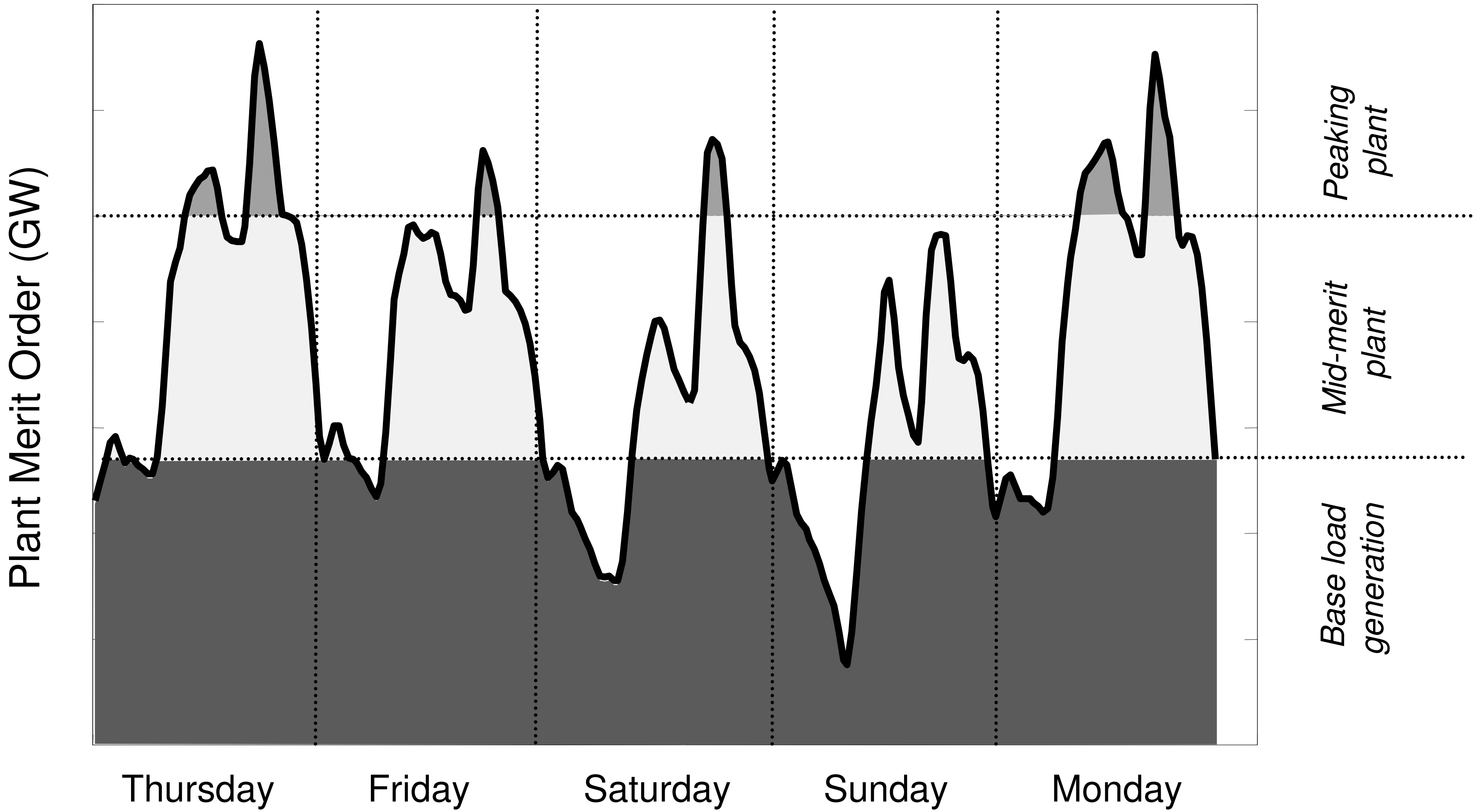
- A *merit order* ensures that the cheapest generating units are committed first

  - *Base load*: units running at 100% output all day to meet minimum load requirement
  - *Variable load*: Power stations need to respond fairly quickly to changes in demand, following daily cycle in demand
  - *Peak load*: Fast-starting units, which can be brought online in a few minutes, to meet short-term peaks in demand

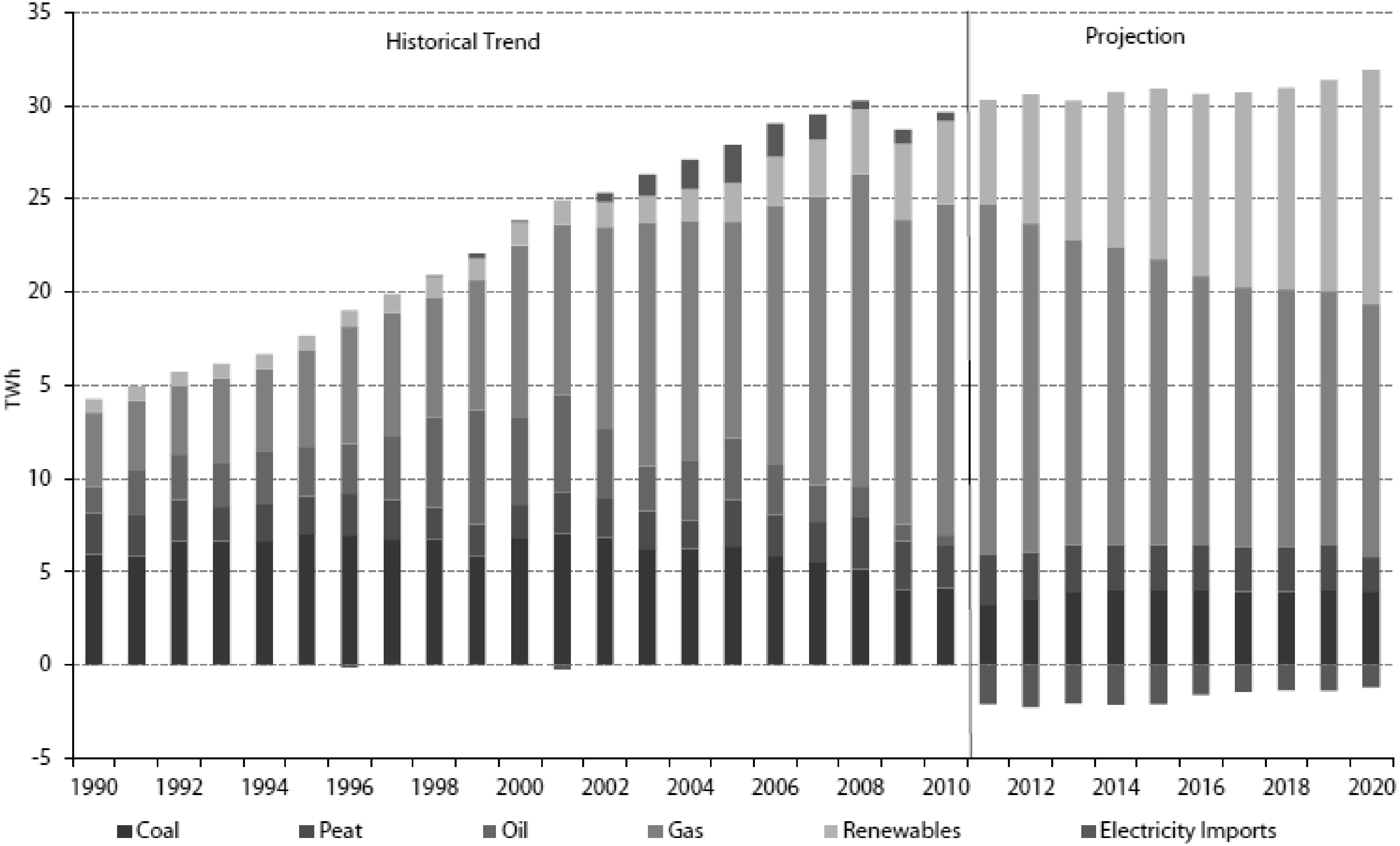
Load-Duration Characteristic



5-Day Plant Merit Order



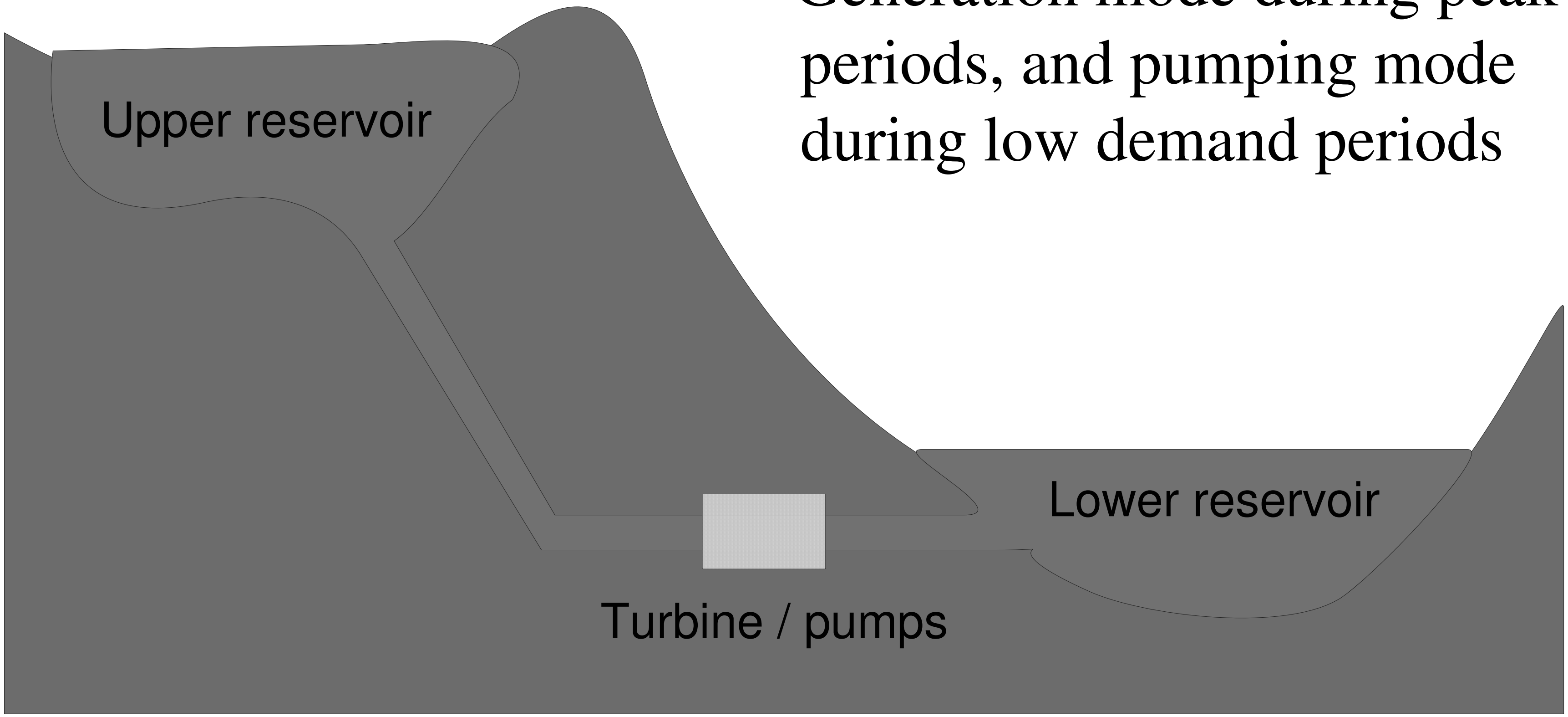
Ireland – Electricity Generation



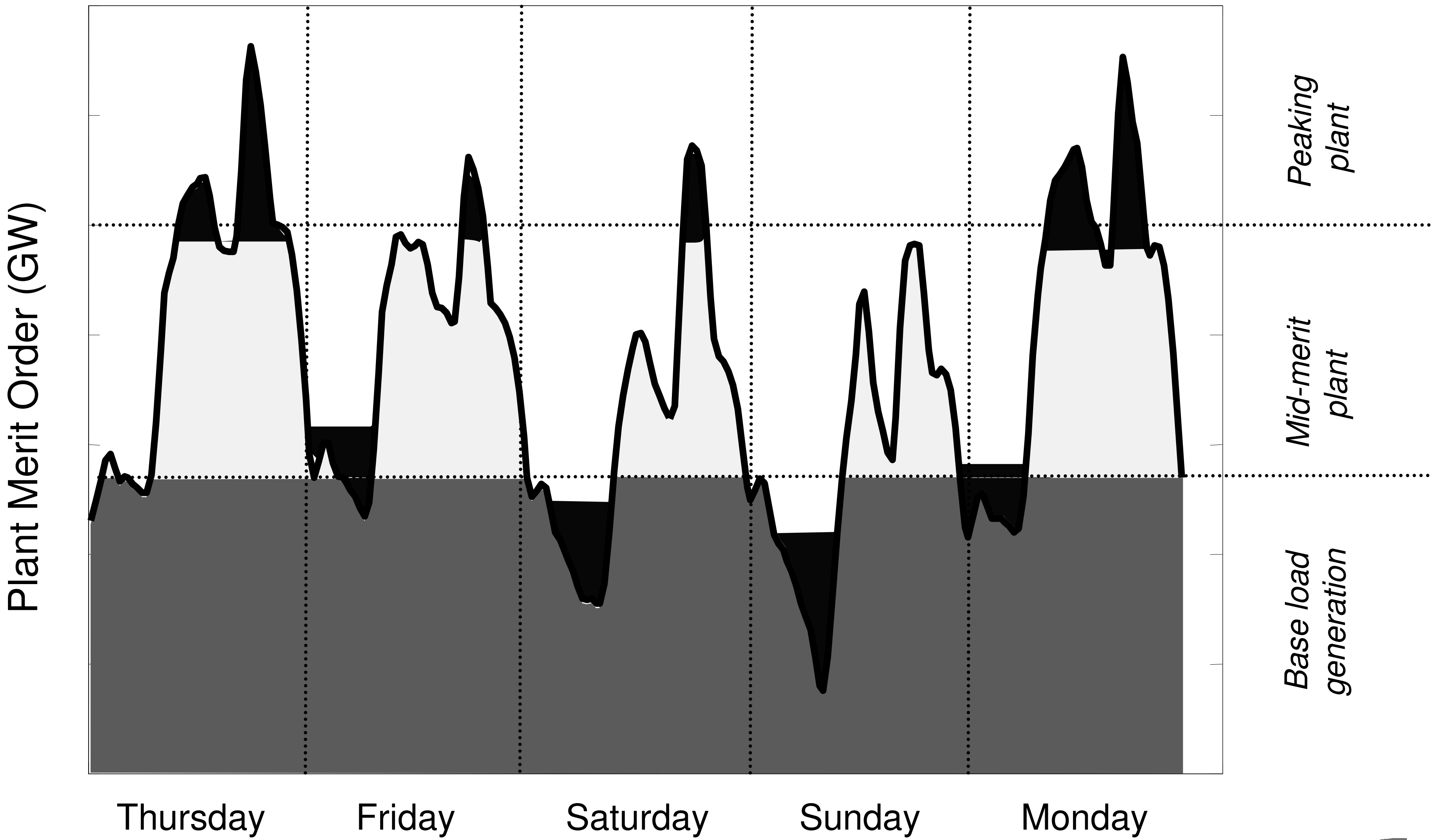
Pumped Storage

- Useful for smoothing out the peaks and troughs of electrical demand
- Fast reaction time but limited storage capability

- Generation mode during peak periods, and pumping mode during low demand periods



Merit Order (+ Pumped Storage)



Unit Commitment

- Generating units utilize a wide range of
  - energy sources
  - differing technologies and designs
  - unit generating capacity
- Significant time required to start units
- Electric utility decides in advance which generators to start up and when to connect them to the network

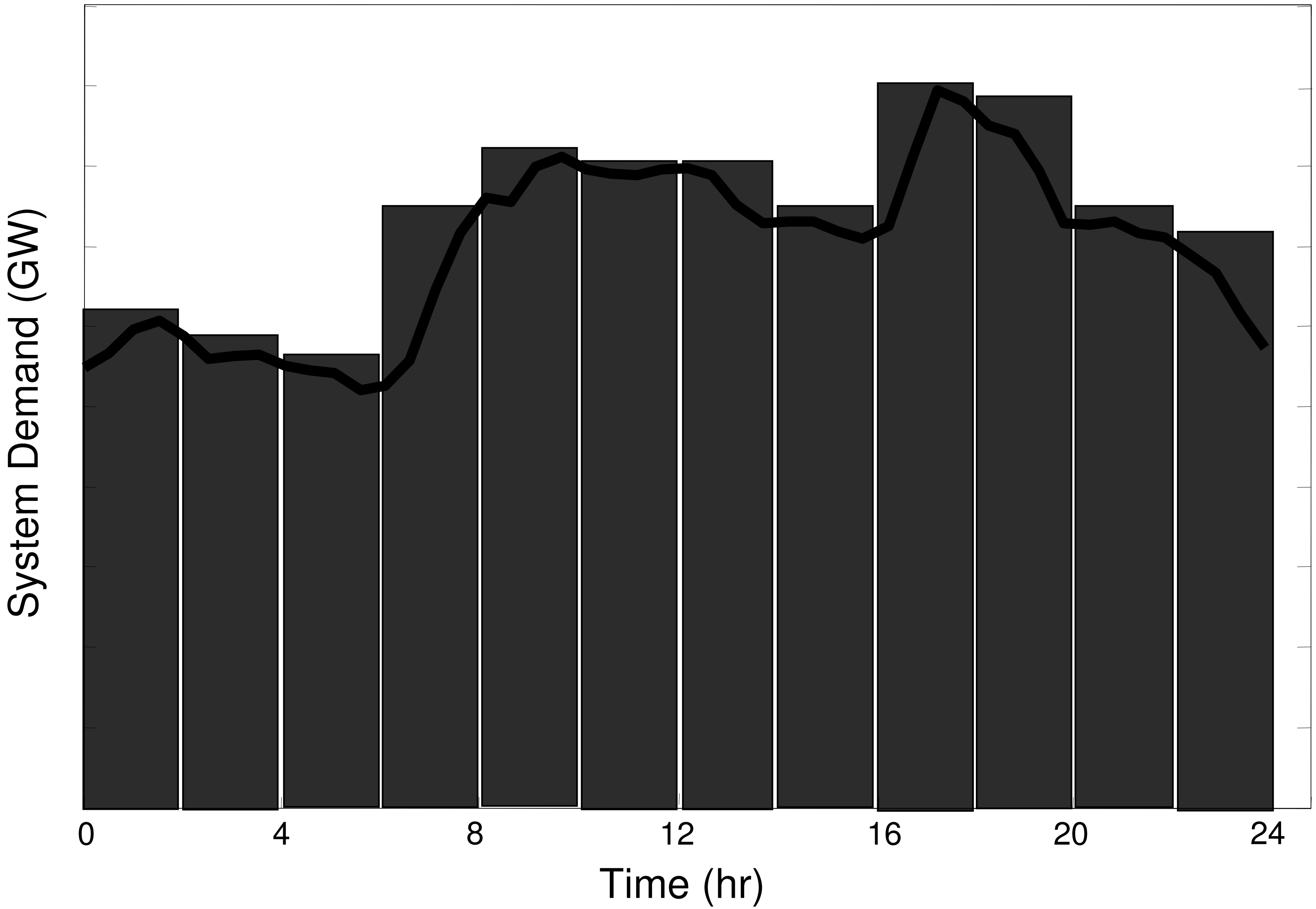
- This scheduling of units, dependent on system load, is called *unit commitment*

Demand Forecasting

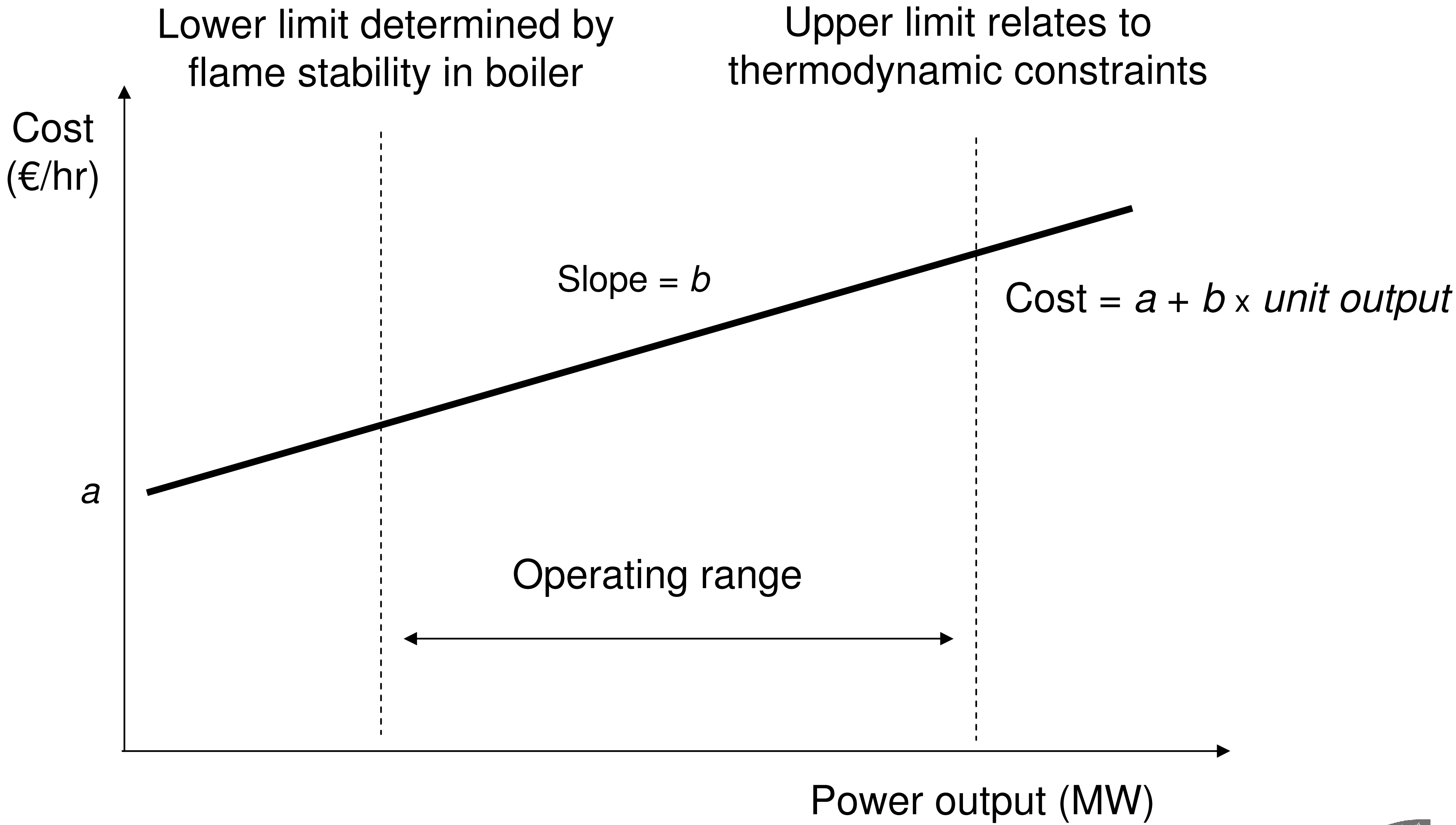
- Individual loads may be random in nature, but patterns emerge as loads are aggregated together
- Load forecasts based on previous years' loading for equivalent period
- Updated by weather trends, TV schedules, *etc*.
- Weather has a greater influence on residential than on industrial demand

- … splitting a day into discrete *stages*, with the predicted load assumed constant over each interval

Demand Forecast - Discrete



Generator Cost Characteristic



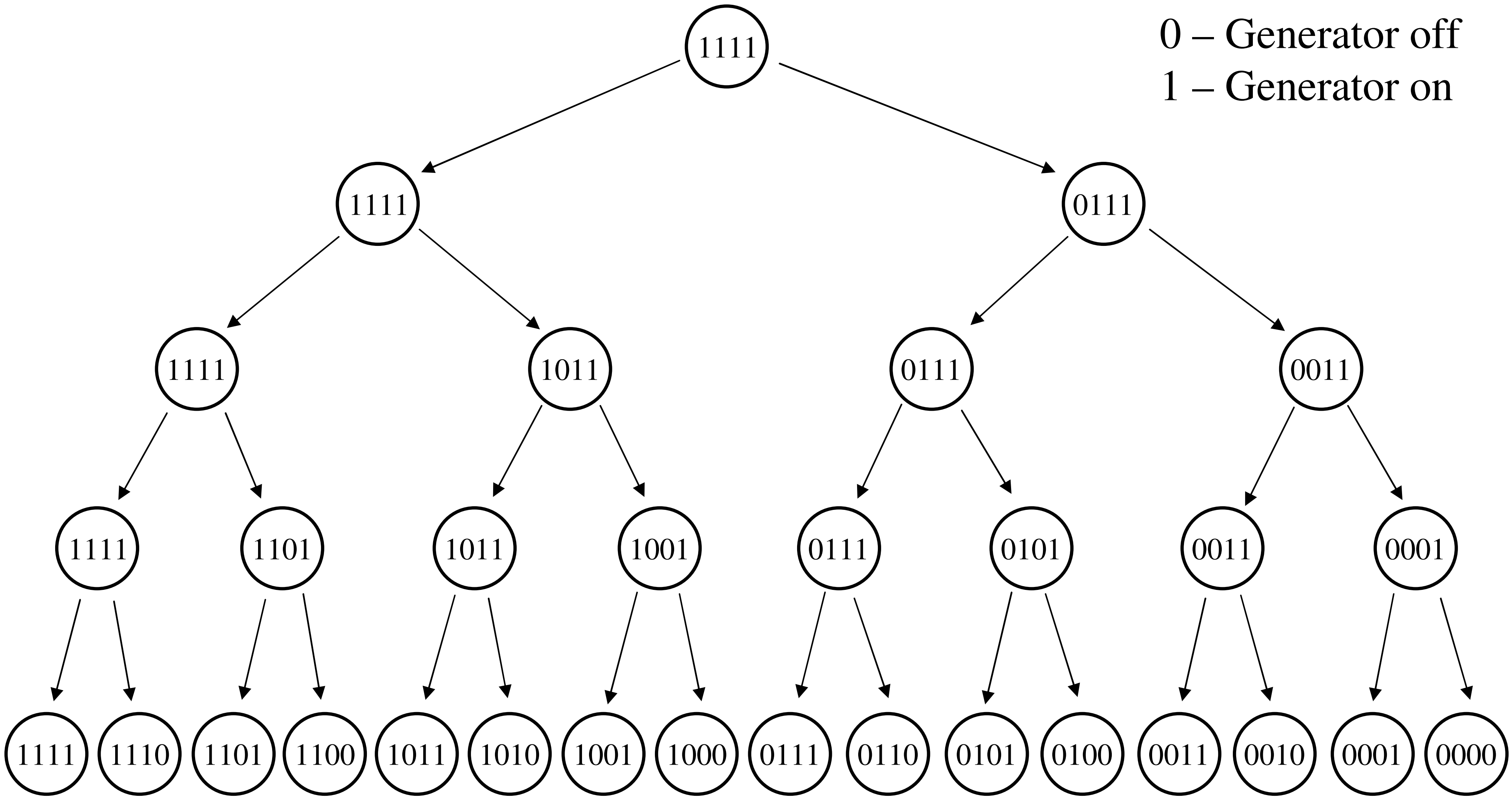
Example

How should a 4 unit power system best supply a load demand increasing over 1 hour from 260 MW to 270 MW?

Unit	**Loading Range** (MW)	**No-Load Cost** (€ /hr)	**Incremental Cost** (€/MWhr)
1	20 – 100	1400	8
2	40 – 125	1000	10
3	30 – 120	800	15
4	20 – 80	400	21

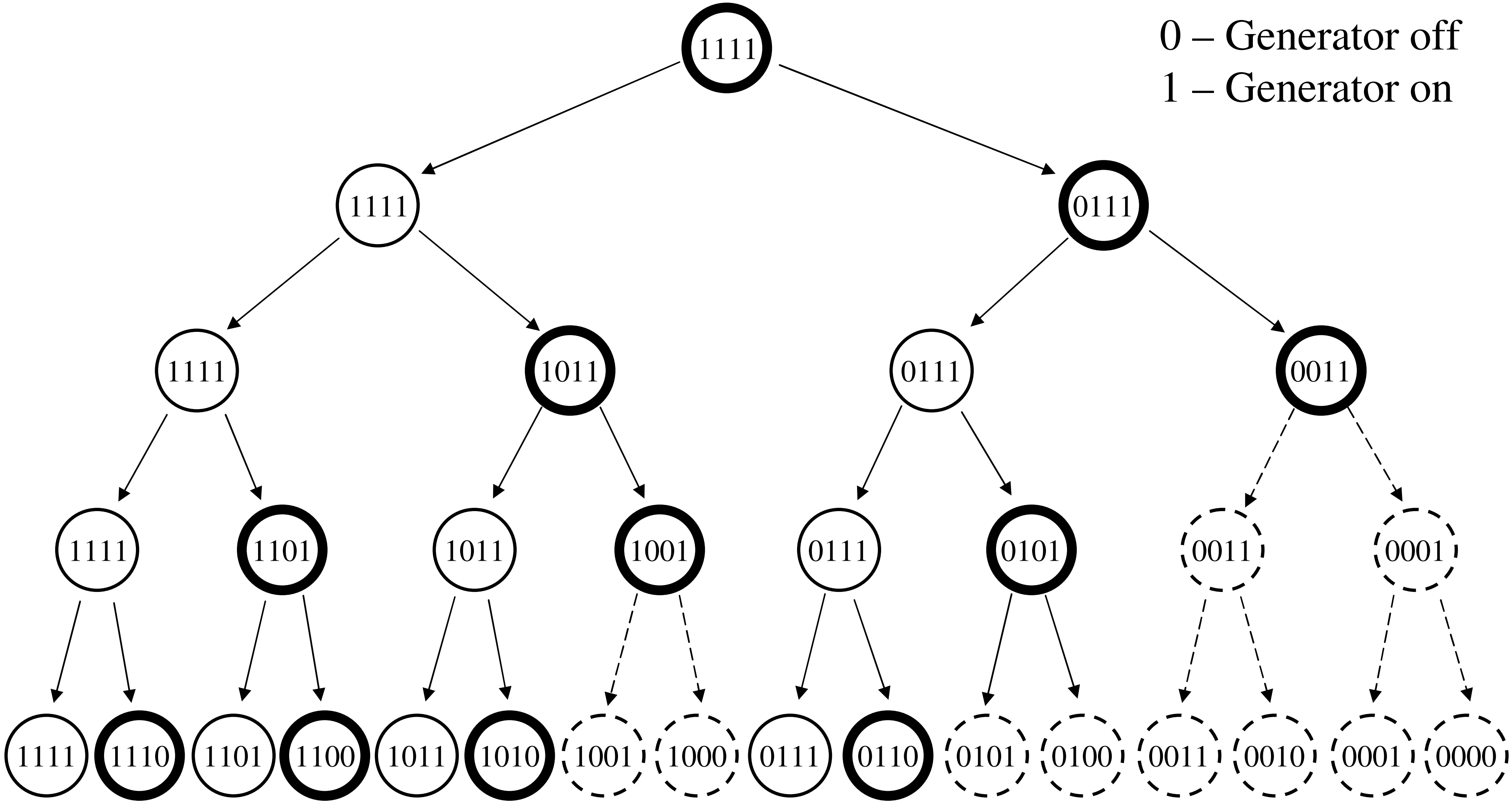
- If a power system has n units, potentially $2^n - 1$ unit combinations can be employed at each stage
- Using a decision tree, the number of options to be examined can be significantly reduced

Decision Tree



0 – Generator off
1 – Generator on

Decision Tree



Transition Costs

- Costs involved when switching from one combination of units to another
  – A fixed cost can be assigned to shutting down a unit
  – The startup cost depends on how long a unit has been shut down (boiler temperature and fuel required to restore operating temperature depend on duration of cooling)
- Minimizing costs at one stage depends on particular units selected for all other stages

Maintenance Requirements

- Desirable to have all units available during peak load periods
- Routine maintenance usually scheduled for periods of low demand
- Taking equipment out of service will affect system economics, and decrease the margin between demand and production capability of available units
- Power stations can not act unilaterally
  – must request to take individual units out of service

Power System Operation

Impact of Renewable Sources

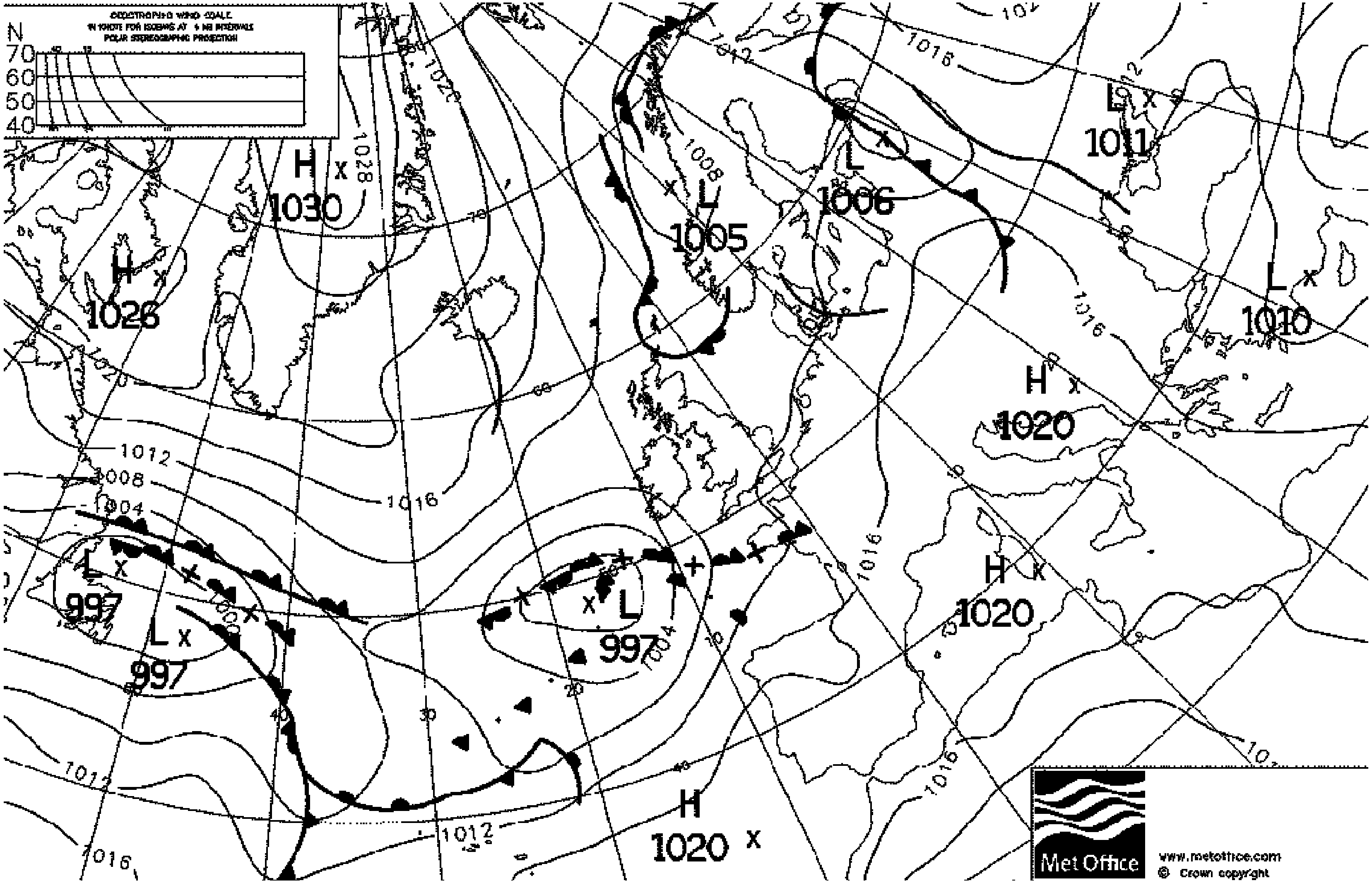
Renewable Sources

- Predictable (forecastable)
  - Tidal, tidal stream, hydro, etc.
- Variable (semi-forecastable)
  - Solar, wind, wave, hydro, etc.
- Controllable
  - Geothermal, ocean thermal, biomass / biofuel, etc.

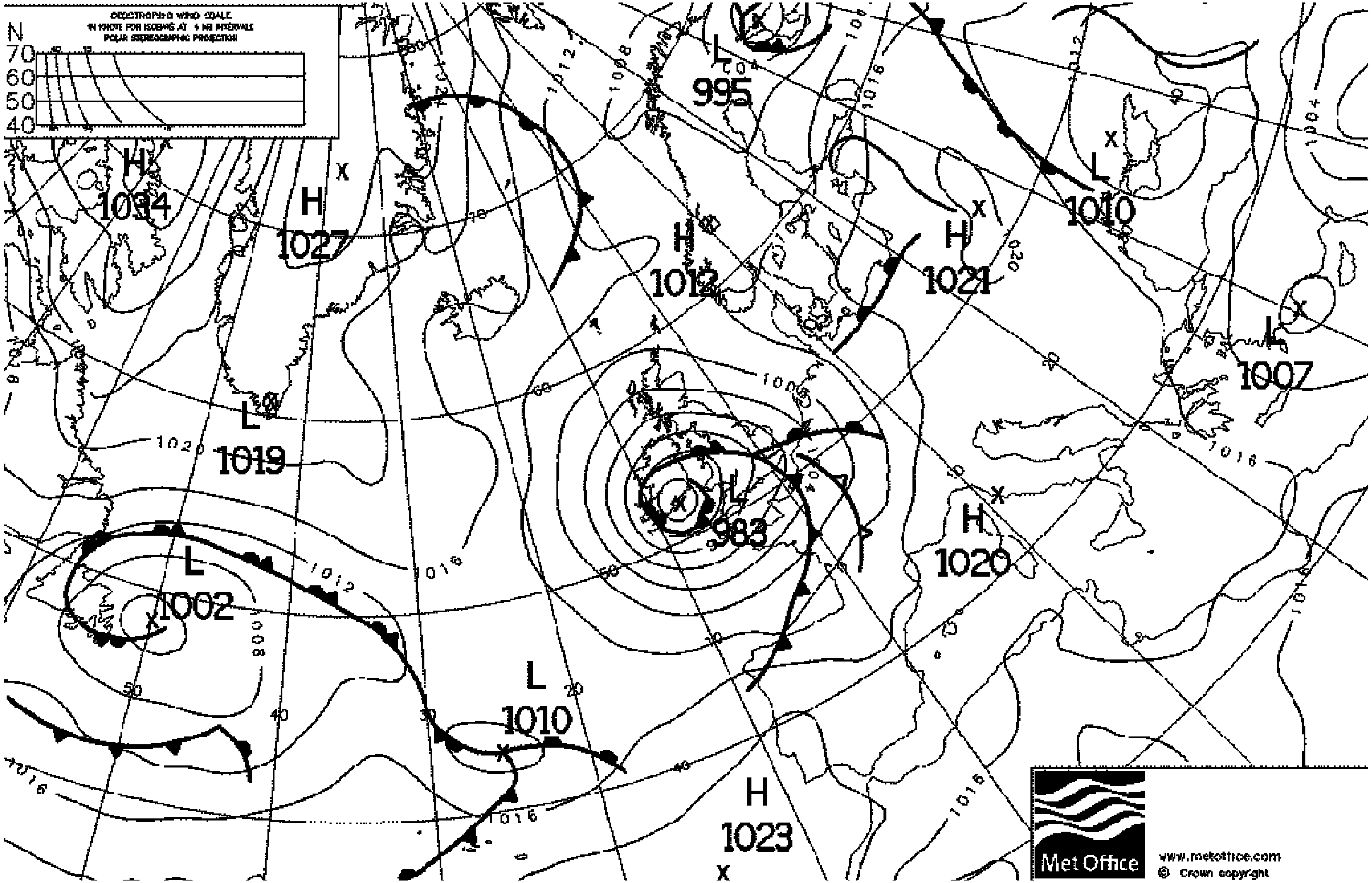
Fuel Saver Operational Mode

- Wind generators treated as negative load
- Conventional generators reduce output to match prevailing wind generation levels
- Extremely secure system operation
- Wind curtailment, subject to generator minimum outputs?
- Emissions reduction?
- Suitable for *low* wind penetration levels

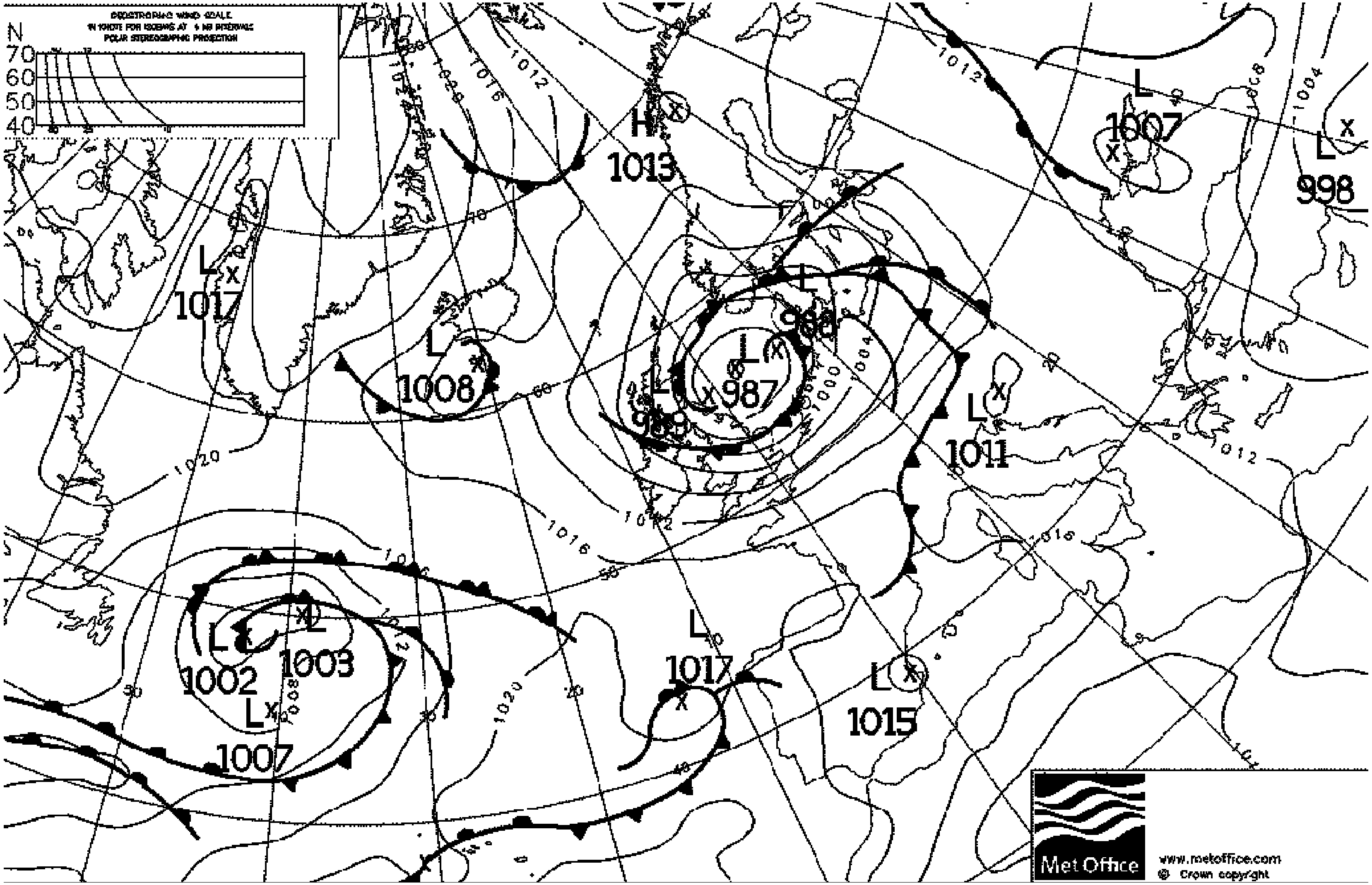
Weather Forecast – Day 1



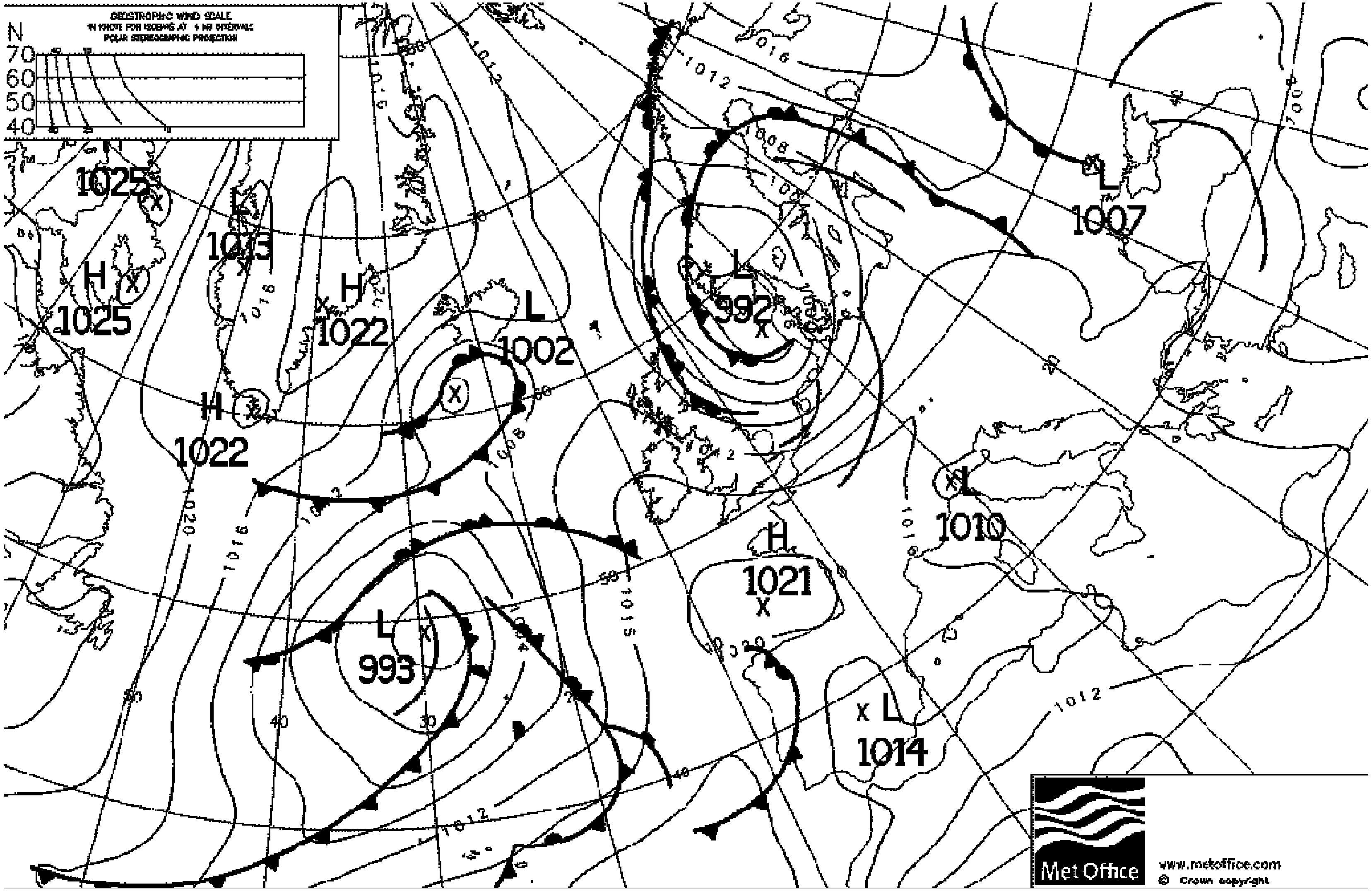
Weather Forecast – Day 2



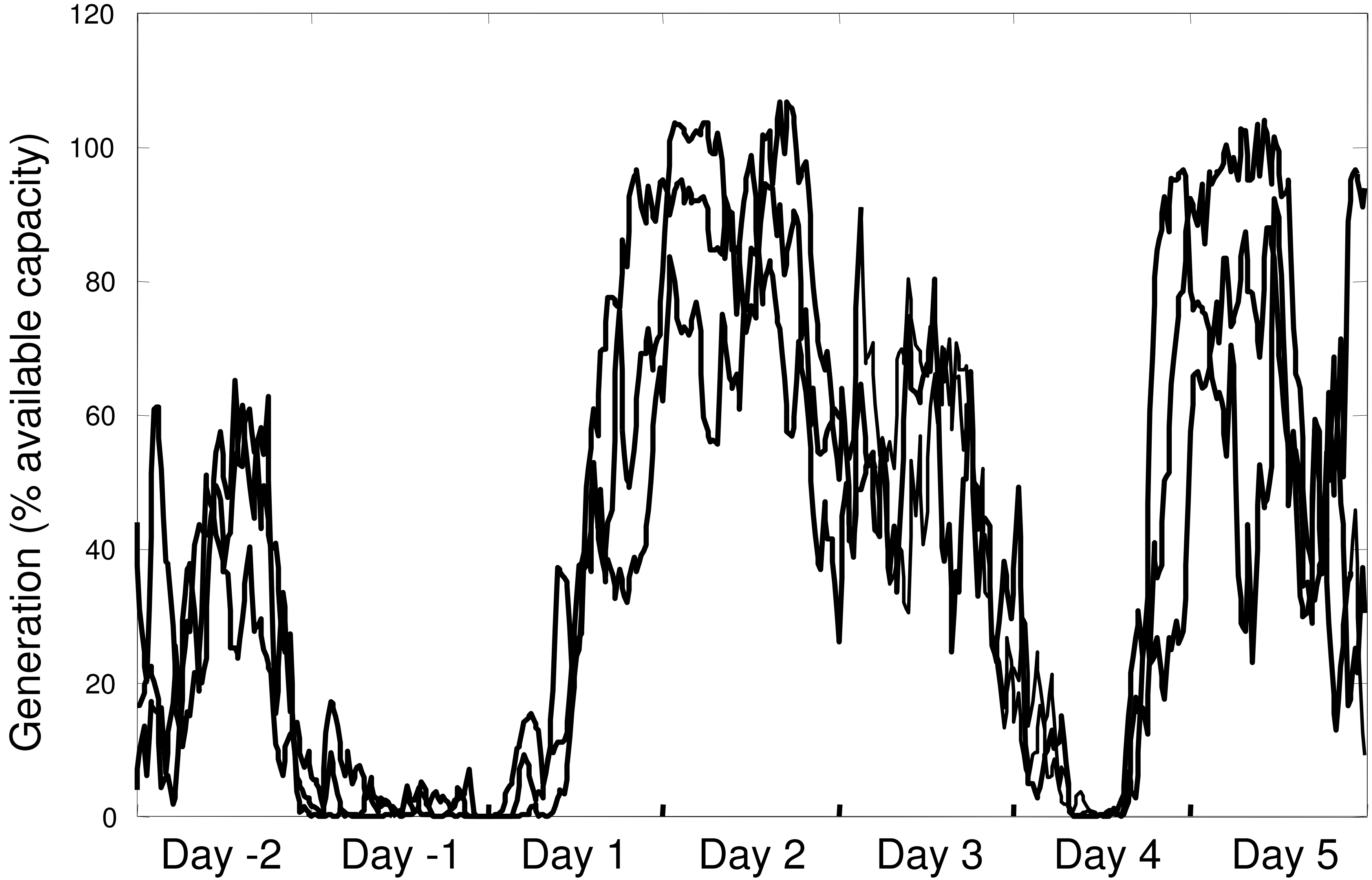
Weather Forecast – Day 3



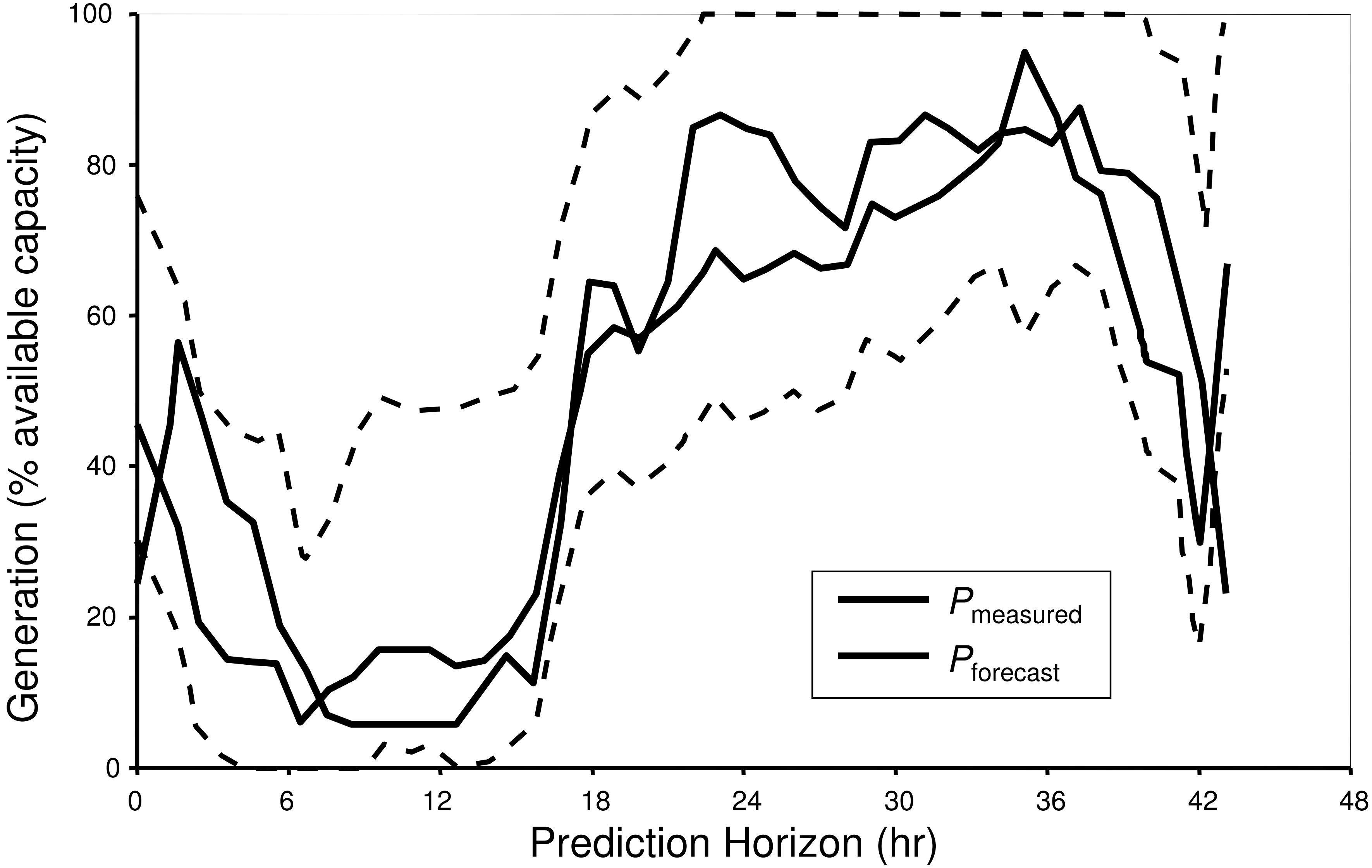
Weather Forecast – Day 4



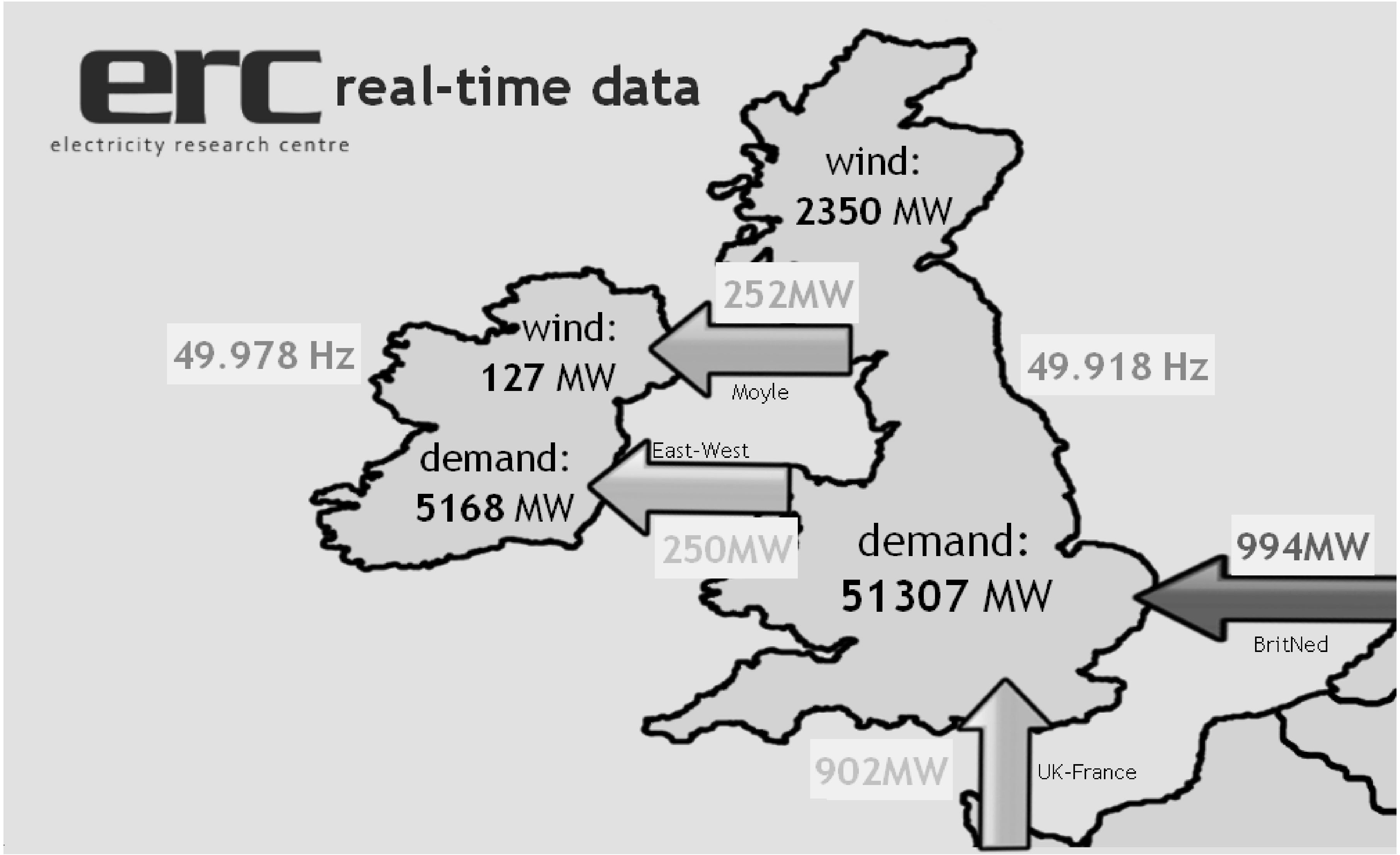
Wind Farm Variability



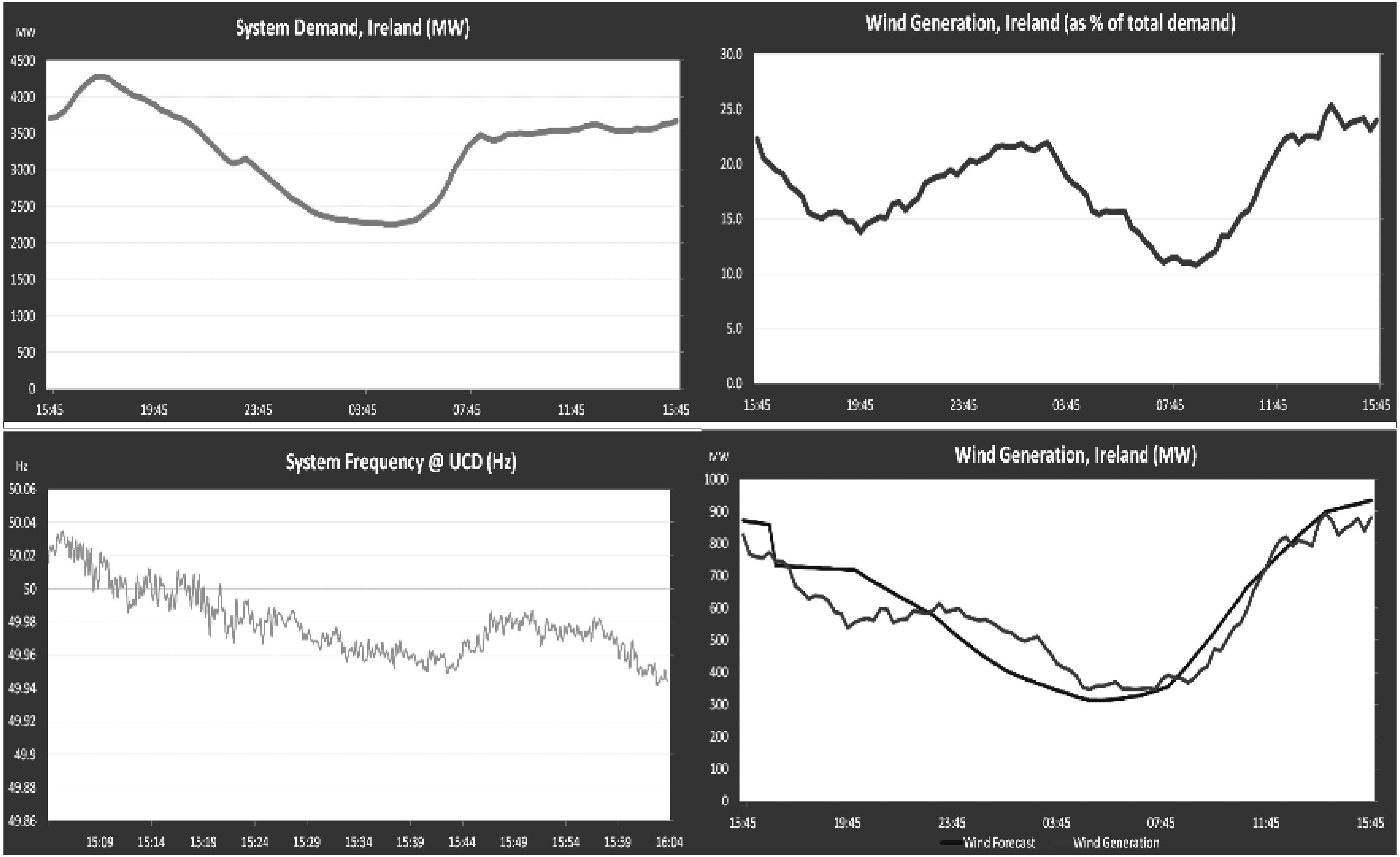
Wind Forecast – 85% Confidence



ERC Real-Time Display



ERC Real-Time Display



http://ercrt.ucd.ie

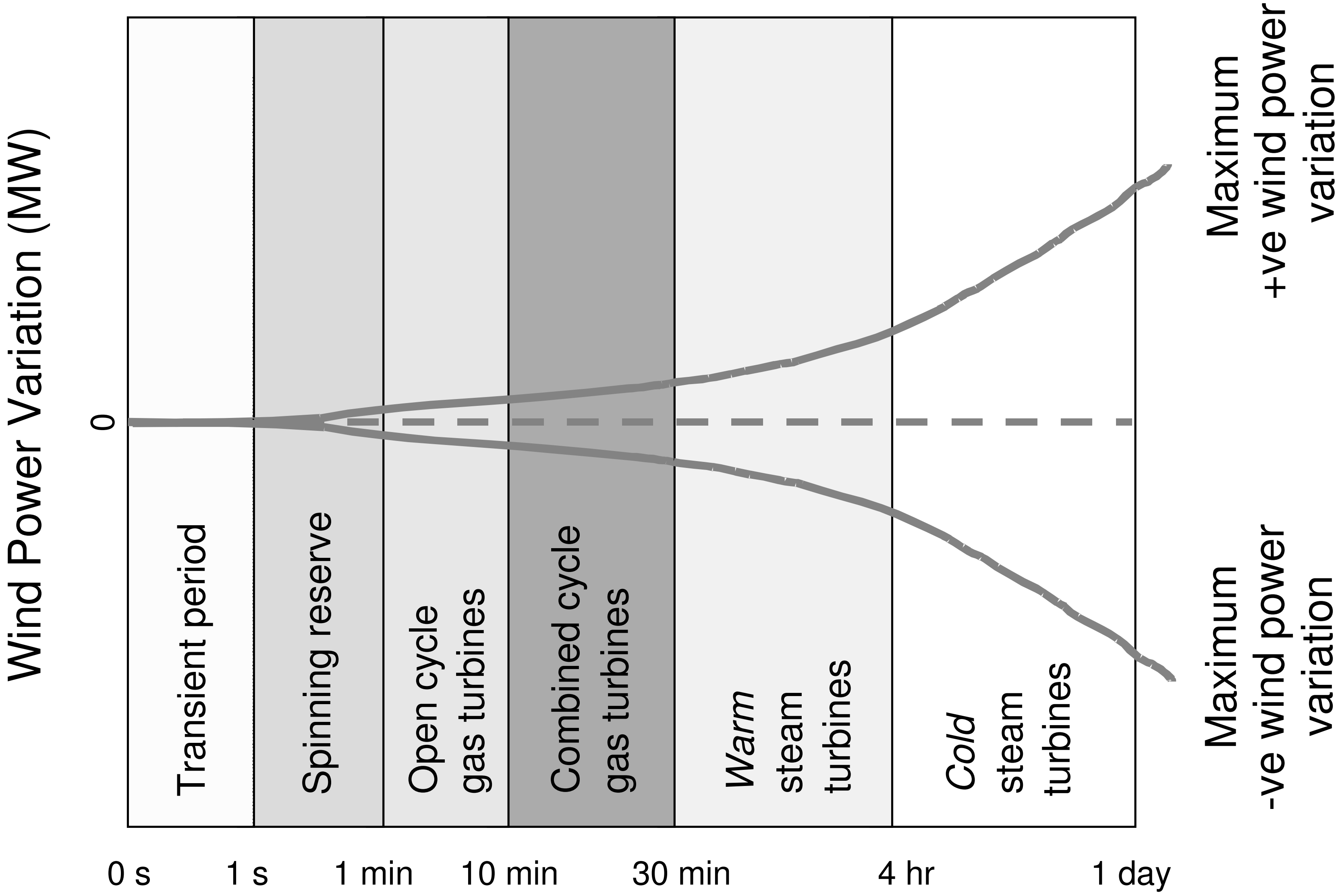
Wind Forecasting Operational Mode

- Imperative at *higher* wind penetration levels
- Unit commitment based on *net* demand forecast

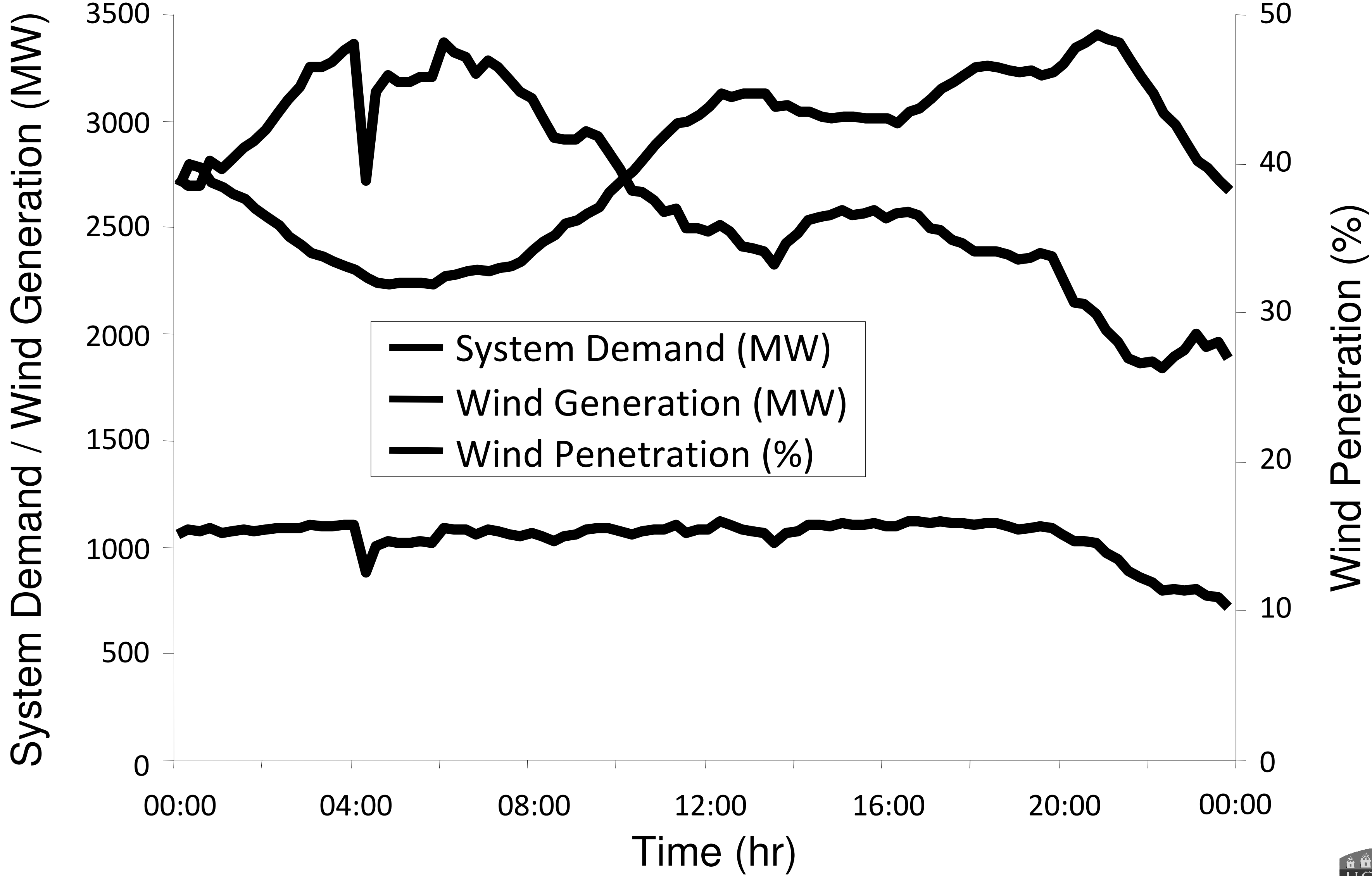
  = predicted demand – predicted wind
- Magnitude of wind forecasting errors?
- Capabilities of conventional generation
  - Minimum load, maximum ramp rates, startup times, etc.
- Small, flexible generation favoured

- High/ low contingency plans pre-defined
- Feedback of operational (+ meteorological) conditions from individual wind farms

Operational Timeframes



Ireland – 5th April 2010



EirGrid plc

Future Options

- *Smart* electricity metering
  - Demand side management
  - Time of day pricing, real-time pricing
- High voltage dc (HVDC) interconnection
- Electric vehicles
  - Plug-in hybrid / pure electric vehicles
- Energy storage
  - Compressed air energy storage, flow batteries, pumped hydro, flywheels, etc.
- Wind generation flexibility

Electricity Markets

Electricity Market Models

- The electrical industry has a product that is made at particular locations and is transported to customers who have contracted to purchase that product at a given price
- Normally, a market is established so that purchasers can shop around for the product that best suits them
- An infrastructure exists whereby intermediaries buy and resell commodities and arrange for delivery to multiple locations
- In the electricity industry there is a single product and at every instant production must equal demand

Electricity Market Models

- Until the early 1980s, almost every utility believed that generation, transmission and in many cases distribution of energy should operate as an integrated monopoly
- In many countries, the commercial and economic benefits of alternative structures has led to an unbundling of electrical utilities

- The objective is to deliver cheaper electricity *via* market forces

Monopoly / Purchasing Agency

- Model 1 – monopolistic or vertically integrated
  - Generation, transmission, distribution and consumer supply provided by a single utility
  - Governmental control is vital to ensure fair pricing

- Model 2 – purchasing agency
  - A single buyer purchases energy from competing electricity generators
  - The buyer arranges for delivery over monopoly transmission and distribution systems and sells at advertised tariffs to all consumers

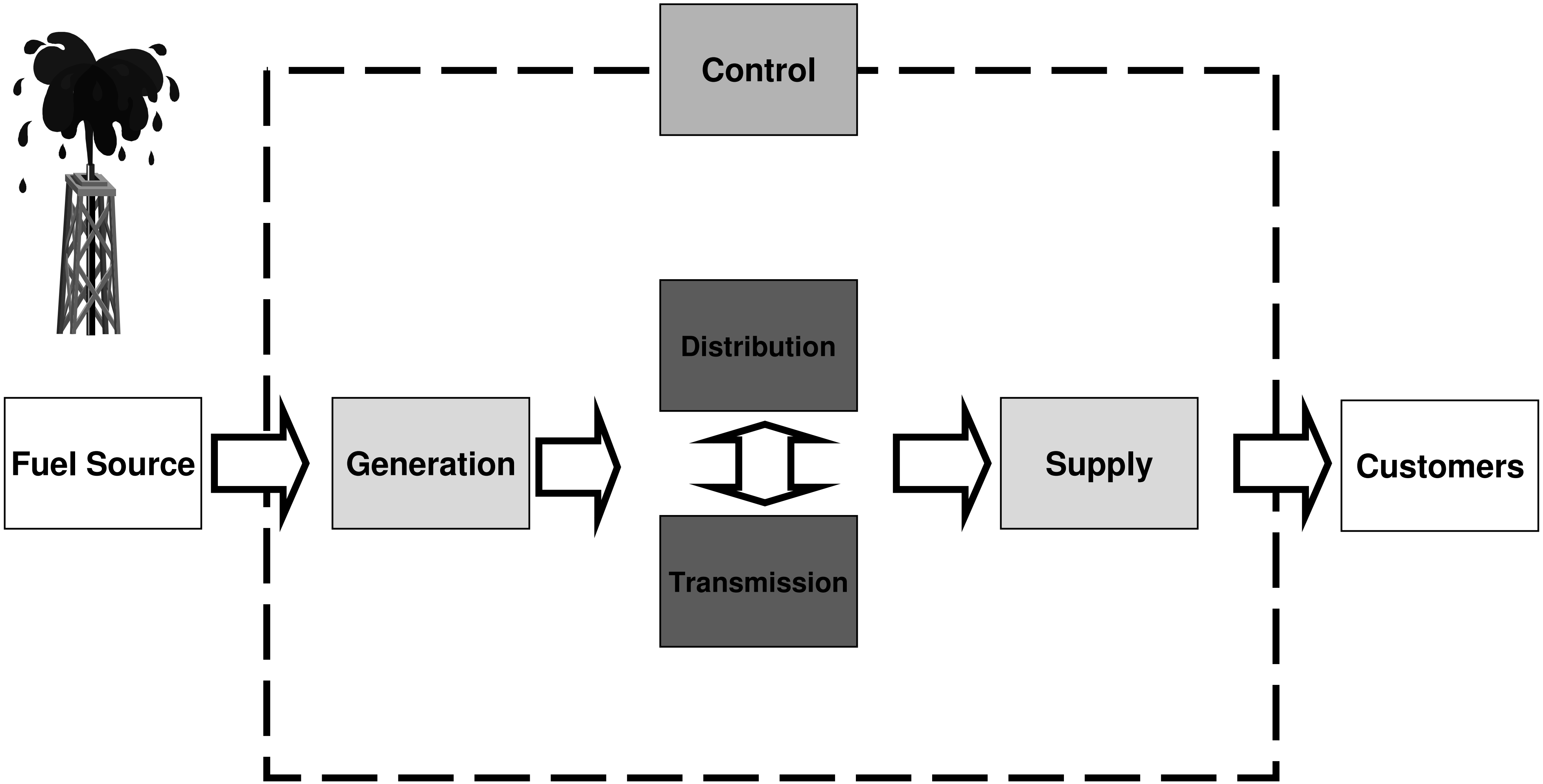
Wholesale / Retail Competition

- Model 3 – wholesale competition
  - Distribution companies buy from generators and deliver to supply points over open access transmission networks
  - Distribution companies have monopoly over customer supply
- Model 4 – retail competition
  - Consumers can choose their supplier and pay for delivery over open access transmission and distribution networks
  - A regulator sets monopoly transmission and distribution charges, unless alternative delivery networks are built
  - Regulator must ensure that a market structure exists for consumers to exercise choice of supplier

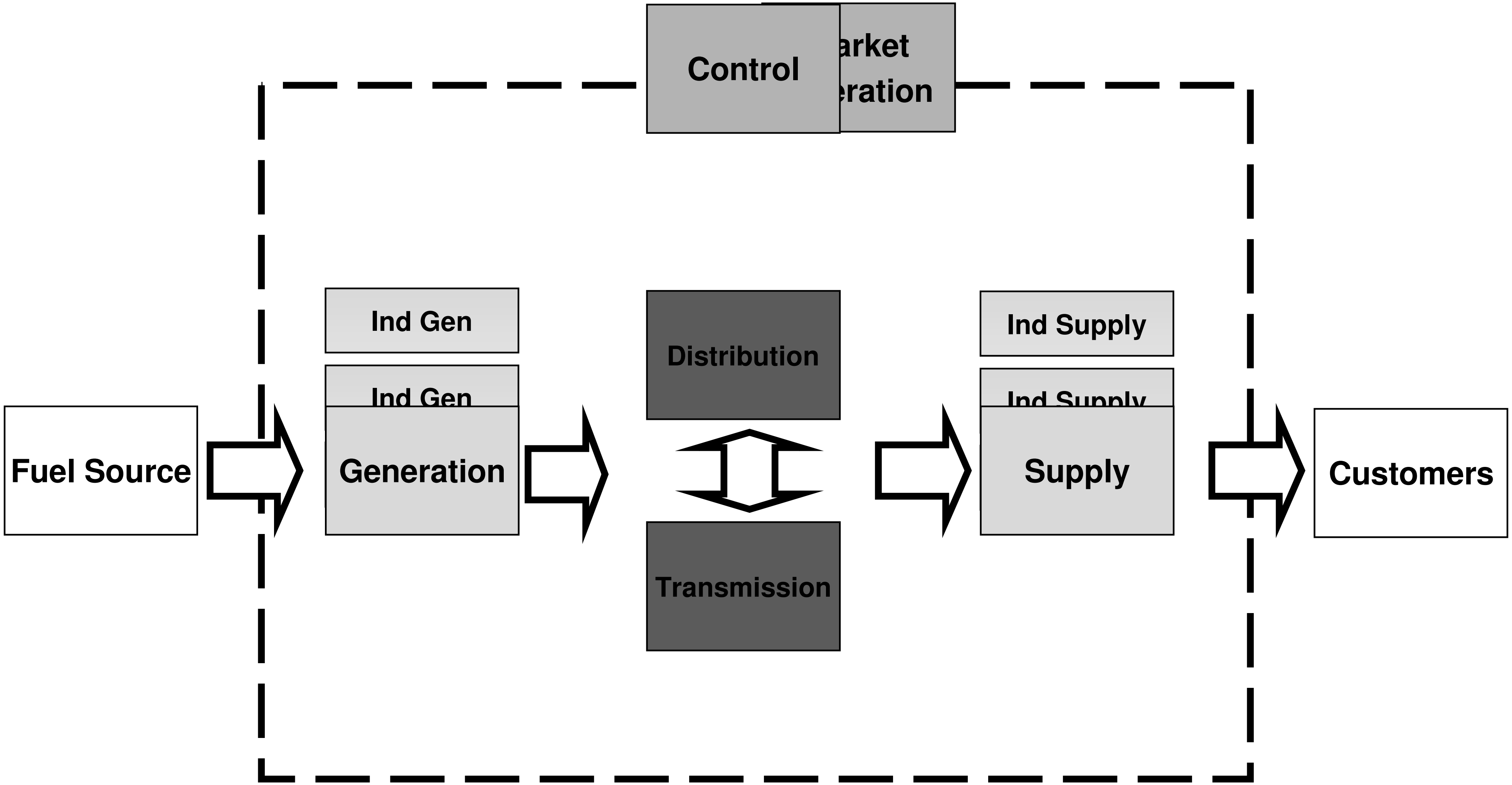
Electricity Market Models

	Model 1 Monopoly	**Model 2** Purchasing Agency	**Model 3** Wholesale Competition	**Model 4** Retail Competition
Generators compete?	✗	✓	✓	✓
Choice for retailers?	✗	✗	✓	✓
Choice for customers?	✗	✗	✗	✓

Monopoly Structure

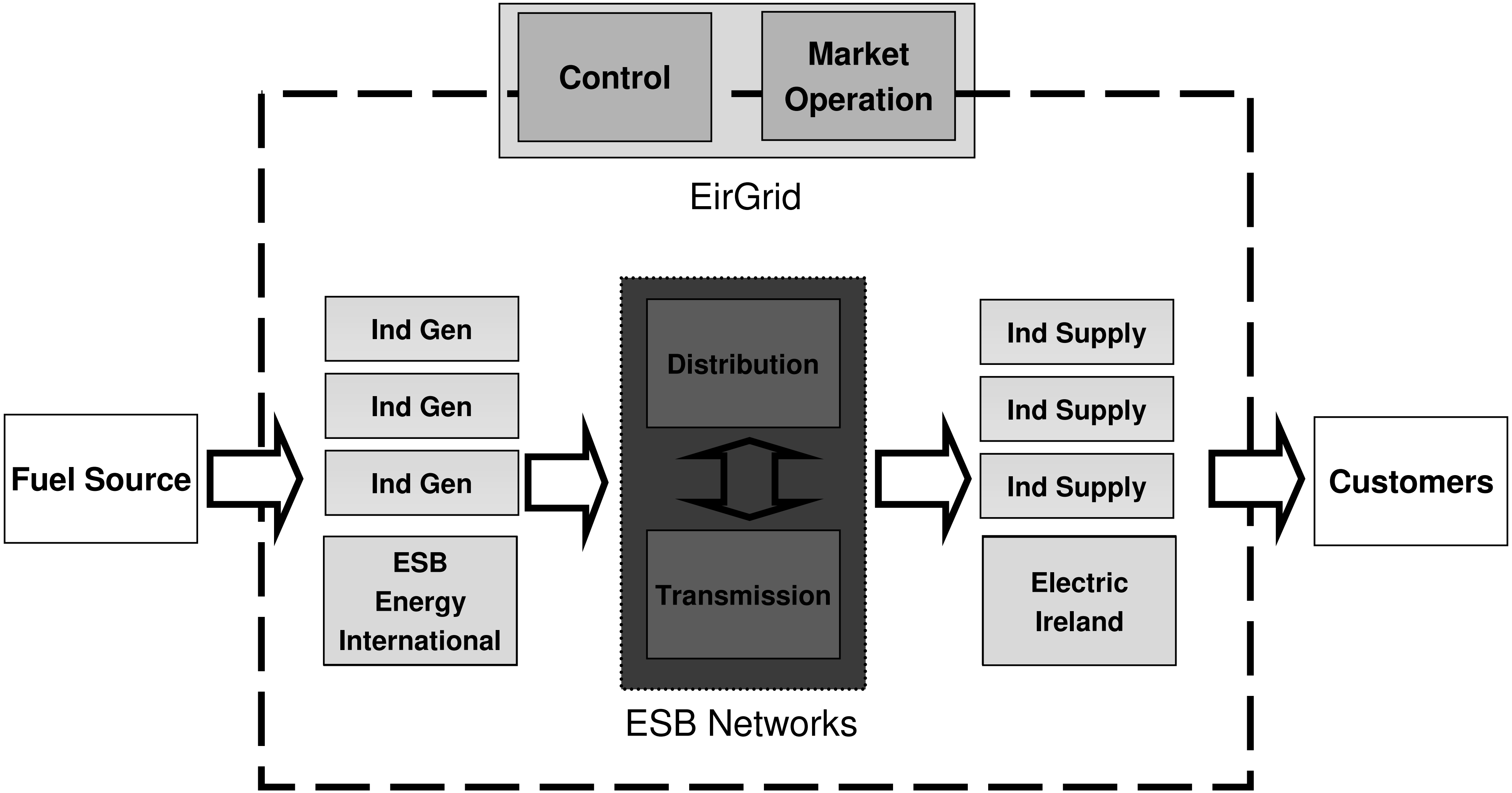


Market Structure after De-Regulation



Ind Gen ≡ Independent Generator
Ind Supply ≡ Independent Supplier

Republic of Ireland Structure



Single Electricity Market (SEM)

- SEM is the wholesale electricity market operating in the Republic of Ireland and Northern Ireland
  - The SEM provides for a competitive, sustainable and reliable wholesale market in electricity
  - Aimed to deliver long-term economic and social benefits through increased competition, reduced energy costs and improved reliability of supply
- The Single Electricity Market Operator (SEMO) facilitates the continuous operation and administration of the SEM
  - A joint venture between EirGrid plc and SONI Limited
- It is a gross mandatory pool physical market operating with dual currencies and multiple jurisdictions

Gross Pool Operation

- Market participants bid into the pool (generators, demand)
- All energy sold to and all energy bought from the pool
- The SEMO selects the most economic units to run to meet expected demand the following day
- Market characteristics
  - 24 hour gate closure, 30 minute scheduling interval
  - Single market price for everyone (per trading period)
  - Separate capacity payments (capacity market)
  - Additional uplift payments (no-load and start up costs)
  - Ex-post pricing
  - No reserve market

Example

How should a 4 unit power system best supply a load demand increasing over 1 hour from 260 MW to 270 MW?

Unit	**Loading Range** (MW)	**No-Load Cost** (€ /hr)	**Incremental Cost** (€/MWhr)
1	20 – 100	1400	8
2	40 – 125	1000	10
3	30 – 120	800	15
4	20 – 80	400	21

Least Cost (*Engineering*) Approach

Meeting a demand level of 260 MW …

1101	100 / 125 / 0 / 35	$1400 + 100 \times 8 +$ $1000 + 125 \times 10 +$ $400 + 35 \times 21$	€ 5585

Each generator is paid based on their *actual* costs

Unit 1 (€2200 = $1400 + 100 \times 8$)

Unit 2 (€2250 = $1000 + 125 \times 10$)

Unit 3 (€0)

Unit 4 (€1135 = $400 + 35 \times 21$)

No incentive for generators to reduce costs or be more efficient

Market Based Approach

Each generator submits a price bid (€/MWhr)

- A generator may *bundle* some no-load costs into price bid

Market price set by most expensive online generator (€/MWhr), with all generators paid the same price

Cost of meeting last MWh demand

Unit 1 (€2100 = 100 × 21)

Unit 2 (€2625 = 125 × 21)

Unit 3 (€0 = 0 × 21)

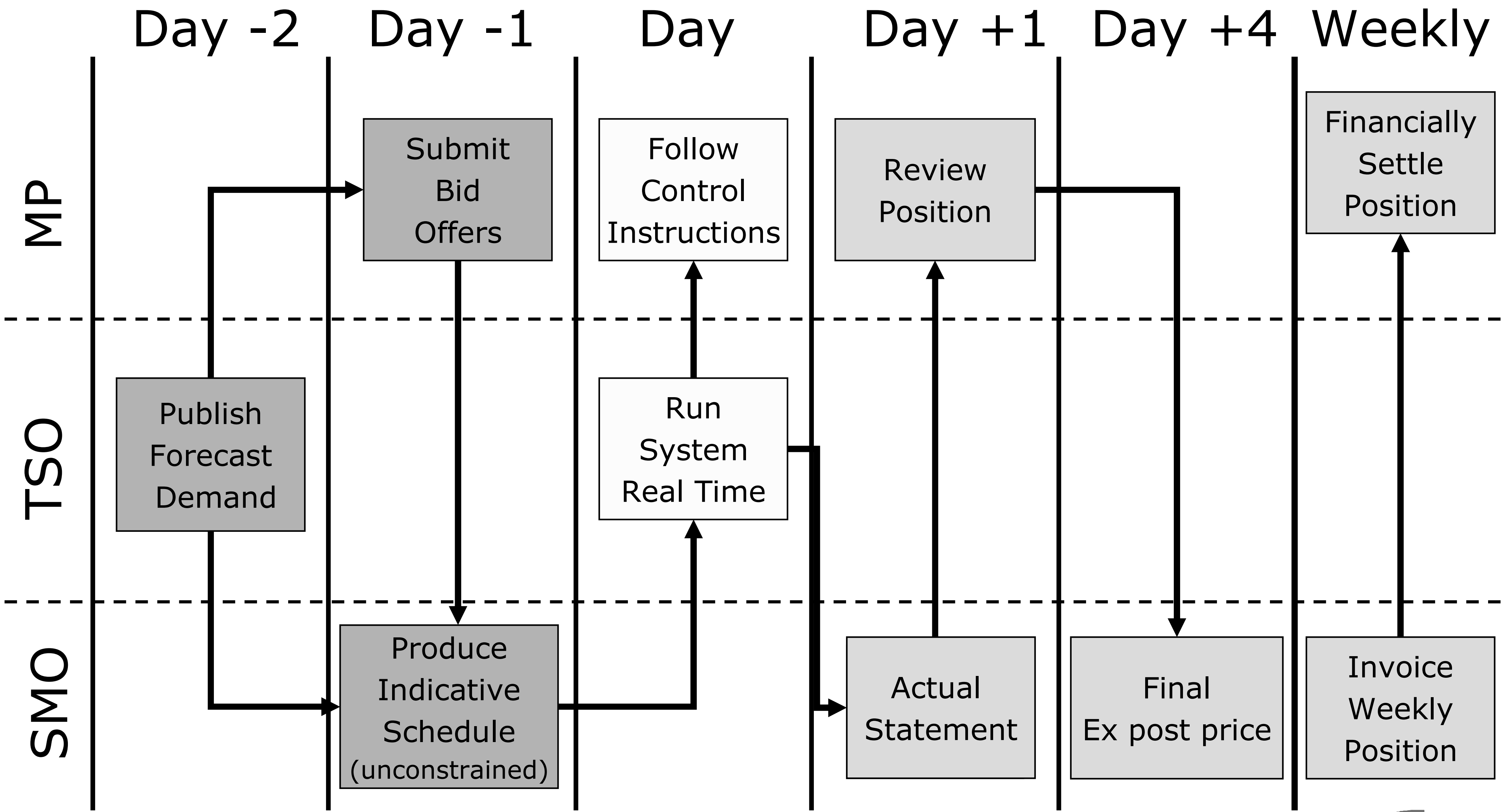
Unit 4 (€735 = 35 x 21)

No-load costs are not included (uplift payments made separately)

Incentive for generators to be more efficient … reduce price bid … be selected to generate more often … increased profit

Increased market competition … lower consumer electricity price

SEM Operation



Electricity Market Design Life Cycle