Viability of the Business Model of Demand Response Aggregator:

Spot Energy Market Based Revenues for an Aggregator under Uncertainty and Contractual Limitation

Antoine VERRIER
Ph. D candidate
Chaire European Electricity Markets (CEEM)
Université Paris-Dauphine

CEEM Paris Dauphine Research Seminar

"The Issue of Consumer Participation in the Electricity Markets via Platform Market and Aggregators"

13th December 2016

DAUPHINE UNIVERSITÉ PARIS

engie Lab

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

What is the Economic potential of Demand Response in Electricity Markets ?

Introduction

- Economics of Demand Response

Economic assessment of Demand Response

- **Day-ahead energy market:**
  - **Economic dispatch under uncertainty**
- Demand Response representation:
  - **Storage model with customer-based constraints**

Case Study and Results

- DR aggregator annual profits
  - **French power system-based data in 2015**

Conclusions

Economic potential: three key points to consider

1) Competition with other technologies and the impact on market prices

DR marginal cost of activation
Investment cost in the enable infrastructure
Large-scale DR deployment will impact the price

2) Different markets to value Demand Response

Wholesale market designs are key to large-scale deployment of Demand Response

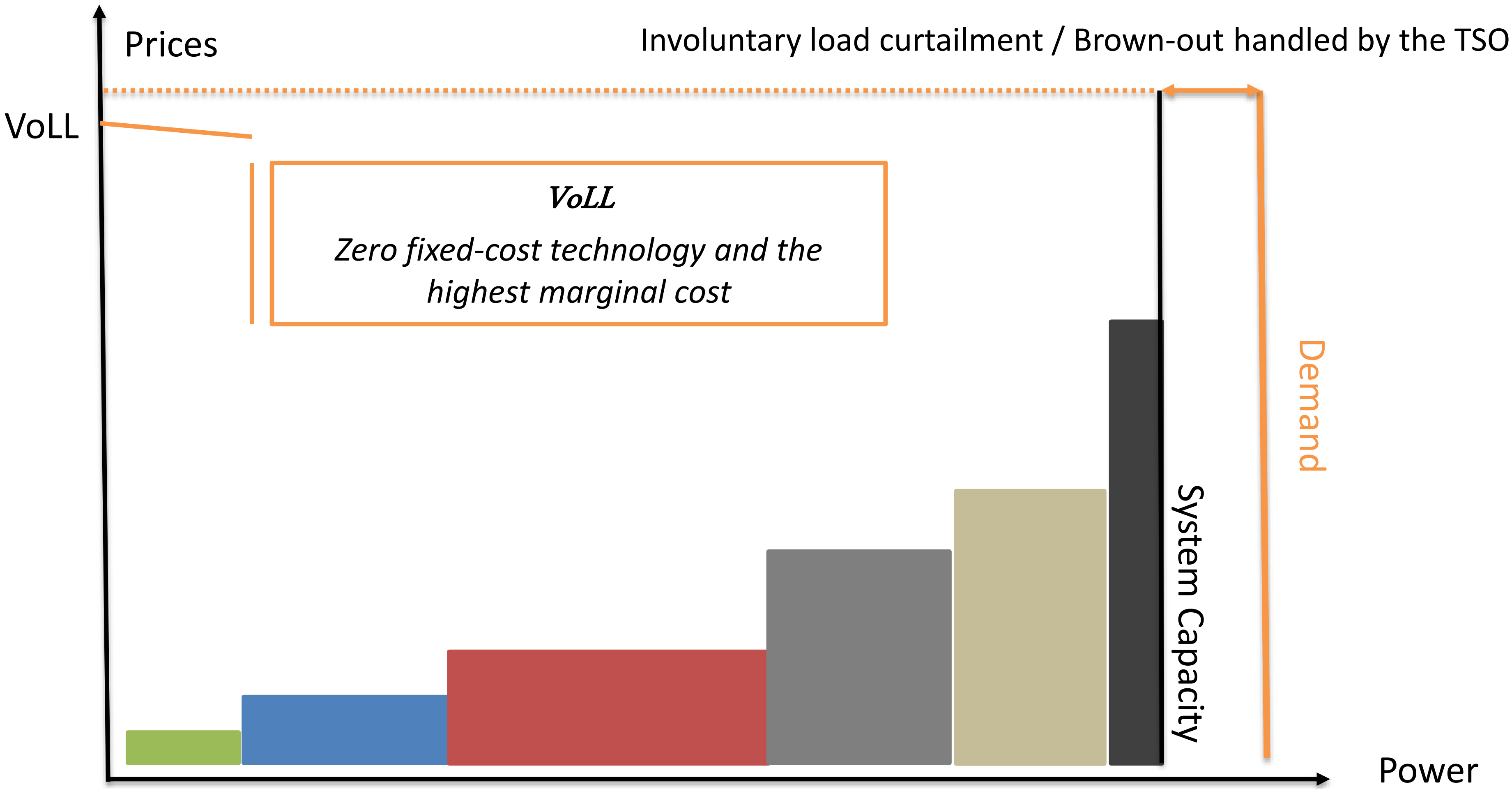
3) Role of Demand Response aggregators

Aggregators are enablers, both at wholesale and retail sides
They have to deal with contract-based constraints

Economics of Demand Response

Dynamics of competition in electricity markets regarding Demand Response

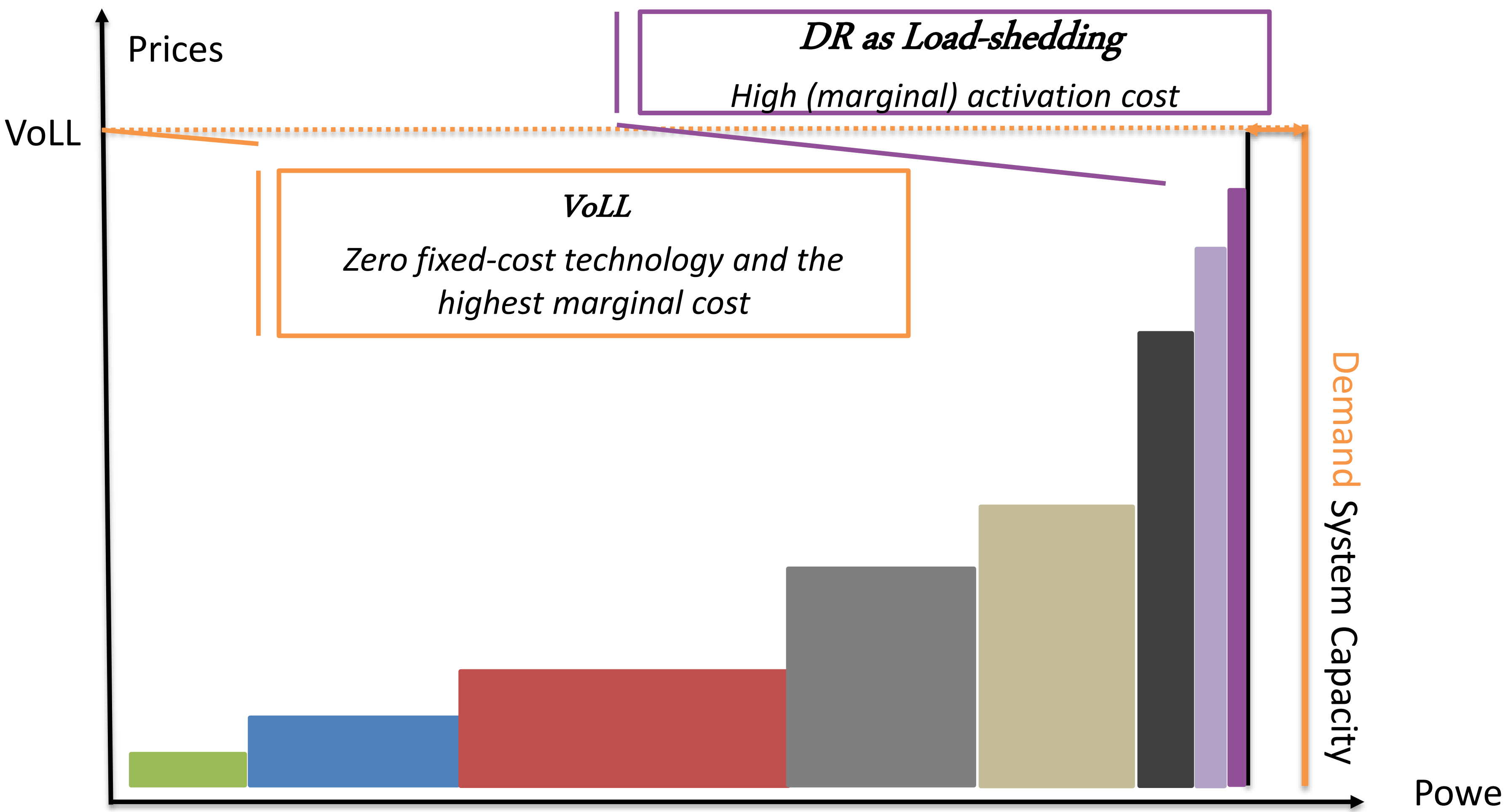
Involuntary load curtailment valued at VoLL are a rough way to clear the market by the demand-side



Economics of Demand Response

Dynamics of competition in electricity markets regarding Demand Response

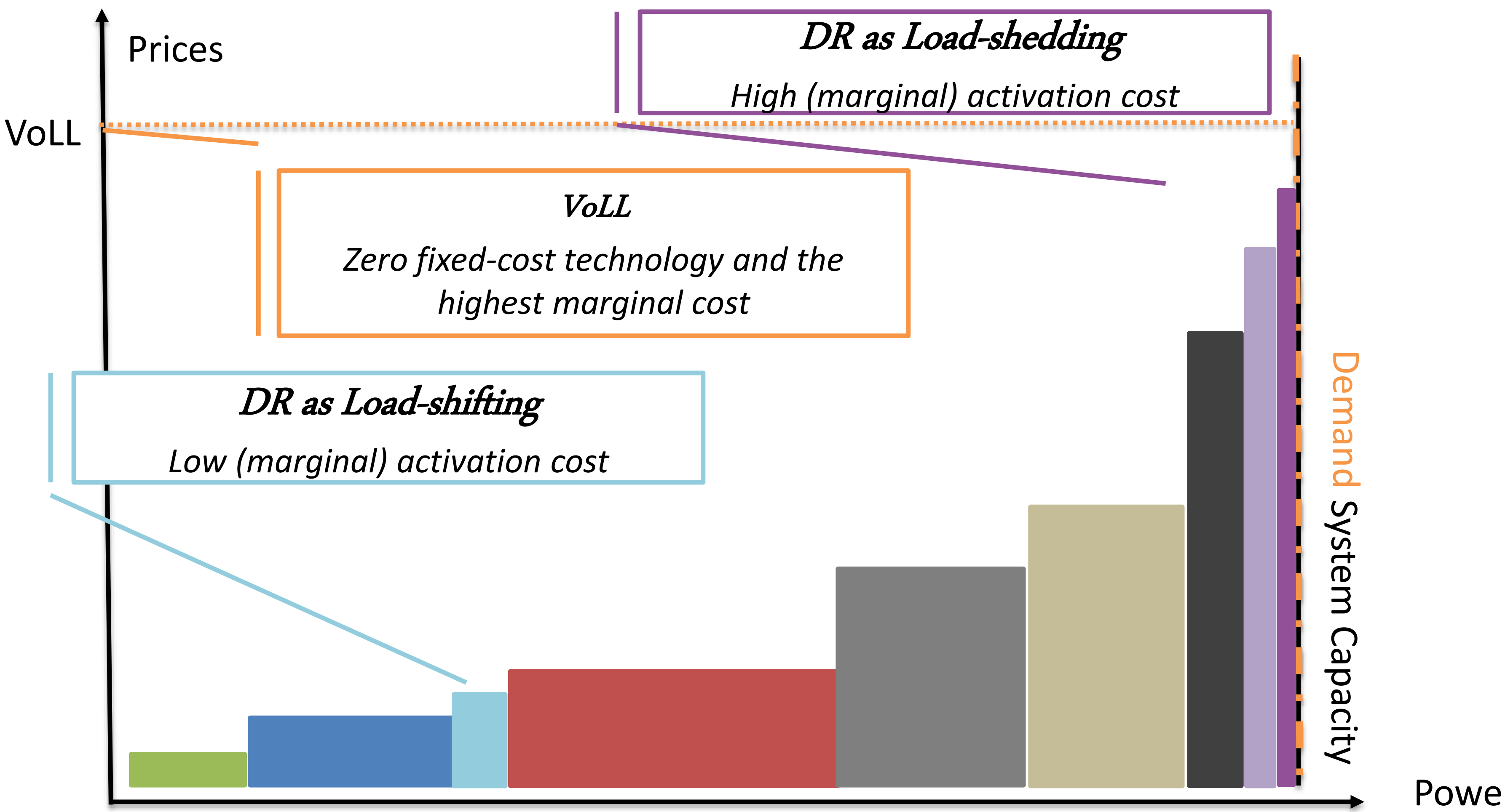
DR can reduce peak demand and take part of generation adequacy



Economics of Demand Response

Dynamics of competition in electricity markets regarding Demand Response

DR can also be activated at a lower marginal cost

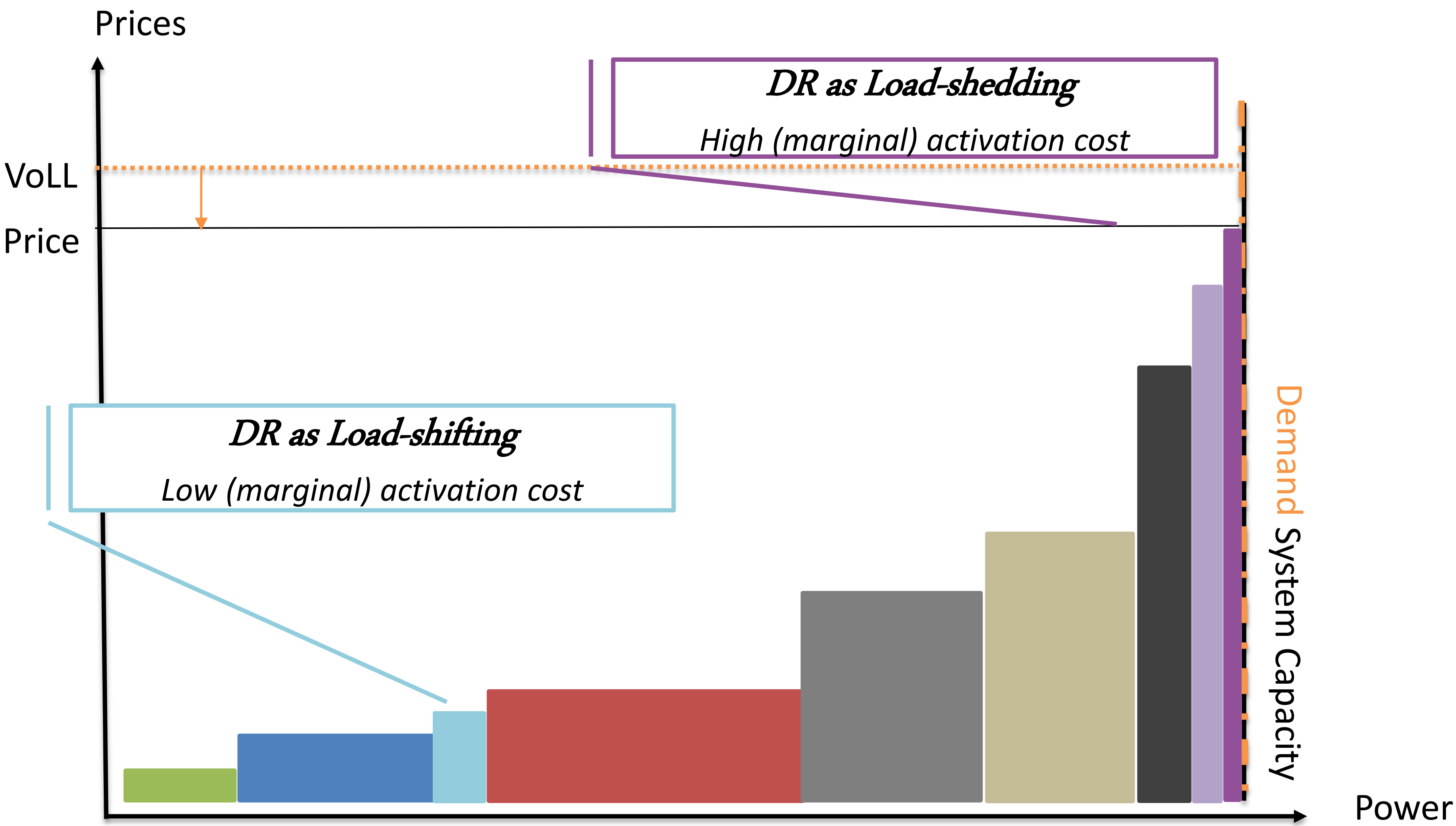


Economics of Demand Response

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

Dynamics of competition in electricity markets regarding Demand Response

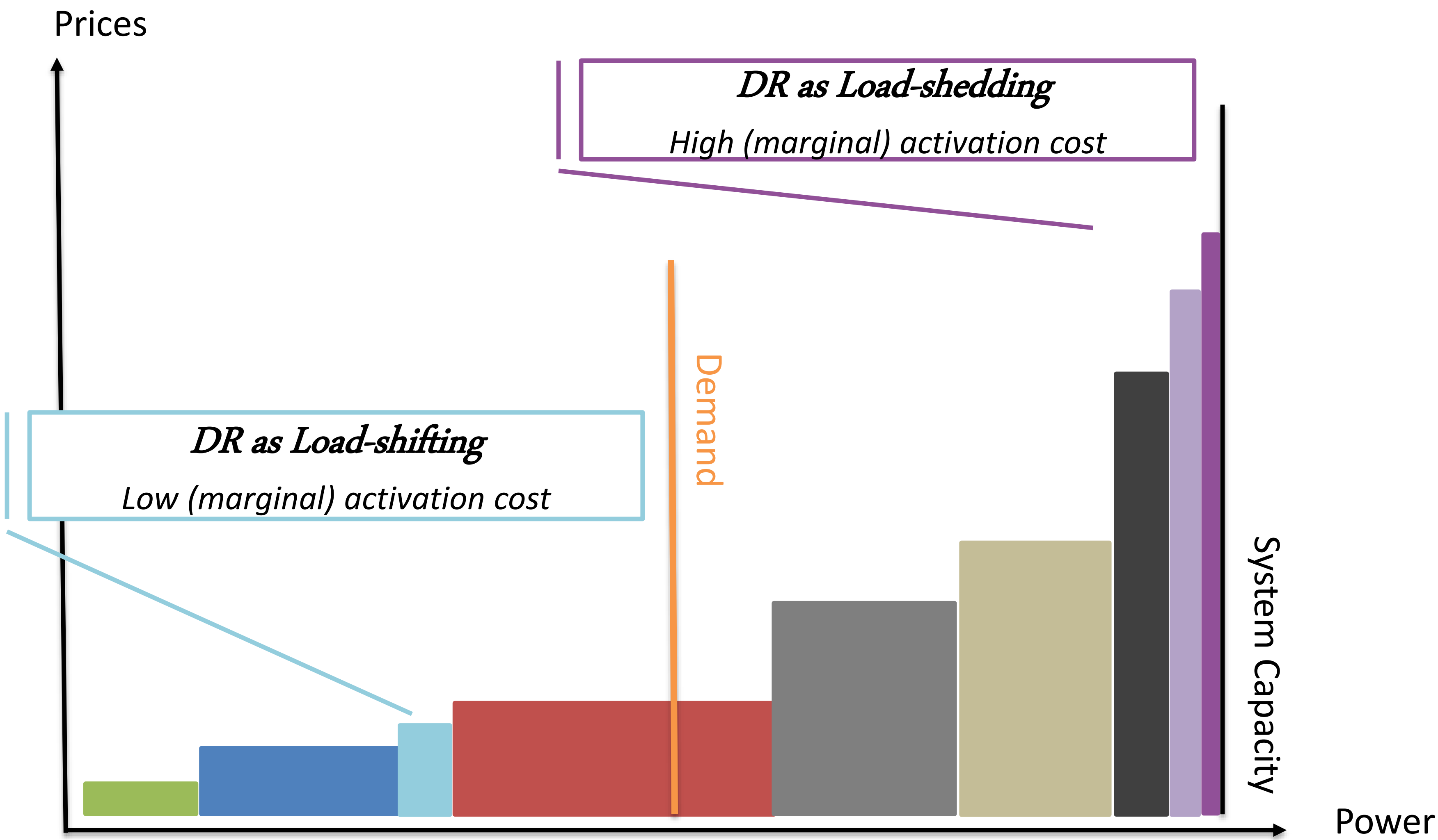
DR lowers market prices, especially during peak periods



Economics of Demand Response

Dynamics of competition in electricity markets regarding Demand Response

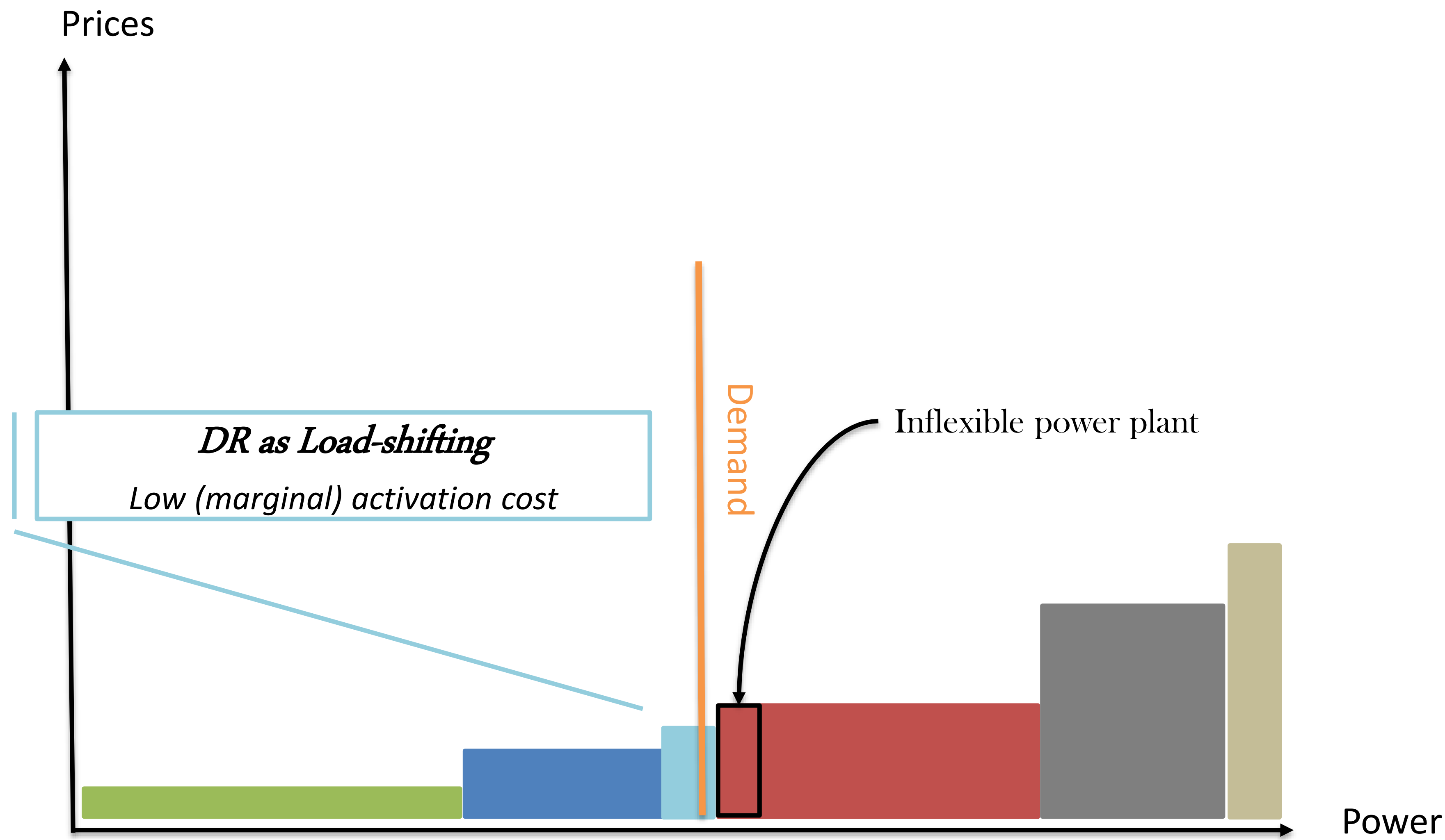
DR provides flexibility and enables the integration of Renewable Energies



CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

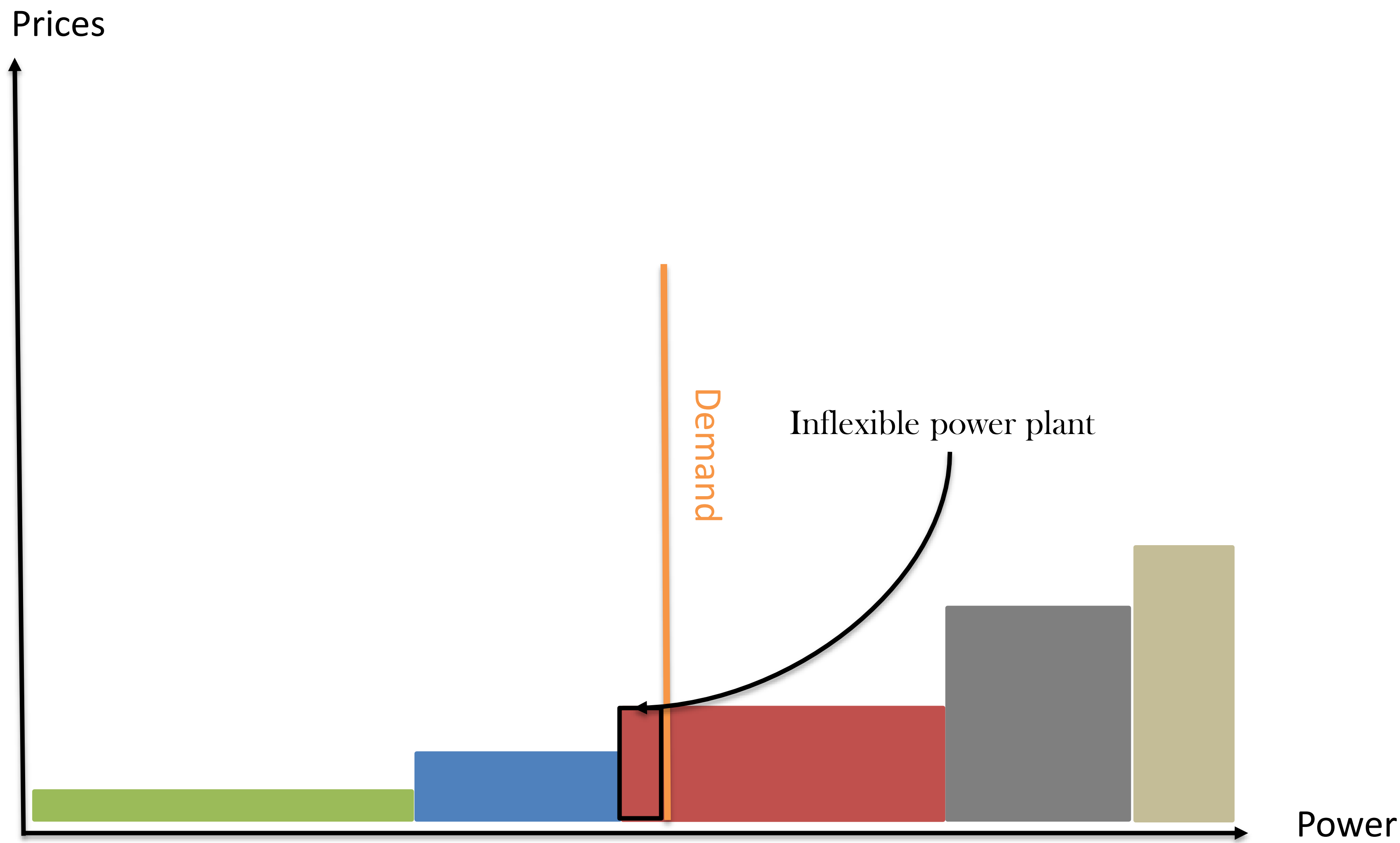
Dynamics of competition in electricity markets regarding Demand Response

DR provides flexibility and enables the integration of Renewable Energies



Dynamics of competition in electricity markets regarding Demand Response

DR provides flexibility and enables the integration of Renewable Energies

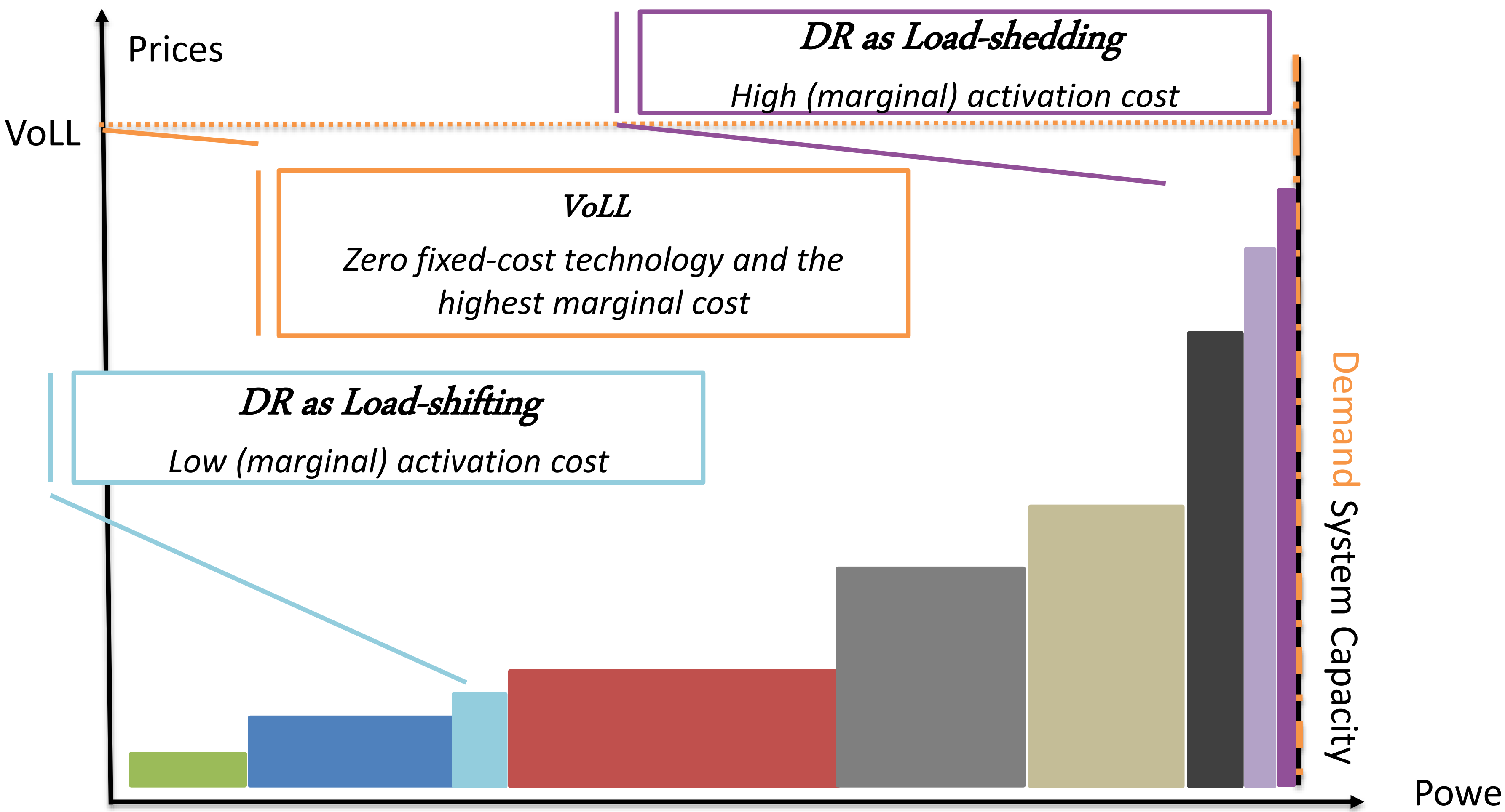


Economics of Demand Response

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

Dynamics of competition in electricity markets regarding Demand Response

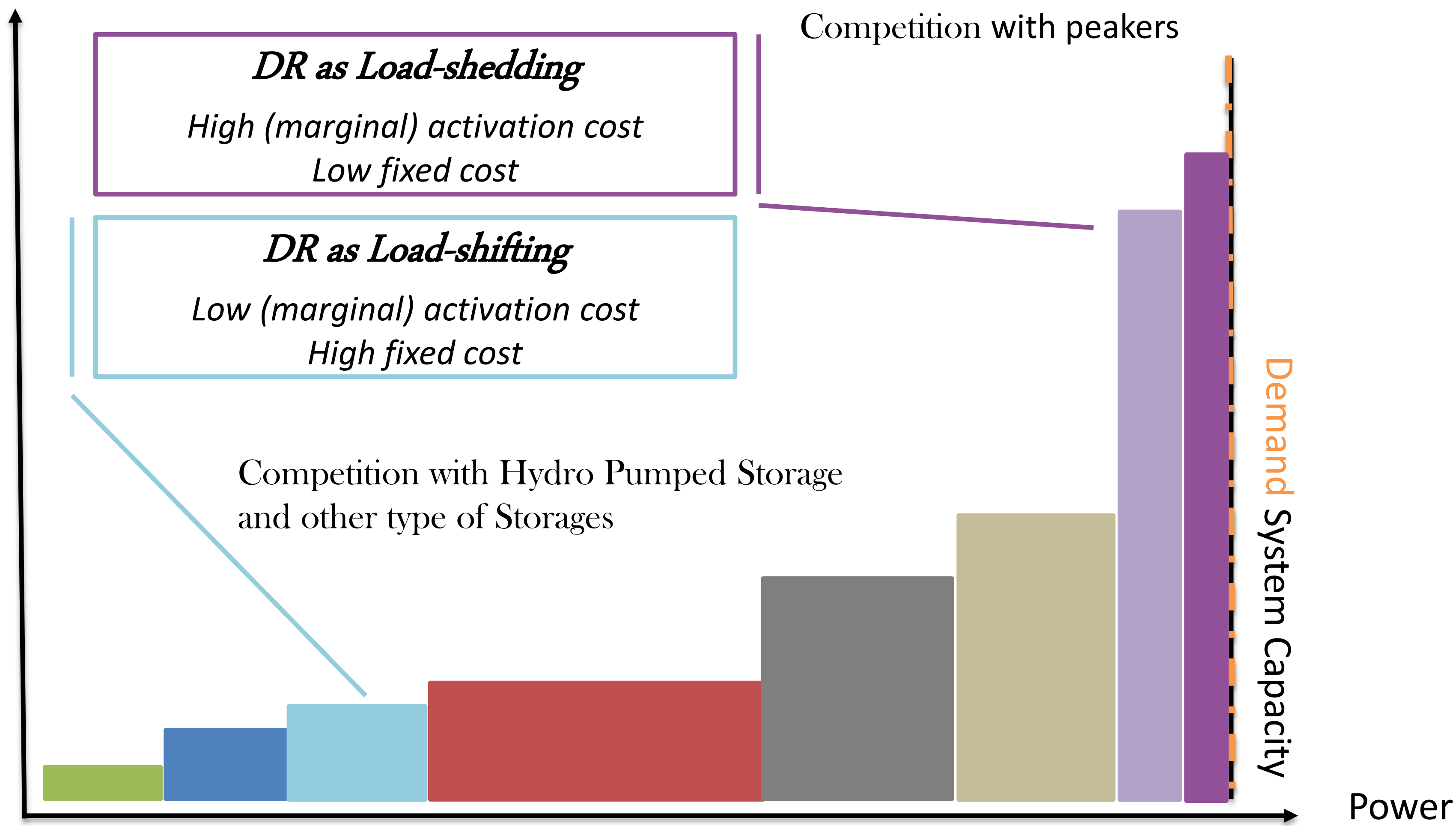
The long-run effect



Economics of Demand Response

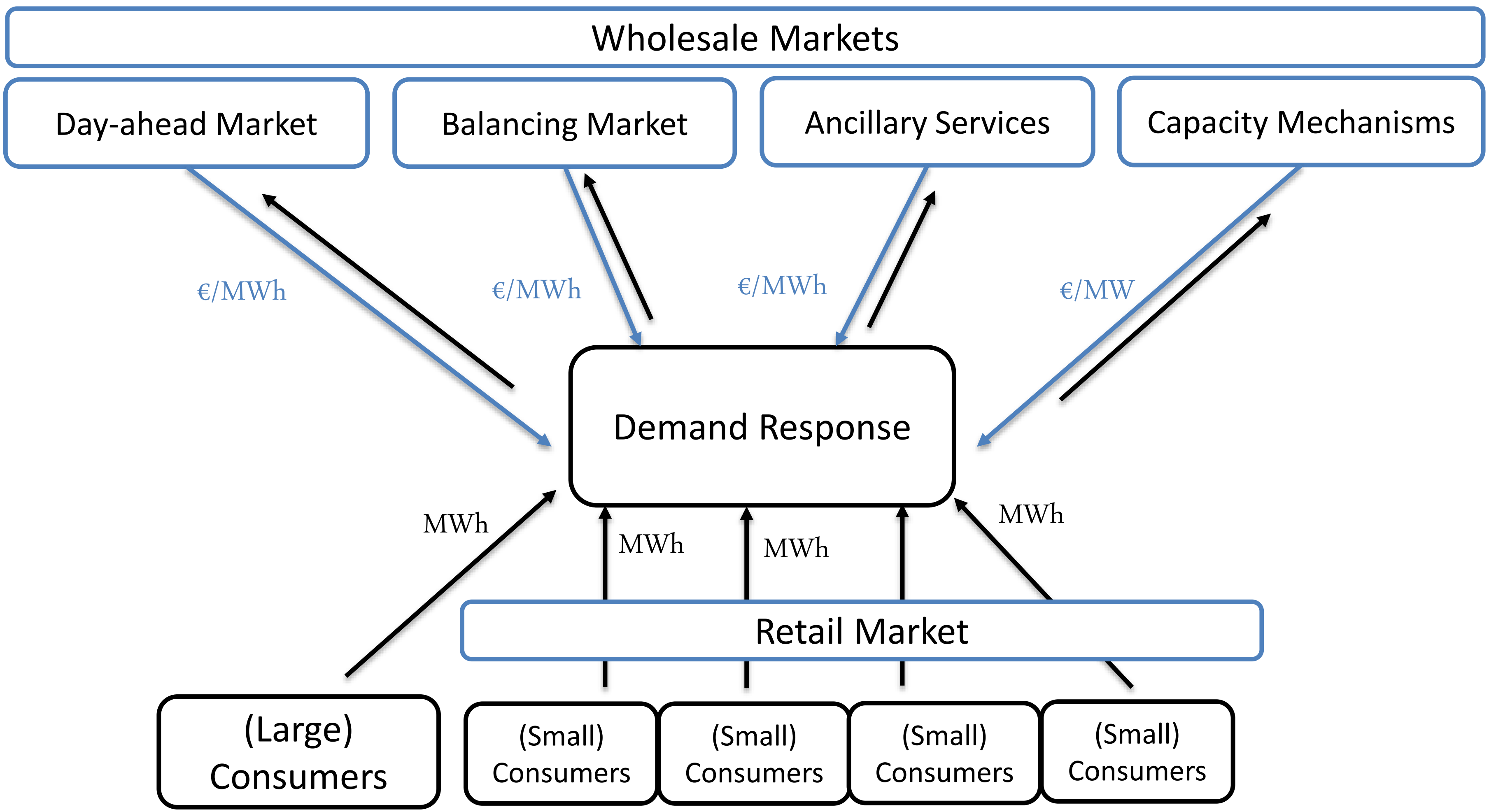
Dynamics of competition in electricity markets regarding Demand Response

The long-run effect



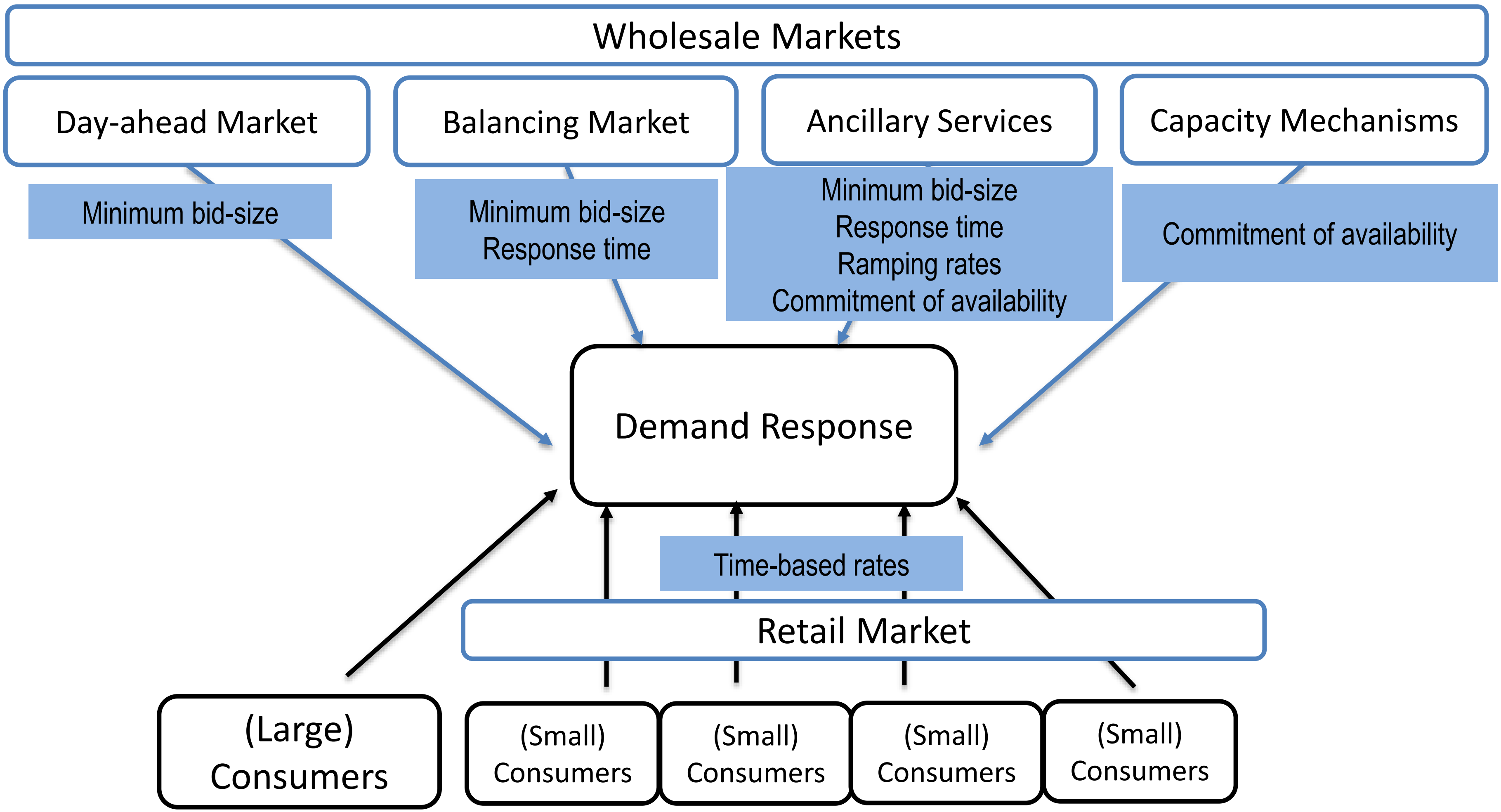
Economics of Demand Response

Demand Response Market Valuation – DR can be valued in at least 4 wholesale markets



Economics of Demand Response

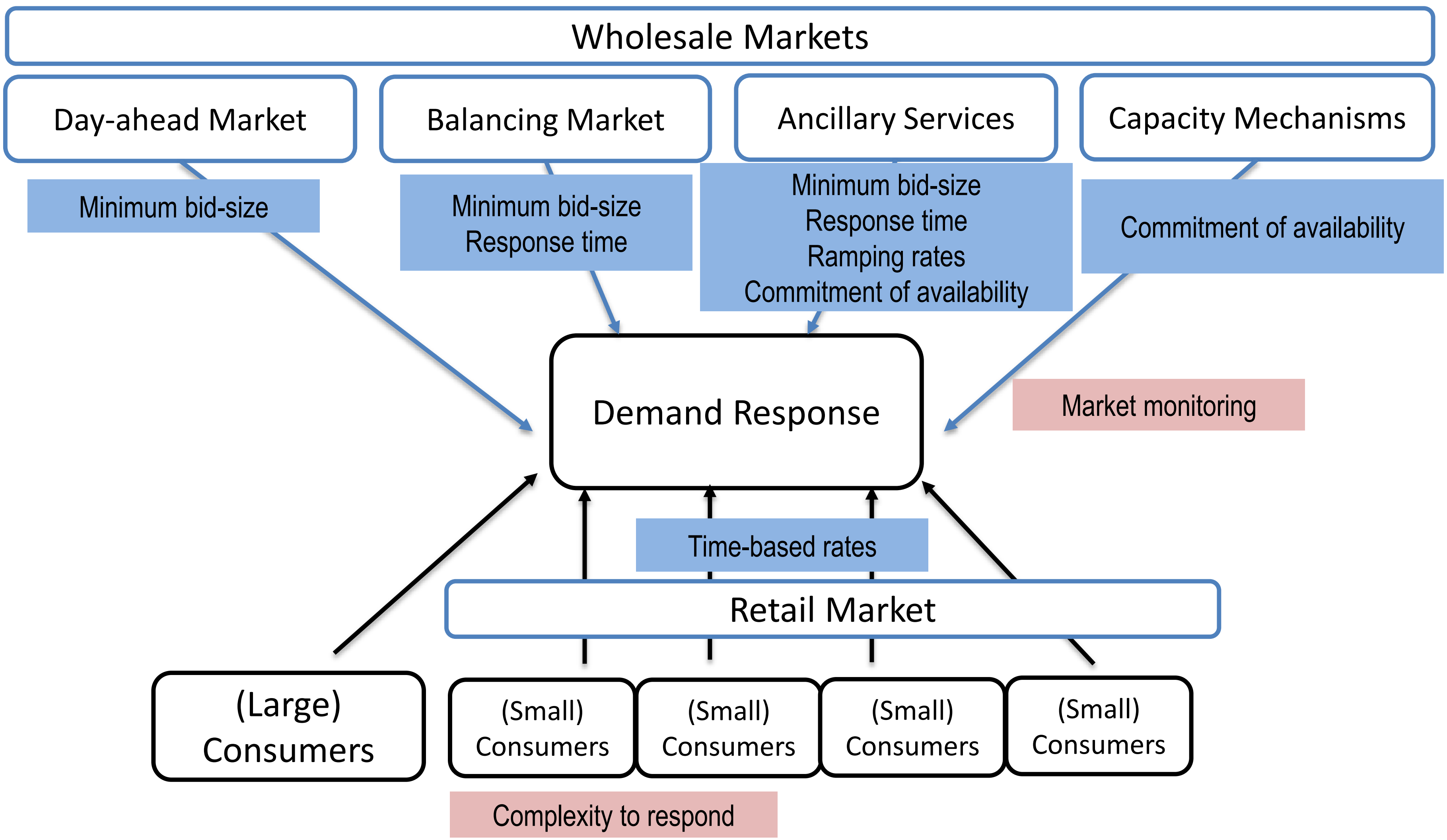
Demand Response Market Valuation – Market design impedes DR to participate in wholesale markets; retail market design might not incentivize DR



Economics of Demand Response

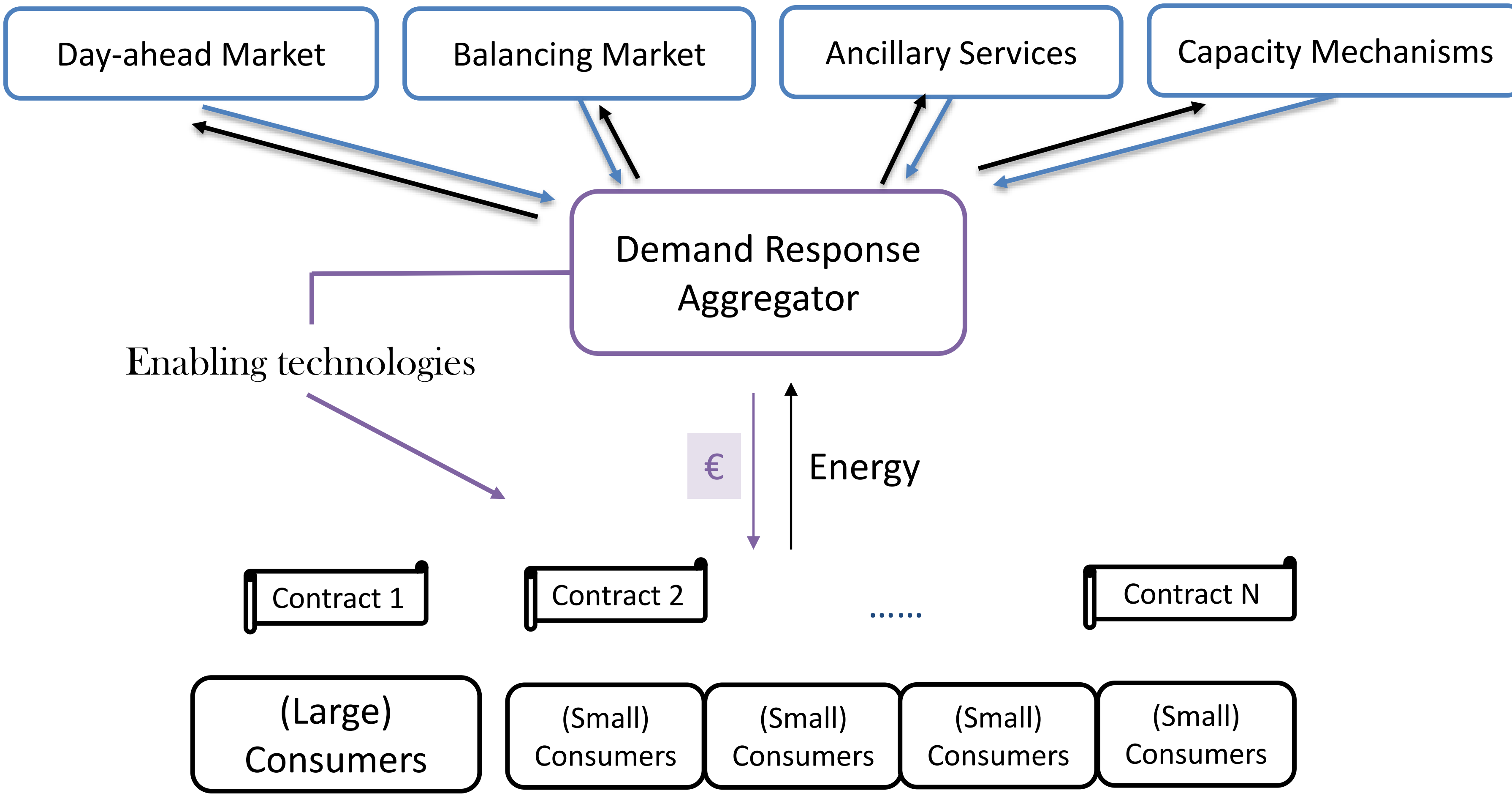
CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

Demand Response Market Valuation – Consumers' constraints can hinder DR to participate in wholesale markets



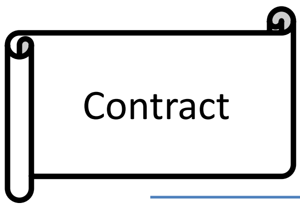
Economics of Demand Response

The role of Demand Response aggregators – DR aggregators are enablers removing the barriers by contracting with consumers and make the link with wholesale markets



Economics of Demand Response

The role of Demand Response aggregators – The contract terms should reflect consumers' willingness to participate in the DR program



Contract terms	Description	Unit
Capacity	Max. amount of curtailable power	MW
Cost of activation	Compensation the consumer gets	€/MWh
Duration	Max. time the load capacity can be shed/shifted	h
Frequency	Max. number of events over a period	N/year
Notice time	Time before the event is actually triggered	h
Recovery time	Max. time energy has to be recovered	h

Economics of Demand Response

The role of Demand Response aggregators – Frequency constraint and Uncertainty together creates an Opportunity Cost of using DR

Contract

Contract terms	Description	Unit
Capacity	Max. amount of curtailable power	MW
Cost of activation	Compensation the consumer gets	€/MWh
Duration	Max. time the load capacity can be shed/shifted	h
Frequency	Max. number of events over a period	N/year
Notice time	Time before the event is actually triggered	h
Recovery time	Max. time energy has to be recovered	h

When will the aggregator use its DR resource on the wholesale markets ?

Market Uncertainty and Frequency => Opportunity Cost to use a DR resource

Outline

Introduction

- Dynamics of competition in electricity markets regarding DR
- The impact on market designs on DR valuation
- The role of Demand Response aggregators

Economic assessment of Demand Response

- **Day-ahead Energy market:**
  - **Economic dispatch under uncertainty**
- Demand Response representation:
  - **Storage model with customer-based constraints**

Case Study and Results

- DR aggregator annual profits
  - **French power system-based data in 2015**

Conclusions

Economic assessment of Demand Response

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

What is the Economic potential of Demand Response in Electricity Markets ?

The business case of a DR aggregator on the Day-ahead Market

Market-based revenues and compare those to the investment cost of enabling technologies

Contributions

1. Competition with other technologies
2. DR impact on the market price
3. Market uncertainty
4. Customer-based constraints specified in contracts

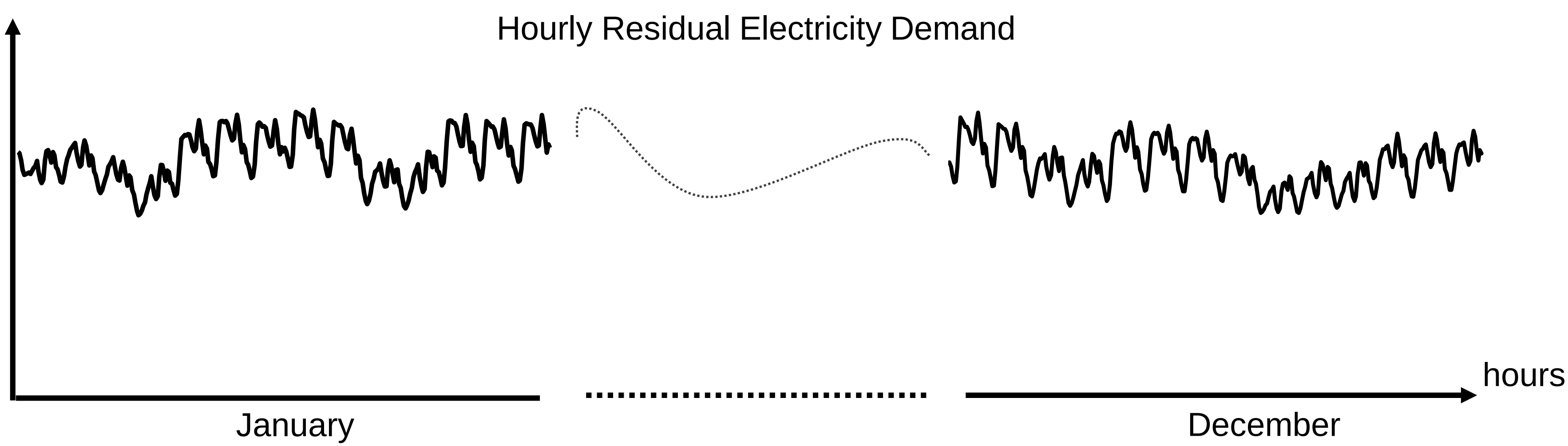
Day-ahead Energy Market model

An optimization-based economic dispatch model under uncertainty is used

- **Minimize the total operational cost of the system**
- **Exogenous electricity mix: no investments**
- **The dispatch is performed**
  - **Over one year**
  - **On a hourly basis**

Main Outcomes
Power generated by each technology
Market prices

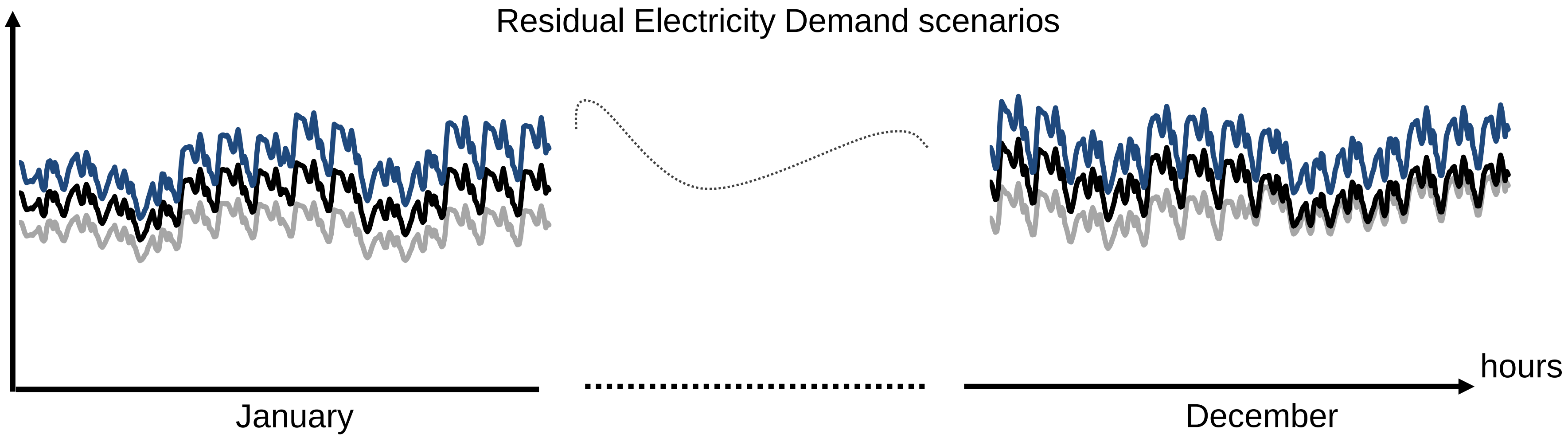
For the 8760 hours



Day-ahead Energy Market model

Focus on the Uncertainty
Residual Demand Scenarios

- **Uncertainty:**
  - **Electricity Demand and Renewable production**
- **Modelling:**
  - **20 Residual Demand Scenarios ; Weekly time steps**

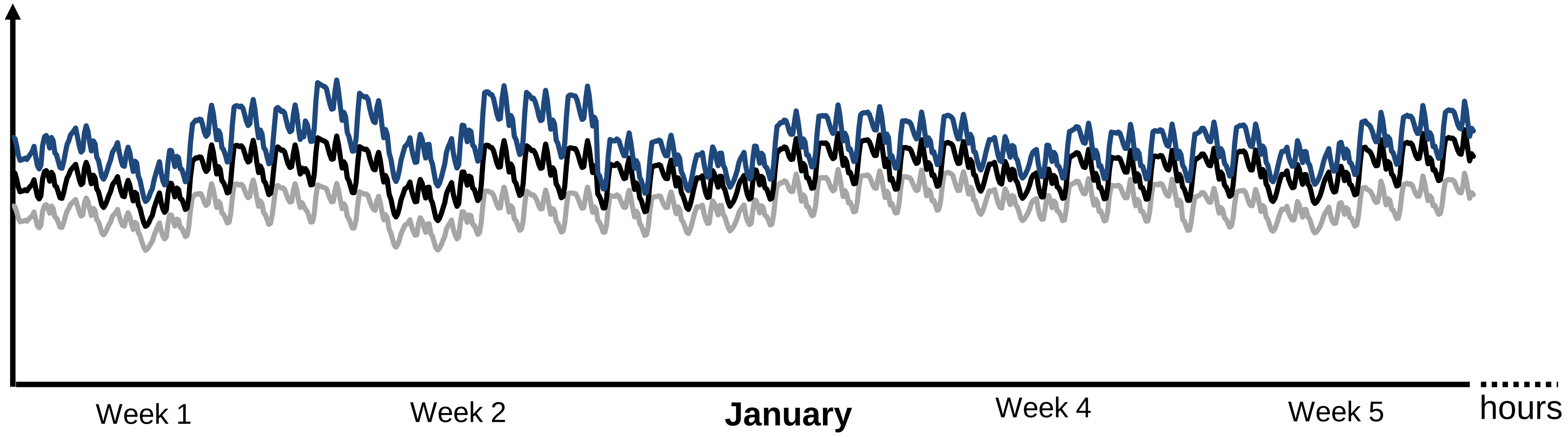


Day-ahead Energy Market model

Focus on the Uncertainty
When does the Uncertainty "hits" the system ?

- **Uncertainty:**
  - **Electricity Demand and Renewable production**
- **Modelling:**
  - **20 Residual Demand Scenarios ; Weekly time steps**

Residual Electricity Demand scenarios

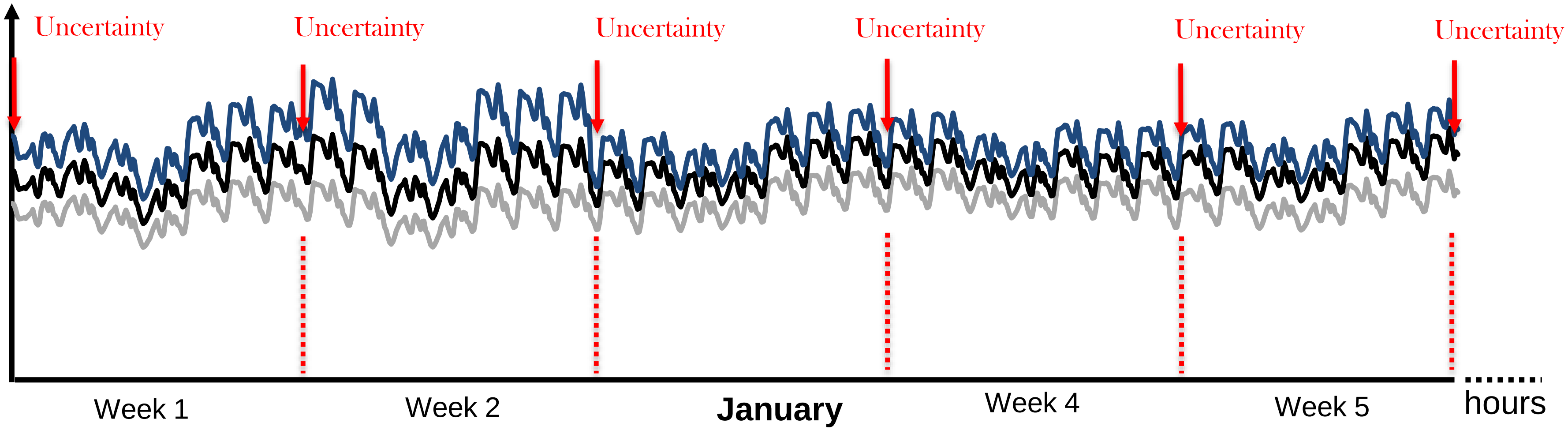


Day-ahead Energy Market model

Focus on the Uncertainty
When does the Uncertainty "hits" the system ?

- **Uncertainty:**
  - **Electricity Demand and Renewable production**
- **Modelling:**
  - **20 Residual Demand Scenarios ; Weekly time steps**

Residual Electricity Demand scenarios

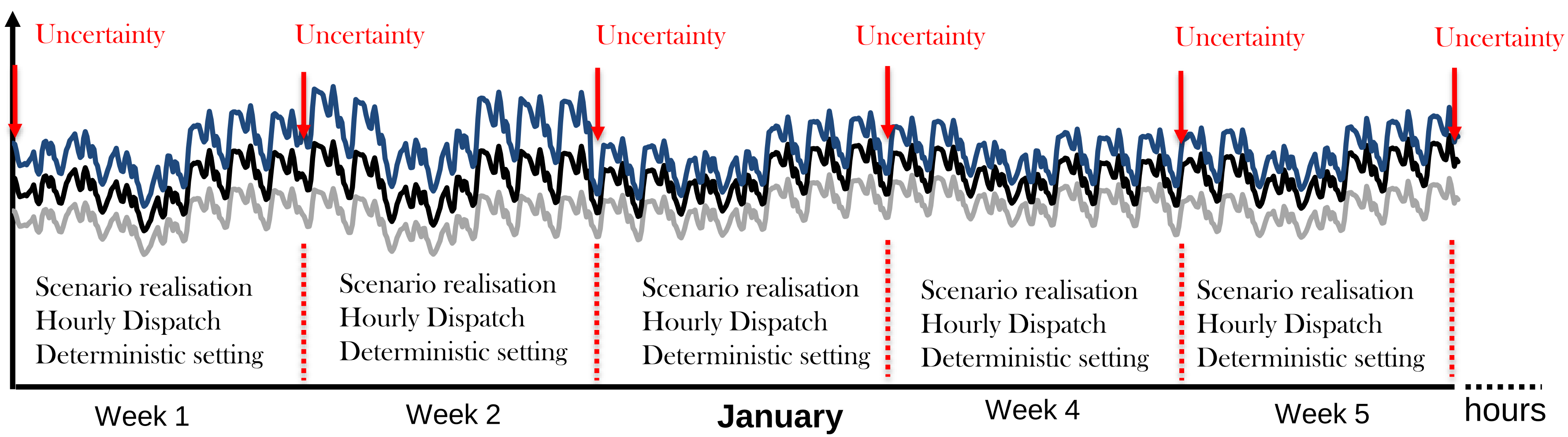


Day-ahead Energy Market model

Focus on the Uncertainty
When does the Uncertainty “hits” the system ?

– **Uncertainty:**
  - **Electricity Demand and Renewable production**
– **Modelling:**
  - **20 Residual Demand Scenarios ; Weekly time steps**

Residual Electricity Demand scenarios



Outline

Introduction

- Dynamics of competition in electricity markets regarding DR
- The impact on market designs on DR valuation
- The role of Demand Response aggregators

Economic assessment of Demand Response

- Day-ahead Energy market:
  - **Economic dispatch under uncertainty**
- **Demand Response representation:**
  - **Storage model with customer-based constraints**

Case Study and Results

- DR aggregator annual profits
  - **French power system-based data in 2015**

Conclusion

Demand Response: modelling approach

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

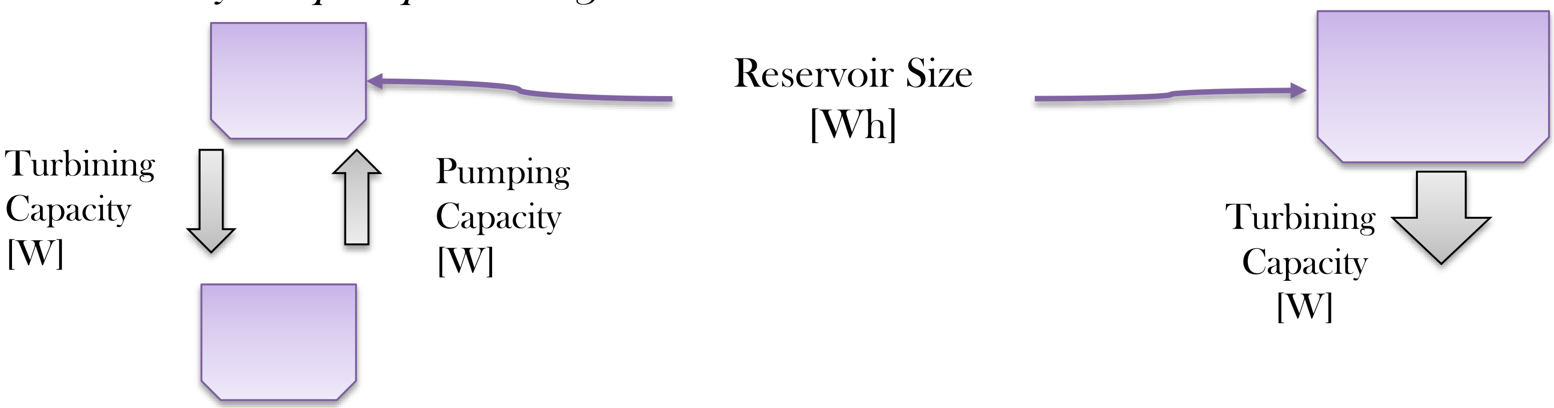
We use a storage representation for Demand Response
Contract terms define constraints for using DR

Contract

Contract terms	Description	Unit
Capacity	Max. amount of curtailable power	W
Cost of activation	Compensation the consumer gets	€/MWh
Duration	Max. time the load capacity can be shed/shifted	h
Frequency	Max. number of events over a period	N/year
Notice time	Time before the event is actually triggered	h
Recovery time	Max. time energy has to be recovered	h

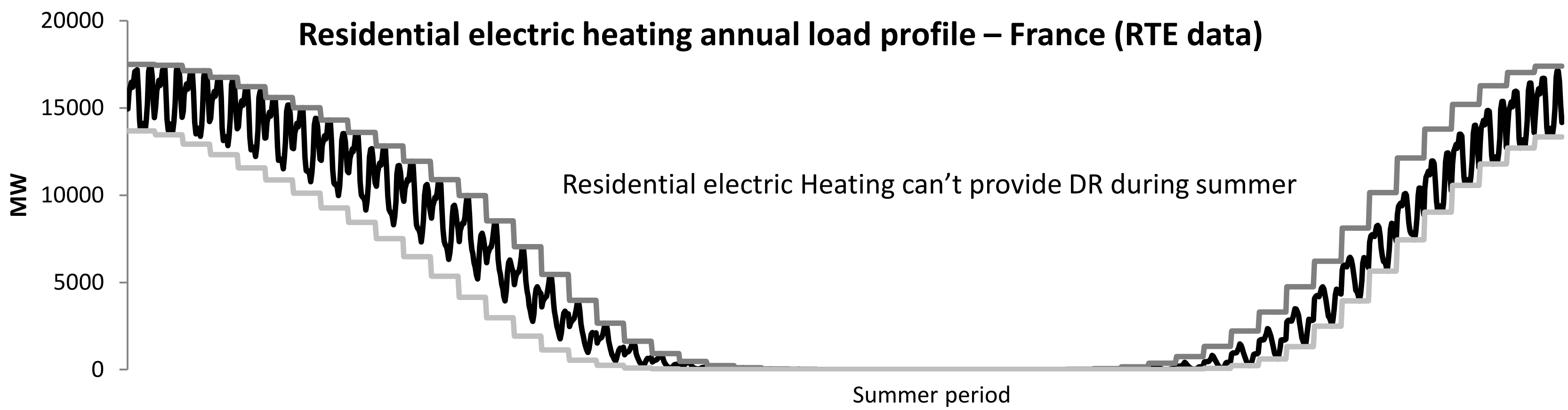
Load-shifting
Modelled as Hydro pumped storage

Load-shedding
Modelled as Hydro reservoir



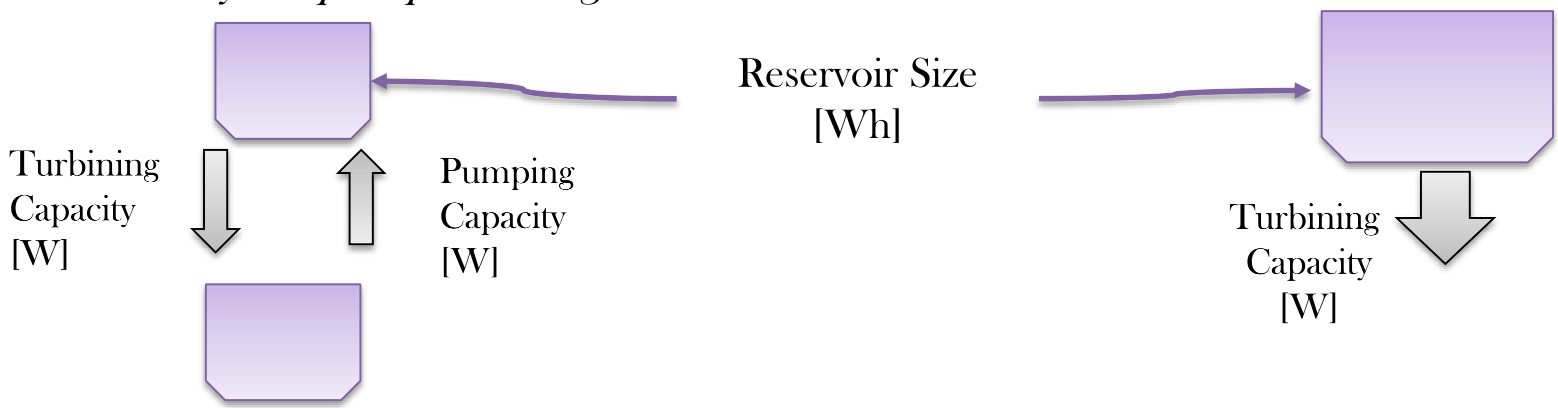
Demand Response: modelling approach

We use a storage representation for Demand Response
Time availability is an important constraint



Load-shifting
Modelled as Hydro pumped storage

Load-shedding
Modelled as Hydro reservoir



Outline

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

Introduction

- Dynamics of competition in electricity markets regarding DR
- The impact on market designs on DR valuation
- The role of Demand Response aggregators

Economic assessment of Demand Response

- Day-ahead Energy market:
    - **Economic dispatch under uncertainty**
- Demand Response representation:
    - **Storage model with customer-based constraints**

Case Study and Results

- DR aggregator annual profits
    - **French power system-based data in 2015**

Conclusions

Case study: French power system data (2015)

The Supply-side

In addition to the existing French electricity mix, DR is integrated

Source: RTE bilan prévisionnel 2015; Gils 2014; IEA projected cost of generating electricity 2015; Gruber 2014

Thermal units

Nuclear
63 100 MW
23 € / MWh

Coal
2 900 MW
35 € / MWh

Gas CCGT
5 700 MW
75 € / MWh

Fuel-Oil
5 100 MW
100 € / MWh

Gas Turbine
1 900 MW
120 € / MWh

Other peakers
3 000 MW
150 € / MWh

Hydro units

Pumped Storage
5 000 MW
9 € / MWh

Hydro Reservoir
9 100 MW
8 € / MWh

Renewables

Production added to make up the Residual Demand

Demand Response

Load-shifting

Residential Heating
17 500 MW
11 € / MWh

Tertiary Heating
8 700 MW
11 € / MWh

Tertiary Cooling
2 800 MW
11€ / MWh

Industry Cement
272 MW
20 € / MWh

Industry Paper
87 MW
20 € / MWh

Industry Cross-tech
402 MW
16€ / MWh

Load-shedding

Industry Steel
272 MW
411 € / MWh

Industry Aluminium
87 MW
164 € / MWh

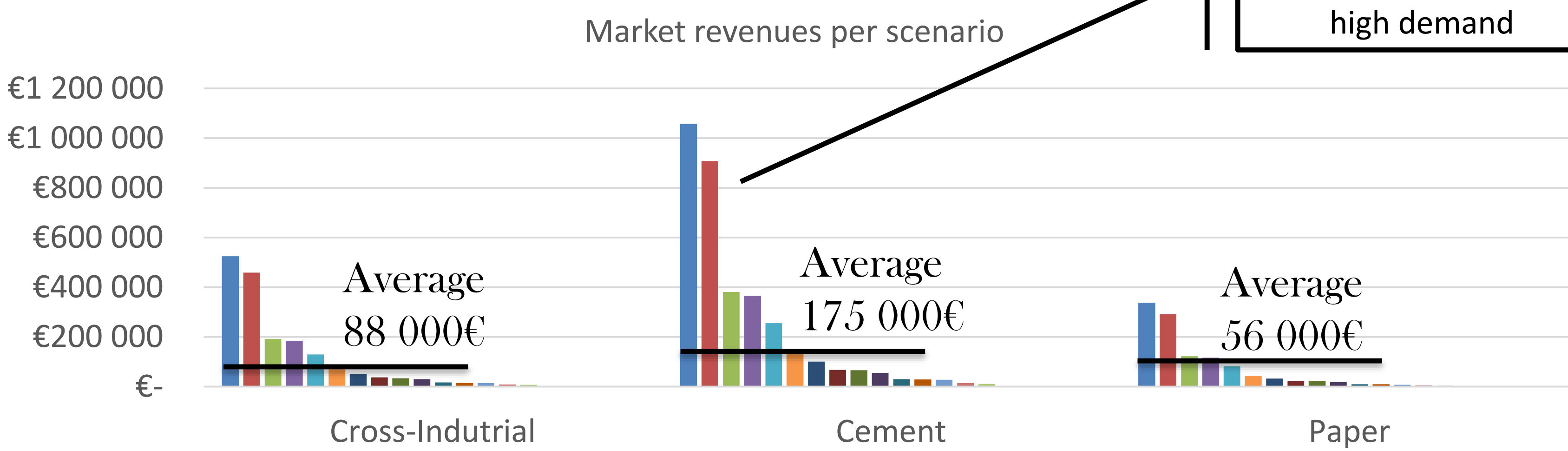
Industry Chemicals
402 MW
100 € / MWh

Case study: French power system data (2015)

Market revenues in the Industrial Sector

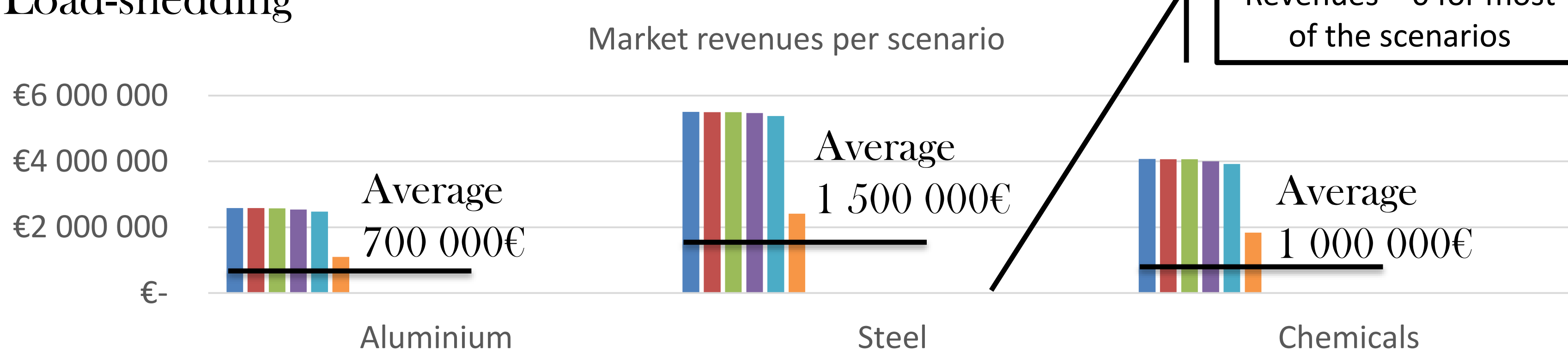
Load-shifting

Scenarios with very high demand



Load-shedding

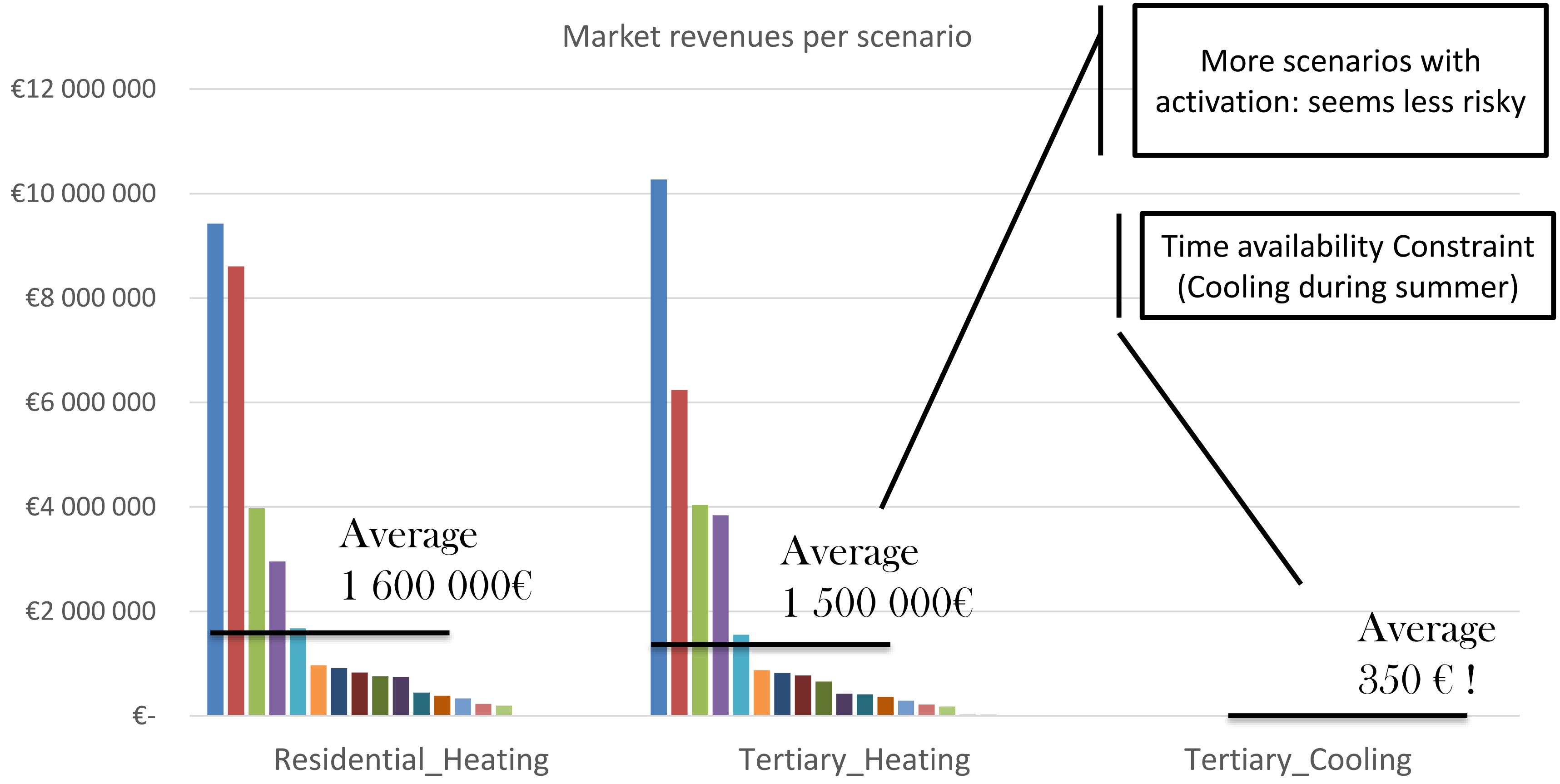
Revenues = 0 for most of the scenarios



Case study: French power system data (2015)

Market revenues in Tertiary and Residential Sectors

Load-shifting



Case study: French power system data (2015)

Average Market revenues by Capacity
Sort by Demand Response categories

		Load-Shifting	Load-shedding
Residential	Heating	90 € / MW / year	
Tertiary	Heating	180 € / MW / year	
	Cooling	0 € / MW / year	
Industry	Cross-tech	220 € / MW / year	
	Cement	650 € / MW / year	
	Paper	650 € / MW / year	
	Aluminium		5 100 € / MW / year
	Steel		3 600 € /MW / year
	Chemicals		5 500 € / MW / year

Case study: French power system data (2015)

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

What is the investment cost in DR enabling technologies ?

	Investment Cost	Source
Industry (Load-shedding)	[200 ; 8 000] € / MW	Stede 2016
Tertiary	200 000 € / MW	Frontier and Formaet 2014
Residential	500 € / meter	Prüggler 2013
	25 € / meter / year	Léautier 2012
	6 € / kW / year	Steurer et al. 2015

Assuming:
- 20-years lifetime;
- a 5% rate of return;
- a meter in the residential sector controls 4 kW

	Investment Cost	Source: Calculation based on
Industry (Load-shedding)	[16 ; 640] € / MW / year	Stede 2016
Tertiary	16 000 € / MW / year	Frontier and Formaet 2014
Residential	10 000 € / MW / year	Prüggler 2013
	6 250 € / MW / year	Léautier 2012
	6 000 € / MW / year	Steurer et al. 2015

Case study: French power system data (2015)

Comparison between Annual Market Revenues and Investment Costs

		Avearge Market Revenues	Investement Costs
Residential	Heating	90 € / MW / year	[6000; 10 000]€/MW/year
Tertiary	Heating	180 € / MW / year	16 000 € /MW/year
	Cooling	0 € / MW / year	
Industry Load-shifting	Cross-tech	220 € / MW / year	No data found
	Cement	650 € / MW / year	
	Paper	650 € / MW / year	
Industry Load-shedding	Aluminium	5 100 € / MW / year	[16; 640] € / MW / year
	Steel	3 600 € /MW / year	
	Chemicals	5 500 € / MW / year	

Outline

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

Introduction

- Dynamics of competition in electricity markets regarding DR
- The impact on market designs on DR valuation
- The role of Demand Response aggregators

Economic assessment of Demand Response

- Spot Energy market:
    - **Economic dispatch under uncertainty**
- **Demand Response representation:**
    - **Storage model with customer-based constraints**

Case Study and Results

- DR aggregator annual profits
    - **French power system-based data in 2015**

Conclusions

Conclusions

What is the Economic potential of Demand Response in Electricity Markets ?

A. <u>What can we say about the business case of a DR aggregator, using French power system data ?</u>

1) Tertiary: no business case for DR based on cooling (time availability constraint)
2) Tertiary and Residential: Heating based DR isn't viable but show more promising results
3) Industrial DR: is a viable business because installed Capacities are lower. However it looks more risky (DR is only activated during high demand scenarios)

B. <u>Consequences regarding Market Designs and Business model of aggregators</u>

1) What class customers to contract with ? (Only Small Consumers / Industrial ; or a mix of both ?)
2) DR should have access to ancillary serives and/or Capacity Mechanisms

A. <u>Further Research</u>

1) Only Day-ahead has been modeled: can the revenues from other wholesale markets change the business case ?
2) What would be the dynamics of Investment in Demand Response ?

The end

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

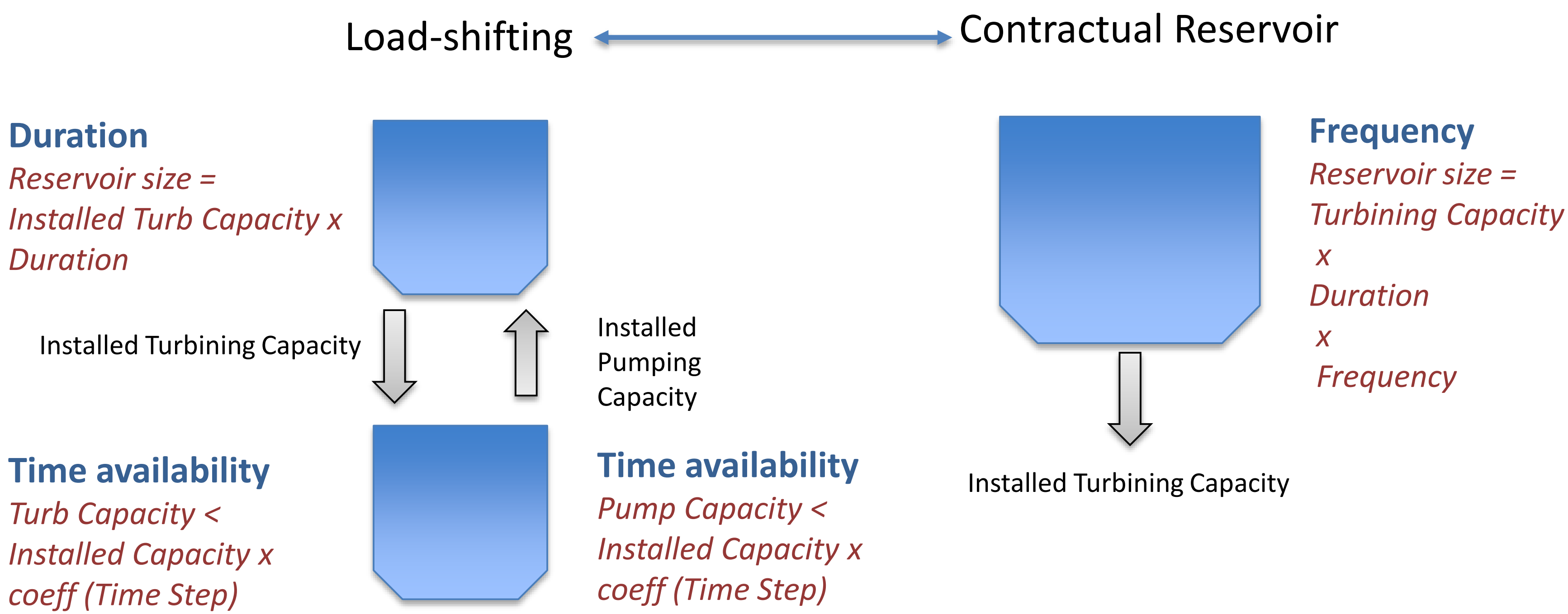
Thank you for your attention

Demand Response: modelling approach

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

Constraints specific to Demand Response

1. **Installed Capacity**
2. **Activation Costs**
3. **Duration:** DR event length **(eg 3 hours)**
4. **Time availability:** load profiles **(eg load for heating is absent during summer)**
5. **Frequency:** limits on the number of events **(eg 20 activations per year)**

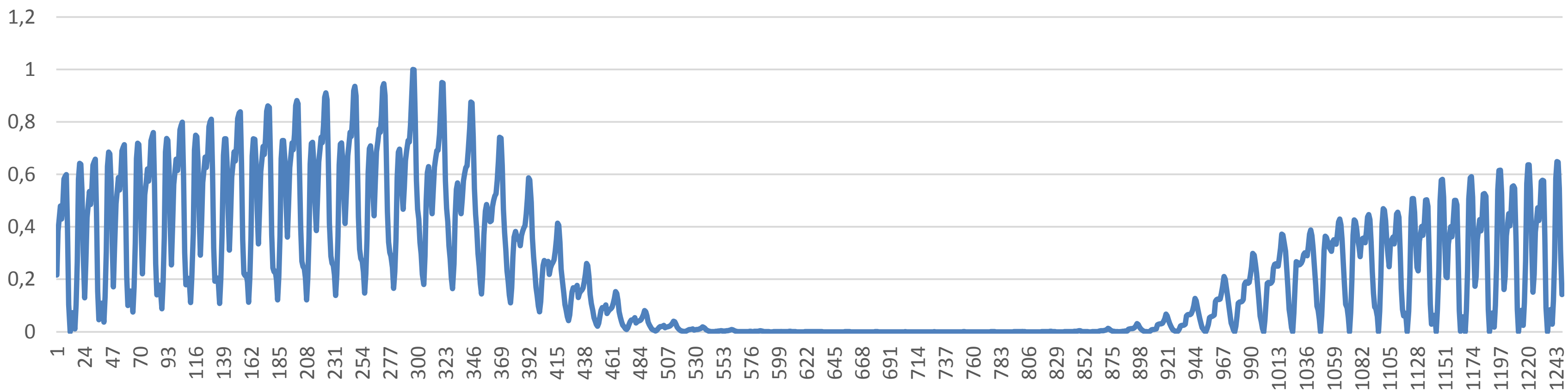


Appendix- Building the time availability parameter

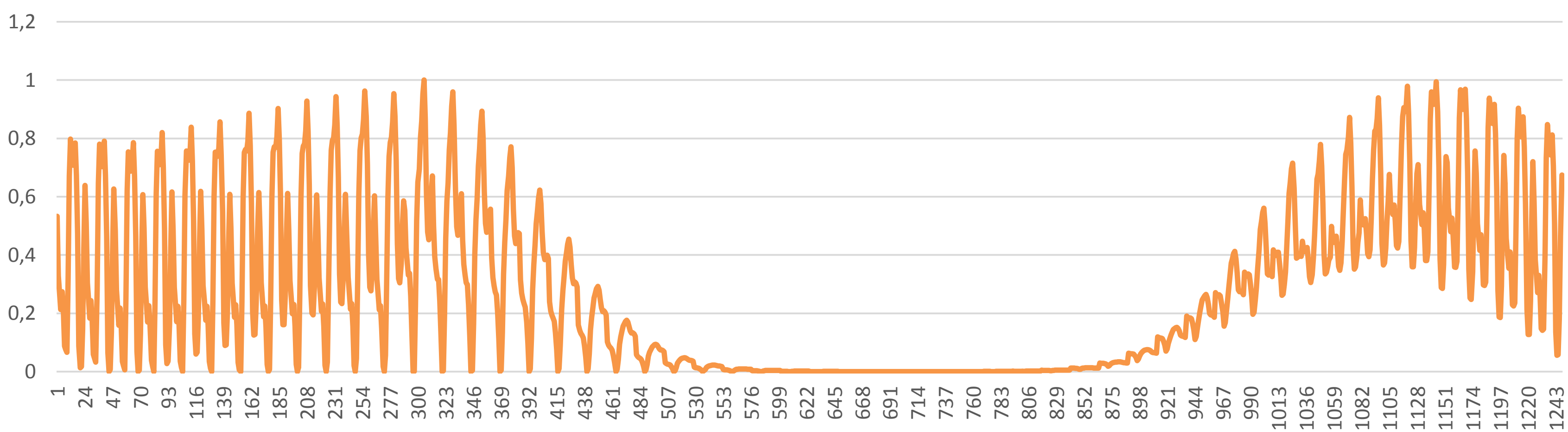
CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

Load Profiles

Availability Turbining (%)



Availability Pumping (%)

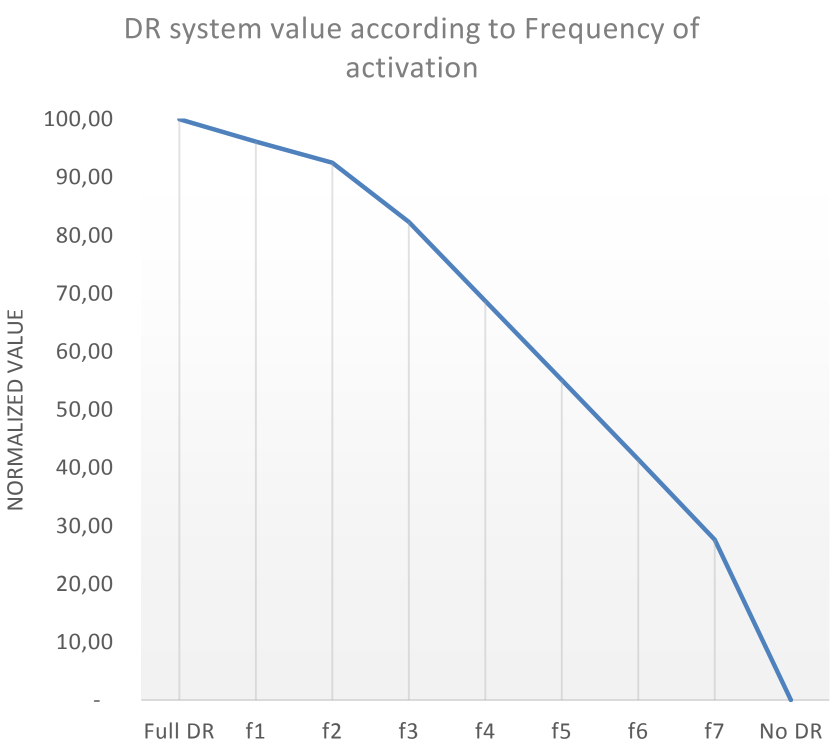


Toy model

Results

$$Demand\ Response\ System\ Value = Total\ Cost_{No\ DR} - Total\ Cost_{DR_{run\ i}}$$

$$Total\ Cost = \mathbb{E}_{\omega}\left\{\sum_{t}^{T} Objective\ Function\ (t,\omega)\right\}$$



Run i	Frequency
Full DR	f= 4
F1	f= 3,5
F2	f= 3
F3	f= 2,5
F4	f=2
F5	f=1,5
F6	f= 1
F7	f= 0,5
No DR	f = 0

Appendix – Model formulation

The multi-stage stochastic problem is formulated as follow:

$$\mathbb{E}_{\omega 0}\left\{\min_{x_0} c_0 x_0 + \mathbb{E}_{\omega 1}\left\{\min_{x_1} c_1 x_1 + \mathbb{E}_{\omega 2}\left\{\min_{x_2} c_2 x_2\right\} + \mathbb{E}_{\omega 3}\left\{\min_{x_3} c_3 x_3\right\}\right\}\right\}$$

s.t. $\mathrm{K} \geq x_t \geq 0$; $x_t \geq d_t^{\omega t}$; $R_t = R_{t-1} + x_{t-1} * h$ for each time step t

Power production — Balancing constraint — Reservoir levels evolution

We end up with the following problem where SDDP builds an approximation of the future cost functions $V_t(R_t, \omega_t)$at each time step

$$V_4 = 0$$

$$V_3(R_3, \omega_3) = \min_{x_3} c_3 x_3 + V_4$$

$$V_2(R_2, \omega_2) = \min_{x_2} c_2 x_2 + \mathbb{E}_{\omega 3}\{V_3(R_3, \omega_3)\}$$

$$V_1(R_1, \omega_1) = \min_{x_1} c_1 x_1 + \mathbb{E}_{\omega 2}\{V_2(R_2, \omega_2)\}$$

$$\min_{x_0} c_0 x_0 + \mathbb{E}_{\omega 1}\{V_1(R_1, \omega_1)\}$$