27ème séance du Séminaire de Recherches en Economie de l'Energie de Paris-Sciences-Lettres

Carbon price instead of support schemes: Wind power investments by the electricity market

Marie Petitet

Paris
13 janvier 2016

Co-authors: Dominique Finon and Tanguy Janssen
Article to be published in *The Energy Journal*, 2016, volume 37, n°4.

Réseau de transport d'électricité (RTE)

Chaire European Electricity Markets (CEEM), Université Paris-Dauphine, Université de Recherche PSL

Rte Réseau de transport d'électricité

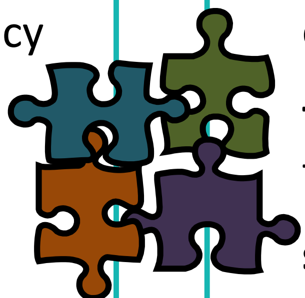
DAUPHINE UNIVERSITÉ PARIS

CHAIRE EUROPEAN ELECTRICITY MARKETS Fondation Paris-Dauphine

Introduction

Increasing importance of renewable energy sources in the European policy debate :

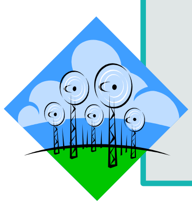
- the European emissions trading system (EU-ETS)
- 20-20-20 targets
- EU guidelines on State Aid



Today, investments in generation capacities are driven by:

the energy market for traditional fossil-based technologies

support mechanisms for renewable energy sources



Objective of the study:

What carbon price to trigger the development of wind power by the electricity market without any support scheme?

Presentation outline

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

1. Motivations
2. Simulation model
3. Case study
4. Mains conclusions

Disclaimer: The views, assumptions and opinions expressed in this article are those of the author and do not necessarily reflect the official policy or position of RTE (Réseau de transport d’électricité).

1. Motivations: Review of literature and research question

Rte Réseau de transport d'électricité

DAUPHINE UNIVERSITÉ PARIS

CHAIRE EUROPEAN ELECTRICITY MARKETS Fondation Paris-Dauphine

Review of literature

Literature about **comparative efficiency of different support mechanisms** (feed-in tariffs vs renewables obligation): Menanteau and Finon (2003), Palmer and Burtraw (2005), Neuhoff et al. (2009).

Literature about **effects of renewables entries** by support mechanisms (out-of market entries):

- Impacts on energy-only markets: focus on merit order effects and decrease of average prices; econometric approach on the impact in Germany, Spain, Italy, etc.
  Sensfuss et al. (2008); Nicolosi and Fürsch (2009).

- Impacts in terms of systems costs: balancing costs, grid costs and effects on the market value.
  Cometto et Keppler, (2013) ; Hirth (2012 and 2014).

Review of literature (cont.)

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

Literature on the **optimisation of the residual system** after exogenous entry of a given capacity of renewables.

- Comparison of the residual thermal system with and without renewables
  Green (2008); Nagl (2011); Lamont (2012); Green and Vasilakos (2011); Bushnell (2010).

- Model of the long term equilibrium after development of renewables
  Hirth and Ueckerdt (2013) assess cost for existing generators and benefits for consumers.

- Dynamic approach of the market value of the RES-E by a long term optimisation of the residual mix after an exogenous entry of renewables
  Green and Léautier (2015).
  Decrease of market value: identification of possible equilibrium if perfect foresight of renewables' capacity growth.

Motivations and research question

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

Very few literature on endogenous entries of renewables through a carbon price:
Fisher and Newell (2008) propose a comparison of social efficiency with FITs.
They conclude in favour of a carbon price but with elementary representation of cost function and electricity markets, no smart representation of wind power variability.

Today, the European debate goes even further than the choice of support mechanisms, bringing the idea that investments in renewables should be market-based.

> Question n°7 of the EU public consultation on a new energy market design (launched on July, 2015):
> *"What needs to be done to allow investment in renewables to be increasingly driven by market signals?"*

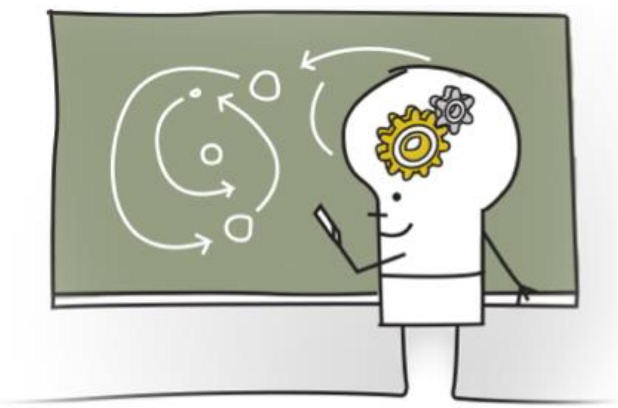
Market-based investment in renewables under the incentive of a carbon price has not been studied in detailed so far. This paper raises **the question of the entry of renewable entirely by the energy-only market without any support schemes**.

Our approach: System dynamics

This research proposes **a method to estimate the possible market-based development of renewables**. On-shore wind power is chosen as a representative mature renewable technology.

Principle of system dynamics: (method developed by J. W. Forrester during the 1960's)

- Using computer programming to enhance learning in complex systems.
- The relation between entities are expressed and the evolution of the whole system is simulated over several time steps.



(Wolfram SystemModeler chalkboard cartoon)

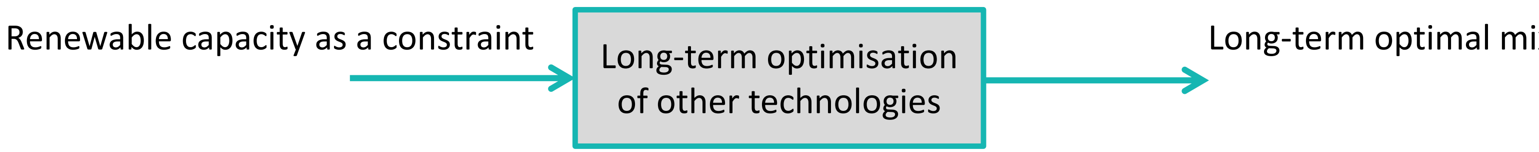
This method has already been used to model the electricity sector (Ford, 2001 ; Cepeda and Finon, 2011 ; Sanchez et al., 2008).

Different approaches

System dynamics approach differs widely from traditional approaches (dispatching programming, long-term optimisation, etc.) because it does not focus on market equilibrium.

Green and Léautier (2015) Development of renewables by subsidies

An analytical model of long-term optimisation of thermal capacities is employed to compared renewables' subsidies and costs in different contexts (flexible or inflexible nuclear; physical dispatch insurance or financial insurance).

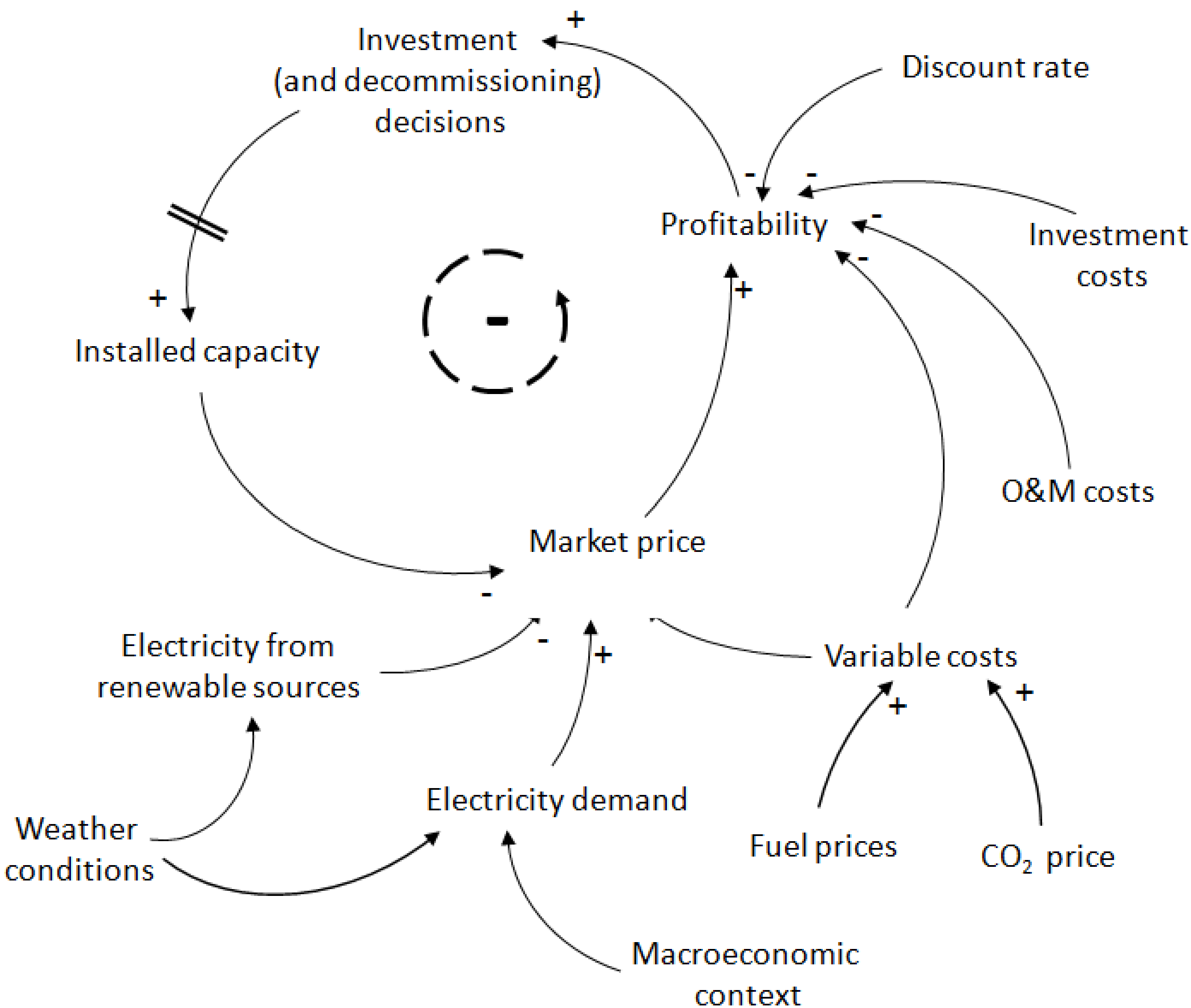


Our model Development of renewables by a carbon price

A System Dynamics model of investments is employed to test the market-based development of renewables with different carbon prices.

2. Simulation model

Overview of the SIDES model

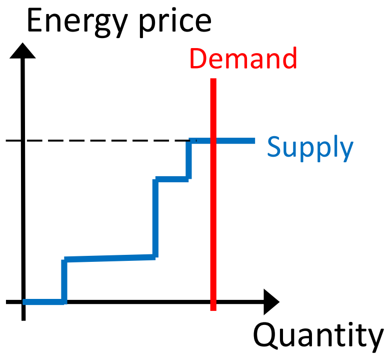


Main features of the SIDES model

Each year of the simulation, **new investments and units' closures** are computed based on the different anticipated future scenarios.

Short-term operation of the system

- **Energy market price:** supposed equal to the marginal production cost of the system (merit-order principle).

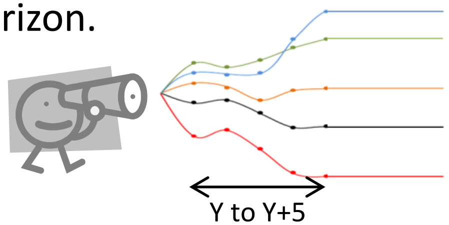


The price cap is set to € 3,000 /MWh.

- **Construction time** is taken into account before a new power plant comes on line.

Anticipations of the future

- **Myopic foresight:** anticipation of the future on a 5-year horizon.



- **Macroeconomics anticipations:** different assumption on the electricity demand growth. Here three anticipations of the annual demand growth: -1% / 0% / +1 %.

- **Short-term uncertainties (weather conditions):** correlated hourly electricity demand and generation of wind turbine. Here, panel of 12 representative years of 8,760 hours.

- **Carbon price:** fixed and known by the investor over the 20-year period.

Decommissioning of existing power plants

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

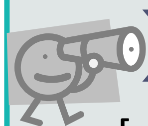
A power plant is closed

- at the end of its life-time

or

- before the end of its life-time if not economically profitable

Early decommissioning decisions are based on a **two-stage evaluation of net profit**:



[π_1]

Estimated net profit for the following year

[π_2]

Estimated net profit for the 5 following years (computed if necessary)

A power plant is closed if $\pi_1 < 0$ and $\pi_2 < 0$

Note: For decommissioning, investment costs are not taken into account (sunk costs).

New investment decisions

Investor decision-making is based on the **internal rate of return (IRR)** computed on mean flows of the project.

Anticipations on macroeconomic growth

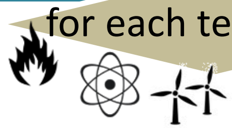
Weather scenarios

Current generation mix

Hourly market prices → market revenues

Internal rate of return (IRR)

for each technology



Investments are obtained by a **recursive loop** witch selects the most profitable project at each step.

(minimum required IRR = 8%)

Volume constraint: each year, investment in new capacity is limited to 10 GW.

Wind power in the model

Cost assumptions remain constant over the whole simulated period. A sensitivity test was conducted with an alternative cost of wind turbines.

Electricity generated by wind turbines

Hourly load factors correlated to the electricity demand (historical data; 12 years).

Load factors do not change with the installed wind capacity.

Our model endogenously reproduce three important effects of wind power development:

(1) the negative correlation between hourly wind power production and hourly price;

(2) the gradual decrease of the average annual price with the development of wind power;

(3) the feedback loop consisting in the “self-cannibalisation” of wind power competitiveness by its own development.

3. Case study

Data of the study

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

Technologies and costs:

The technologies considered are: Combined cycle gas turbine (CCGT), coal-fired power plant (coal), oil-fired combustion turbine (CT) and wind turbine (WT); and nuclear in case B. Costs are supposed to remain constant over the period.

	CCGT	Coal	CT	Nuclear	WT
Investment cost (k€/MW)	800	1,400	590	2,900 | 5,000	1,600
Annual O&M cost (k€/MW/year)	18	50	5	100	20
Annualised fixed cost* (k€/MW/year)	89	167	60	334 | 504	170
Nominal power capacity (MW)	480	750	175	1,400	45
Fuel variable cost (€/MWh)	64	37.5	157	10	0
Carbon emission factor (ton of CO_2/MWh)	0.35	0.8	0.8	0	0
Construction time (years)	2	4	2	6	2
Life time (years)	30	40	25	60	25

Notes: Data is from IEA and NEA (2010) and DGEC (2008). Assumptions on fuel prices: gas price is €10.2 per MMBtu (€9.7 per GJ); coal price is €150 per ton (€4.2 per GJ) and oil price is €88.7 per barrel (€15.3 per GJ).
* The annualised fixed cost is computed with annual discount rate of 8%.

Initial generation mix:

Two cases are tested with and without nuclear option.

Technology	CCGT	Coal	CT	Nuclear	WT
Capacity in case A (GW)	17.76	57.75	3.50	0	0
Capacity in case B (GW)	17.76	12.2	3.50	46.10	0

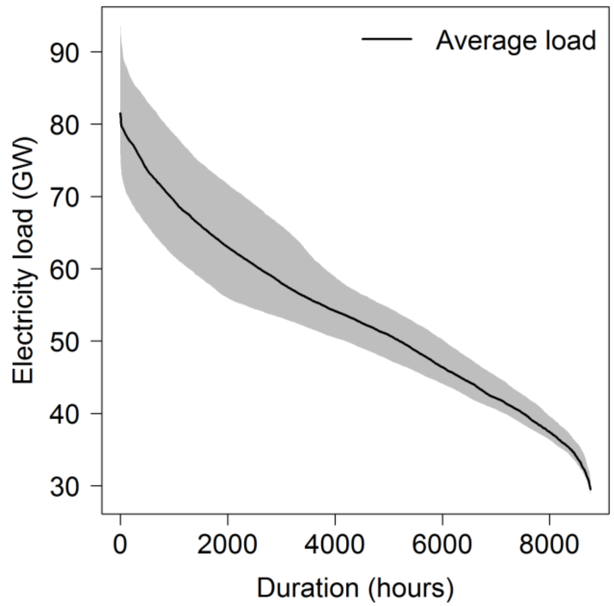
The initial mix corresponds to the optimal mix, obtained by the screening curves method.

Data of the study (cont.)

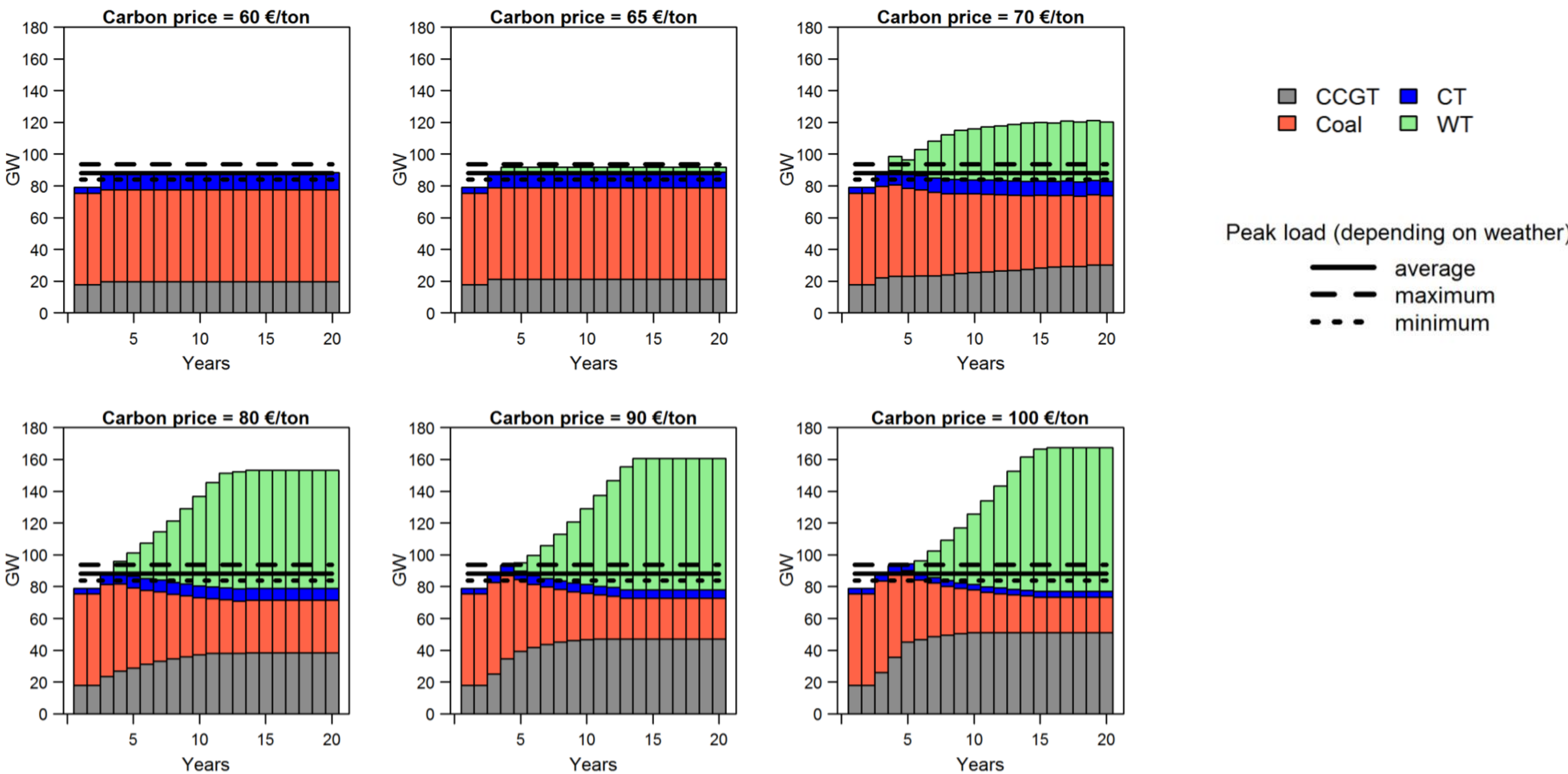
Electricity demand and wind power generation profile:

Hourly electricity demand is correlated to electricity generation of wind power.

A panel data of 12 weather scenarios were used, corresponding to French data from 2000 to 2011.



Results in case A: Generation mix

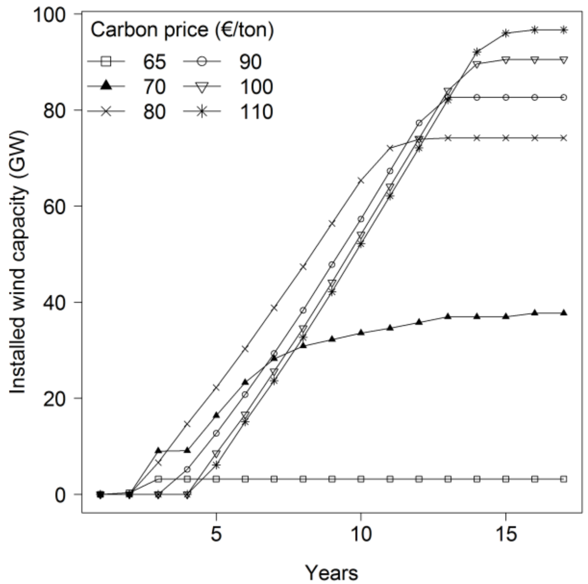


Wind power is part of generation mix if carbon price is higher than **€70 / ton of CO_2**.
Installed wind capacity increases with the carbon price.

[(details)]

Results in case A: Generation mix

Installed capacity of wind power:



Between € 110 and € 60 / ton of CO_2 with no wind power:

96.7 GW in wind power capacity replace **12.0 GW** of thermal capacity

corresponding to 38.6% of energy generation

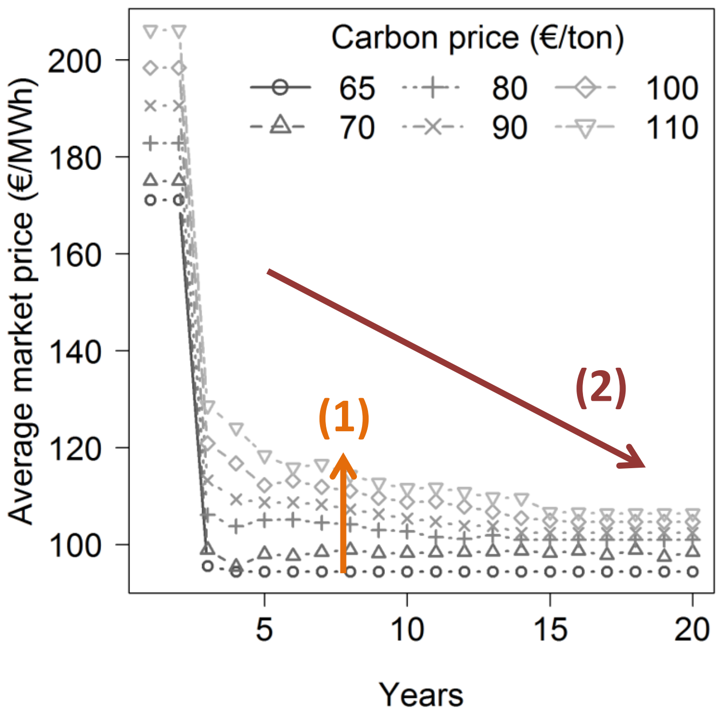
Share of wind generation:

Carbon price (€/ ton of CO2)	65	70	80	90	100	110
Share of wind capacity	3.5%	31.1%	48.5%	51.4%	54.1%	55.8%
Share of wind energy	1.3%	15.3%	30.0%	33.3%	36.3%	38.6%

Results in case A: market prices

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

Evolution of average market price:

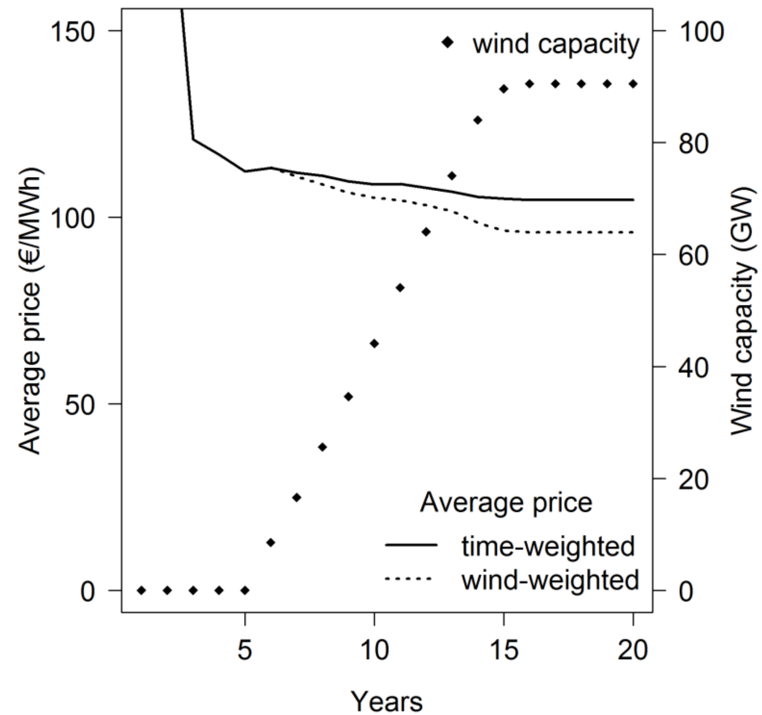


(1) direct effect: increase of the carbon price pushes up thermal variable costs and increases market prices.

(2) indirect effect: increase in wind capacity lowers the market price (variable cost of wind power is zero).

Time-weighted and wind-weighted average prices:

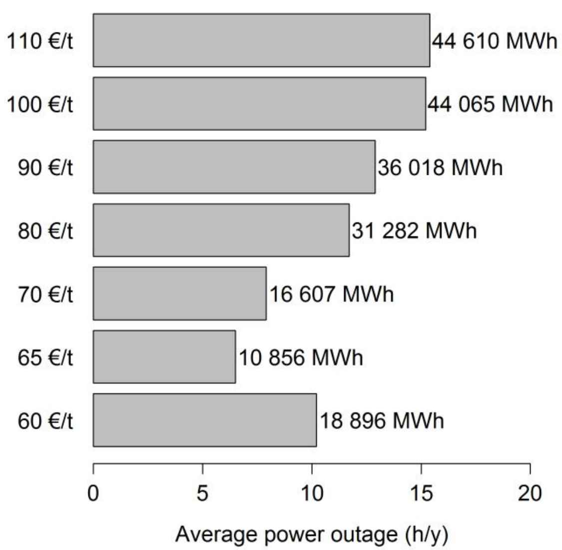
The figure displays the results with a carbon price of € 100 per ton of CO_2.



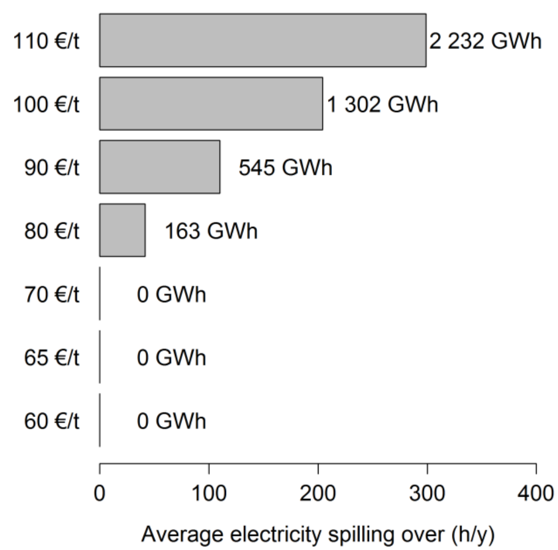
The market value of WT is **0.92%** of time-weighted average price for an installed wind capacity of 90.5 GW (36.3% of electricity generated by WT).

Results in case A: Effects on the electricity system

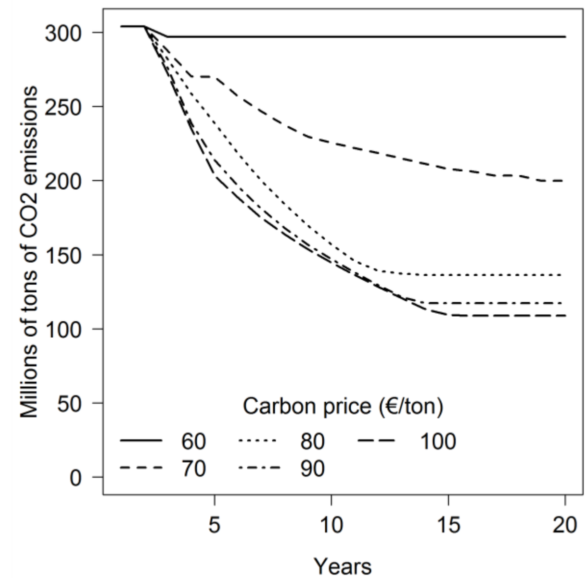
Energy outage:



Energy spills over:



CO_2 emissions:



Power outage increases with wind capacity.

- **social efficiency issue**

Above € 80 / ton of CO_2, large volumes of electricity is spilled over.

- **storage and demand side management**

A carbon price of € 70 / ton of CO_2 decreases CO_2 emissions by **22%** over the 20 years, compared to the case of € 60 / ton of CO_2 with no wind power.

Results in case B: Effects of nuclear option

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

Two subcases are tested:

Case B-1 existing nuclear capacity is maintained at its initial level (no new nuclear power plant)

Case B-2 new nuclear development is allowed

	Nuclear
Investment cost (k€/MW)	2,900 | 5,000
Annual O&M cost (k€/MW/year)	100
Annualised fixed cost* (k€/MW/year)	334 | 504
Nominal power capacity (MW)	1,400
Fuel variable cost (€/MWh)	10
Carbon emission factor (ton of CO_2/MWh)	0
Construction time (years)	6
Life time (years)	60

Results

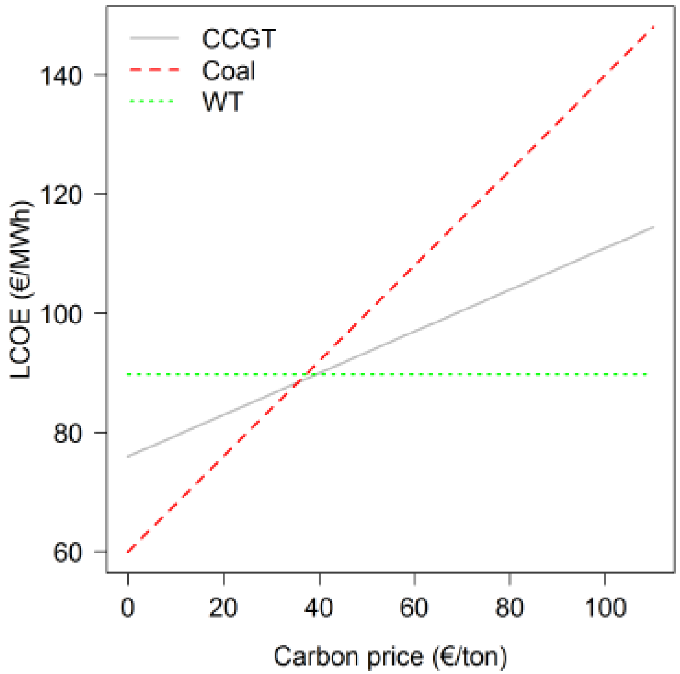
Case B-1 compared to case A

Carbon price (€/tCO_2)	70	80	90	100	110	150	200	250	300
Wind capacity (GW) – Case A without any nuclear	37.7	74.2	82.6	90.5	96.7	119	140	159	175
Wind capacity (GW) –Case B-1 with existing nuclear (46.1 GW)	0	0	0	0	0	4.9	14.4	21.2	26.8

Case B-2

- With the low assumption on nuclear cost: no WT even with a carbon price of € 500 / ton of CO_2.
- With the high assumption on nuclear cost: 2 GW of WT with a carbon price of € 300 / ton of CO_2 and 13 GW of WT with a carbon price of € 500 / ton of CO_2.

Comparison with LCOE



Carbon tax scenario (€ per ton of CO_2)		0	50	100
CCGT	LCOE (€/MWh)	76.0	93.5	111.0
	Fixed cost share	15.7%	12.8%	10.8%
Coal	LCOE (€/MWh)	60.0	100.0	140.0
	Fixed cost share	37.5%	22.5%	16.1%
Nuclear	LCOE (€/MWh)	54.9	54.9	54.9
	Fixed cost share	81.8%	81.8%	81.8%
WT	LCOE (€/MWh)	89.8	89.8	89.8
	Fixed cost share	100%	100%	100%

Levelized cost of electricity (LCOE)

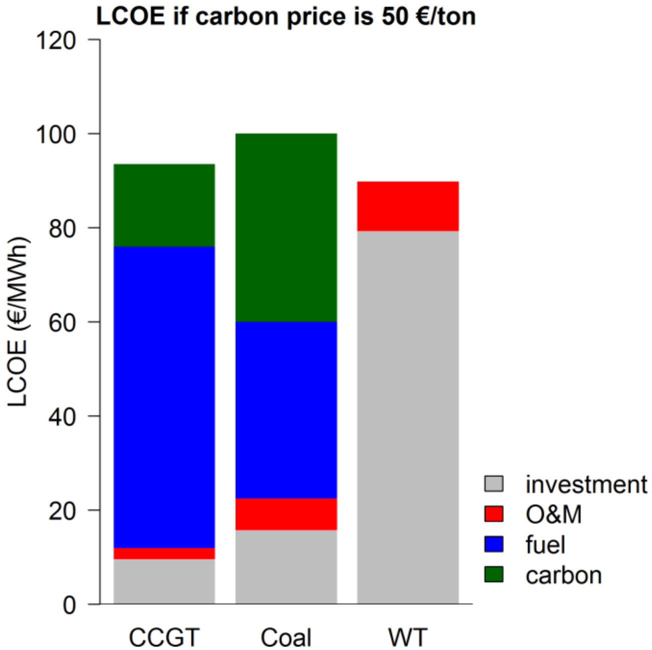
In terms of LCOE, wind power is economically profitable if the carbon price is **higher than € 45 /ton of CO_2**.

But **fixed cost represents 100% of LCOE of wind power** while it represents less than 38% of LCOE of fossil-based technologies (CCGT, coal).

Significant gap

The threshold value given by SIDES simulations is considerably higher than the value obtained by the LCOE method.

Comparison with LCOE



Carbon tax scenario (€ per ton of CO_2)		0	50	100
CCGT	LCOE (€/MWh)	76.0	93.5	111.0
	Fixed cost share	15.7%	12.8%	10.8%
Coal	LCOE (€/MWh)	60.0	100.0	140.0
	Fixed cost share	37.5%	22.5%	16.1%
Nuclear	LCOE (€/MWh)	54.9	54.9	54.9
	Fixed cost share	81.8%	81.8%	81.8%
WT	LCOE (€/MWh)	89.8	89.8	89.8
	Fixed cost share	100%	100%	100%

Levelized cost of electricity (LCOE)

In terms of LCOE, wind power is economically profitable if the carbon price is **higher than € 45 /ton of CO_2.**

But **fixed cost represents 100% of LCOE of wind power** while it represents less than 38% of LCOE of fossil-based technologies (CCGT, coal).

Significant gap

The threshold value given by SIDES simulations is considerably higher than the value obtained by the LCOE method.

4. Main conclusions

Main conclusions

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

Not only **economic profitability** but also **economic competitiveness** against traditional fossil-based technologies are necessary conditions for market-oriented development of wind power.

System dynamics results show that wind power development is achieved only if the carbon price is high (€70 per ton of CO_2) while LCOE analysis suggests a lower carbon price (€45 per ton of CO_2). **This underlines that cost analysis is not sufficient to estimate economic competitiveness of different generation technologies.**

Based on this research, the development of wind power by an energy-only market (without any support scheme) seems to be possible; but **only if supported by gradual and strong political commitment** on a high and fixed carbon price.

Thank you for your attention.

Any questions?

marie.petitet@rte-france.com

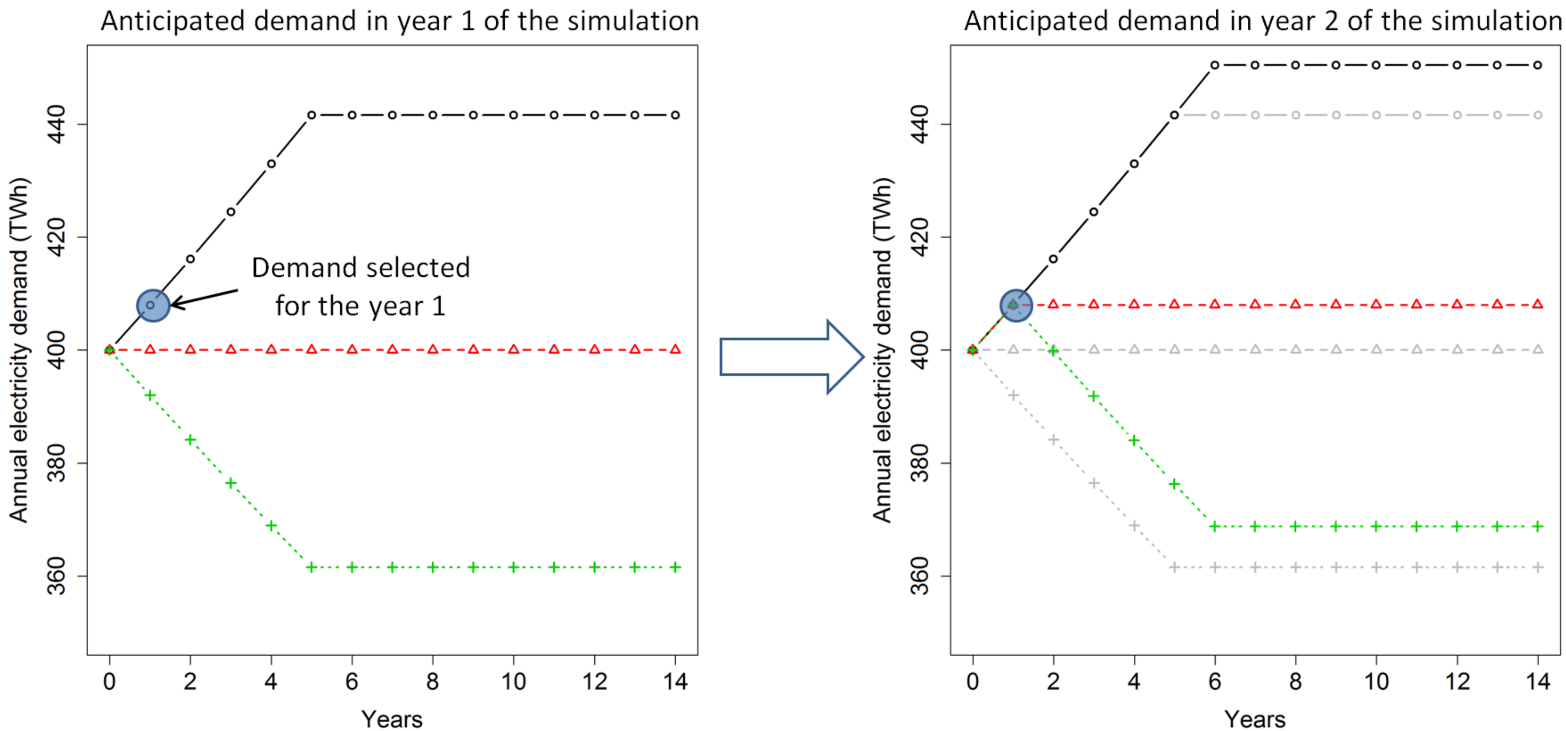
Réseau de transport d'électricité (RTE)

Chaire European Electricity Markets (CEEM), Université Paris-Dauphine, Université de Recherche PSL

APPENDIX

Anticipation of the future

Annual growth of electricity demand: 3 hypothesis (+1% / 0% / -1%)



Short-term weather sensitivity of electricity demand and generation of wind power are taken into account : 12 weather profiles are used.

Details on generation mix in case A

CHAIRE EUROPEAN ELECTRICITY MARKETS
Fondation Paris-Dauphine

Generating mix at the end of the simulation

Carbon price (€ /tCO_2)	CCGT (GW)	Coal (GW)	CT (GW)	WT (GW)	Total thermal capacity (GW)
60	19.7	57.8	11.0	0	88.5
65	21.1	57.8	9.8	3.2	88.7
70	30.2	44.3	8.9	37.7	83.4
80	38.4	33.0	7.5	74.2	78.9
90	47.0	25.5	5.4	82.6	78.0
100	50.9	22.5	3.5	90.5	76.9
110	53.8	20.3	2.5	96.7	76.5

(back)

Sensitivity of the results to the cost of WT

Another set of simulations was conducted with a lower value of the investment cost of wind turbines of €1,200/kW instead of €1,600/kW (decrease of 25%).

Carbon price (€/tCO_2)	20	30	40	50	60	70	80	90
Wind capacity (GW)—Case A	0	0	0	0	0	37.7	74.2	82.6
Wind capacity (GW)—WT investment cost of €1,200/kW	0	3.6	17.7	91.2	109	120	127	132

The results in relative terms are quite the same:

On one hand, **LCOE analysis suggests a carbon price of €17 per ton of CO_2** to make wind power competitive with thermal power plants.

On the other hand, **system dynamics simulations show that a carbon price of €30 per ton of CO_2** is needed to see market-driven investments in wind power.