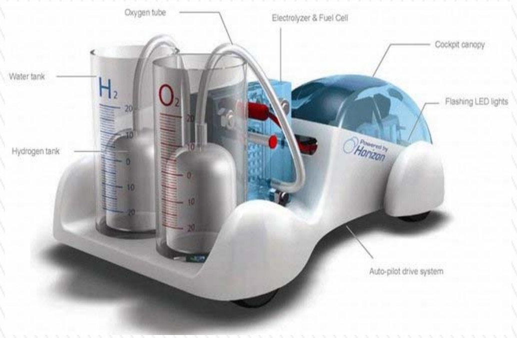

Defining the Abatement Cost in Presence of Learning-by-doing: Application to the Fuel Cell Electric Vehicle

Anna Creti
(Université Paris Dauphine and Ecole Polytechnique)

Joint work with
A. Kotelnikova (E. Polytechnique), G. Meunier (INRA), J-P Ponssard (E. Polytechnique and CNRS)

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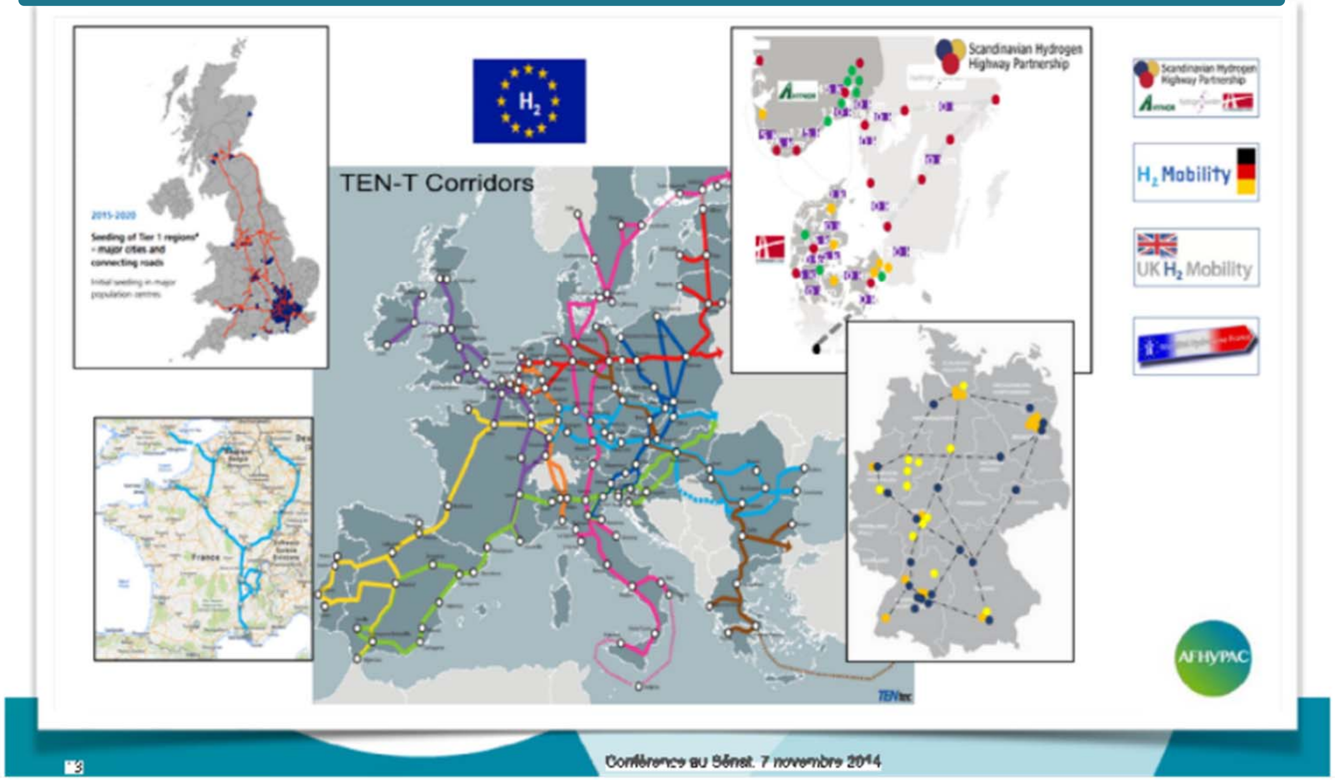
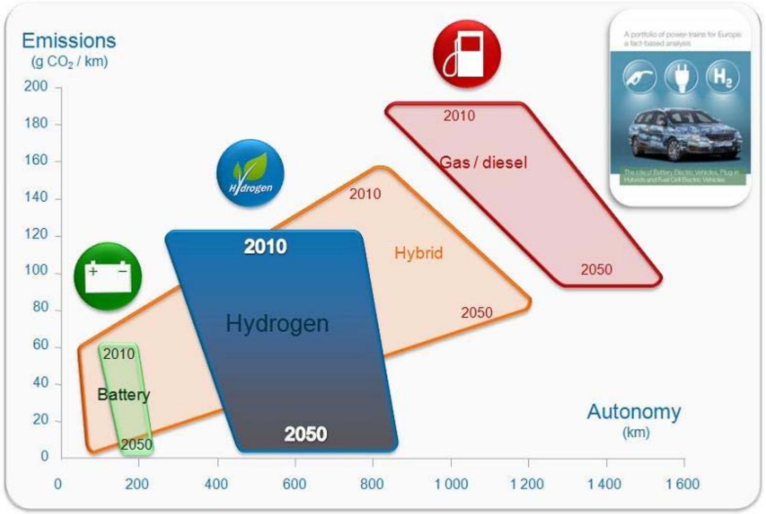
EUROPEAN ROAD MAPS FOR THE DEPLOYMENT OF FCEV



The FCEV as part of the solution for the decarbonation of the transport system?



FCEV may reach a substantial market share by 2050 iff

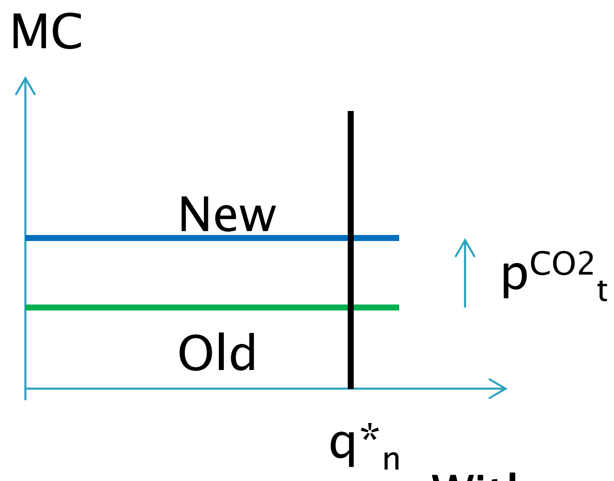
- Manufacturing cost decreases (Toyota Mirai sells at 65 k€ in 2015)
- Clean and cheap H2 production (renewables + electrolysis)
- Network for H2 distribution is deployed

Some references: Mc Kinsey (2010) Bruegel (2012), Rösler et al. (2014), Fuelling Europe's Future (2014)

Introduction

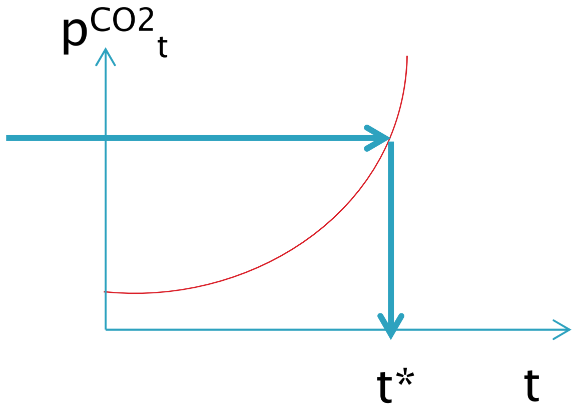
- Marginal abatement cost (MAC) curves are a standard tool in environmental economics
- Practical assessment of a MAC in a dynamic setting is not straightforward
- We contribute to the debate on the MAC curves by extending of the standard concept of static abatement costs to a dynamic one.
  - To do so, we introduce learning-by-doing together with cost convexity, as these two characteristics adequately describe many low-carbon technologies such as renewables

An illustration

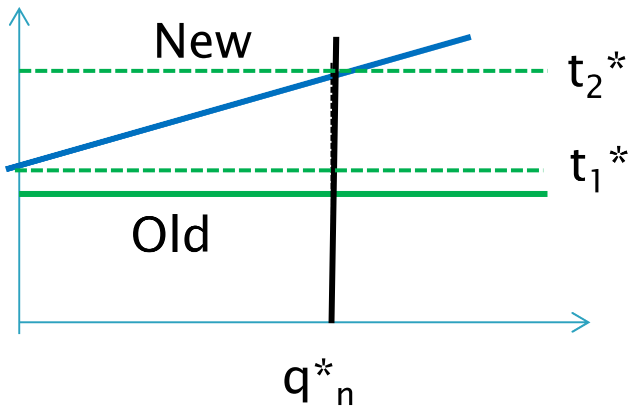


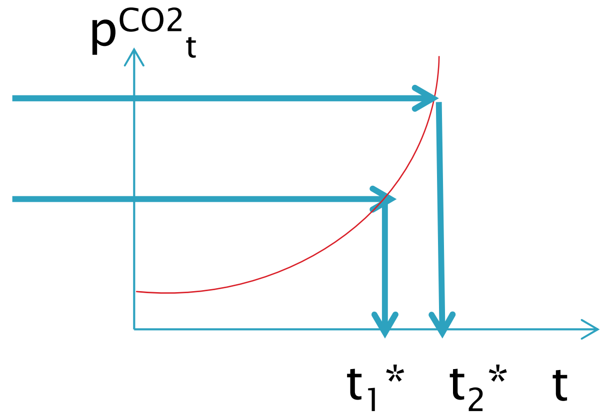
Basic MAC

$$p^{CO2}_{t^*} = (c_o - c_n)/e$$



With convexity a range of static MAC for a trajectory





What if convexity and learning by doing?

1. Convexity induces a transition in the deployment
2. Along the optimal trajectory the static MACs are equal to the cost of carbon
3. With learning-by-doing a learning effect has to be introduced in this equality
4. Does the transition starts earlier or later?
5. Suppose the trajectory is given, when to start the transition?
6. What if there is more than one sector?

→In this paper we explore (revisit) questions 1 to 5

Related literature (I)

- Our modeling choices are close to papers analysing the role of cost convexities in the dynamics of abatement costs:
-
  - The shape and the structure of MAC curves are sensitive to many factors, in particular to technical change (Goulder and Mathai, 2000; Manne and Richels, 2004)
  - Amigues et al. (2014) analyze the optimal timing of carbon capture and storage policies under increasing returns to scale and find that the carbon capture of the emissions should start earlier than under a constant average cost assumption.
  - Bramoullé and Olson (2005) examine why infant technologies may be preferred to mature technologies because of learning-by-doing and cost convexity
  - Vogt-Schilb et al. (2012) introduce convexities in the cost functions of various sectors and show that the date at which the respective renewable technologies should be launched depends on the degree of the cost convexities.

Related Literature (II)

- Our contribution is complementary to large scale bottom-up models which have integrated endogenous technological change with learning-by-doing (MESSAGE, MARKAL and POLES) or sectorial ones (Rösler et al., 2014).

- Our approach allows to analytically characterise optimal deployment trajectories, and to calibrate them in the context of an empirical case study:

  - the transition from Internal Combustion Engine (ICE) vehicles to Fuel Cell Electric Vehicle (FCEV).

Main results

- We analyse the transition issue as the whole deployment phase of the new technology in substitution to an old polluting technology.
- The optimal trajectory is a smooth transition in which green cars progressively replace old cars.

  - *During the transition* the CO_2 price should be equal to the sum of two terms: the difference between the cost of the marginal green car and a polluting car; and the learning benefits over the future.
  - *At the end of the transition* the fleet is completely green.

- We characterize the second best MAC by addressing the following questions:
  - At which date the date the new technology should be launched? At which rate would its deployment occurs?
- As for the FCEV case study, the dynamic abatement cost which allows to launch hydrogen car deployment in 2015 is 53 €/tCO_2.

Outline

The model

Optimal abatement trajectories

Launching date and deployment strategies: second best

Illustration: the FCEV case

Further research

The model

- Consider a car fleet of size N, measured in tCO_2 per year;
- Initially the fleet is entirely composed of "old" cars;
- At date t there are x_t "green cars" and $N - x_t$ old cars;
- Costs :
  - an old car costs c_0 that does not depend on t nor past production;
  - and green cars are subject to **learning-by-doing** their cost is $C(X_t, x_t)$ in which

$$X_t = \int_0^t x_\tau d\tau.$$

  - $C(X, x)$ and $C_x(X, x)$ are decreasing and convex with respect to X.
  - $C(X, x)$ is convex.

The model
Optimal trajectory -1

- There is a discount rate r;
- The price (social cost) of carbon is

$$p_t^{CO2} = p_0 e^{rt}$$

- The objective of the social planer is to minimize :

$$\Gamma = \int_0^{+\infty} e^{-rt} \left[(p_t^{CO2} + c_o).(N - x_t) + C(X_t, x_t) \right] dt$$

$$\text{s.t.}$$

$$\dot{X}_t = x_t \qquad \lambda_t$$

$$0 \leq x_t \leq N \qquad \theta_t, \delta_t.$$

The model
Optimal trajectory -2

Proposition

The production of green cars increases over time. There are two dates T_s and T_e, with $T_s \leq T_e$, at which the transition respectively starts and ends:

$$x_t = 0 \text{ for } t \leq T_s$$

$$0 < x_t < N \text{ for } T_s < t < T_e$$

$$x_t = N \text{ for } t \geq T_e$$

During the transition,

$$p_t^{CO2} = \underbrace{[C_x(X_t, x_t) - c_o]}_{\text{static abatement cost}} + \underbrace{\int_t^{+\infty} e^{-r(\tau - t)} C_X(X_\tau, x_\tau) d\tau}_{\text{learning benefit } (<0)} \qquad (1)$$

The model

The deployement perspective (1)

- We propose to decompose the problem:
  - There is an exogeneous "deployment scenario" that lasts D years, during which $\bar{X}$ cars are produced with a schedule (x_τ);
  - The planner should only choose the date T_I at which the deployment is launched
  - after date $T_I + D$, the deployment is achieved and the fleet is entirely green.
- The planner objective could be written

$$\Gamma(T_I) = \underbrace{\int_0^{T_I+D} e^{-rt}(c_o + p_t^{CO2})Ndt}_{\text{fully old fleet}} + \underbrace{e^{-rT_I} I - p_0 \bar{X}}_{\text{deployment phase}} + \underbrace{e^{-r(T_I+D)}\Omega(\bar{X})}_{\text{fully green fleet}}.$$

with

$$\Omega(X) = \int_0^{+\infty} e^{-rt} C(X + tN, N)dt.$$

The model

The deployement perspective (2)

Proposition

The optimal launching date T_I^* of the deployment scenario (ξ_τ) is such that:

$$p_0 e^{rT_I^*} = \frac{rI}{N} + \left[\frac{r\Omega(\bar{X})}{N} - c_0\right] e^{-rD} \qquad (2)$$

- It is *as if* the deployment is a big plant that reduces emissions by N with an investment cost I and an operating cost $r\Omega - c_0 N$.
- The resulting CO_2 price, that triggers the deployment, can be interpreted as the abatement cost of the deployment scenario;
- The metric is relevant for sub-optimal deployment trajectories.

The model

Some comparative statics(3)

- To analyse how the sub-optimality of deployment scenario impacts the launching date, we describe an optimal trajectory as an optimal deployment scenario and the associated optimal launching date.

Proposition

If the deployment scenario is suboptimal :

- *If the deployment cost is not minimized* $(\xi_T \neq \xi_T^*)$, *the launching should be postponed;*
- *If the total number of green cars produced during deployment is larger than the optimal one* $(\bar{X} > \bar{X}^*)$, *the launching should be postponed;*
- *If the total number of green cars produced during deployment is slightly lower than the optimal one* $(\bar{X} < \bar{X}^*)$, *the launching should take place earlier.*

Illustration
The case of the FCEV

Model building: CBA

Questions

- When to launch the deployment of the program
  as calibrated from industry data
- Why the static abatment cost is a poor indicator
- What is the appropriate abatement cost
- What if to launch the program in 2015

Data and model building
the susbstitution of ICE to FCEV for the German market

FCEV car park in million units

15% market share in 2050

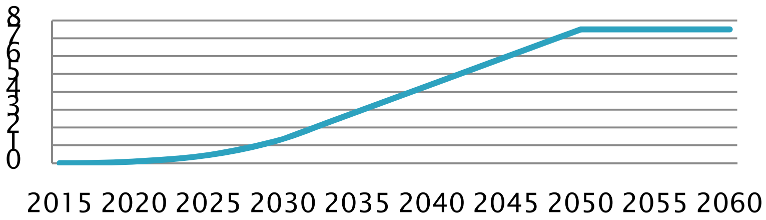
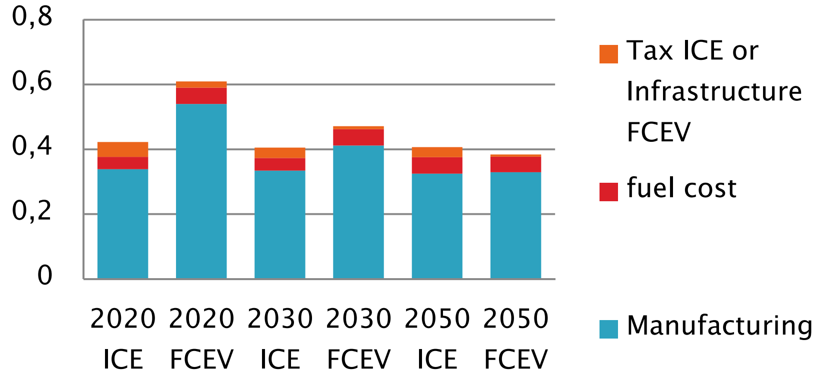
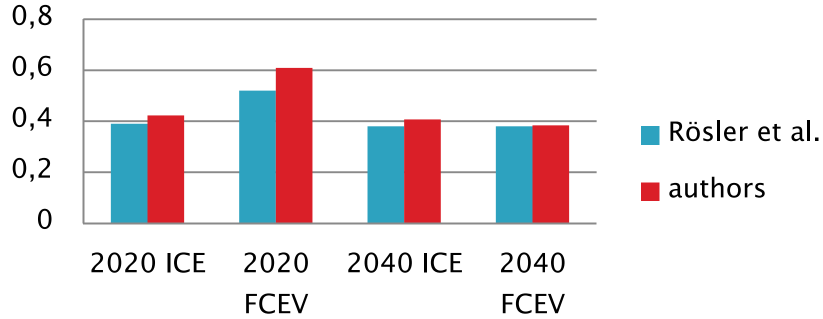


Fig 1: TCO in €/km per year



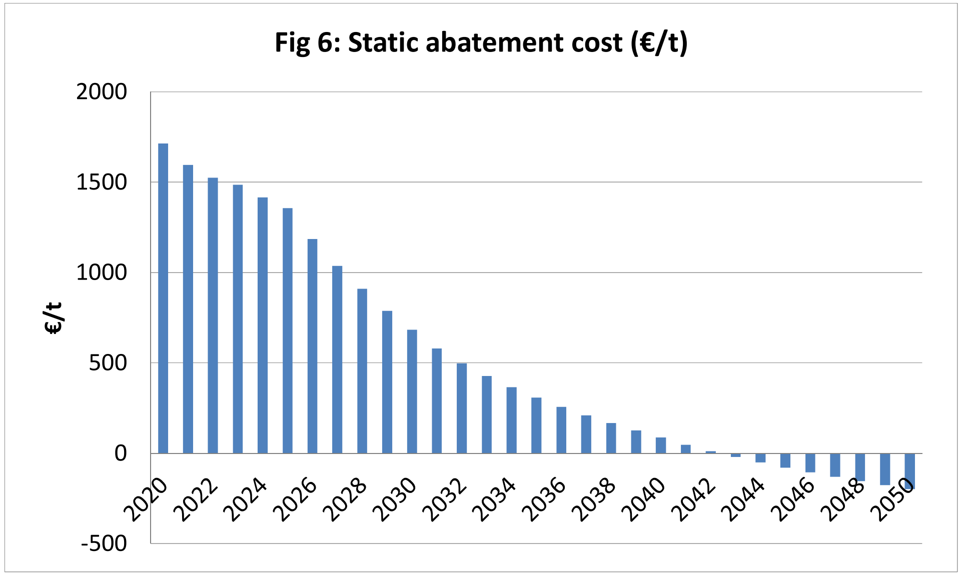
From an exogenous ramp up scenario
to a simple (Excel) model for
- manufacturing, fuel, infrastructure costs
- CO2 emissions
- calibrated on previous studies

Fig 2: TCO authors versus Rösler et al. (2014)



TCO=Total Cost of Ownership

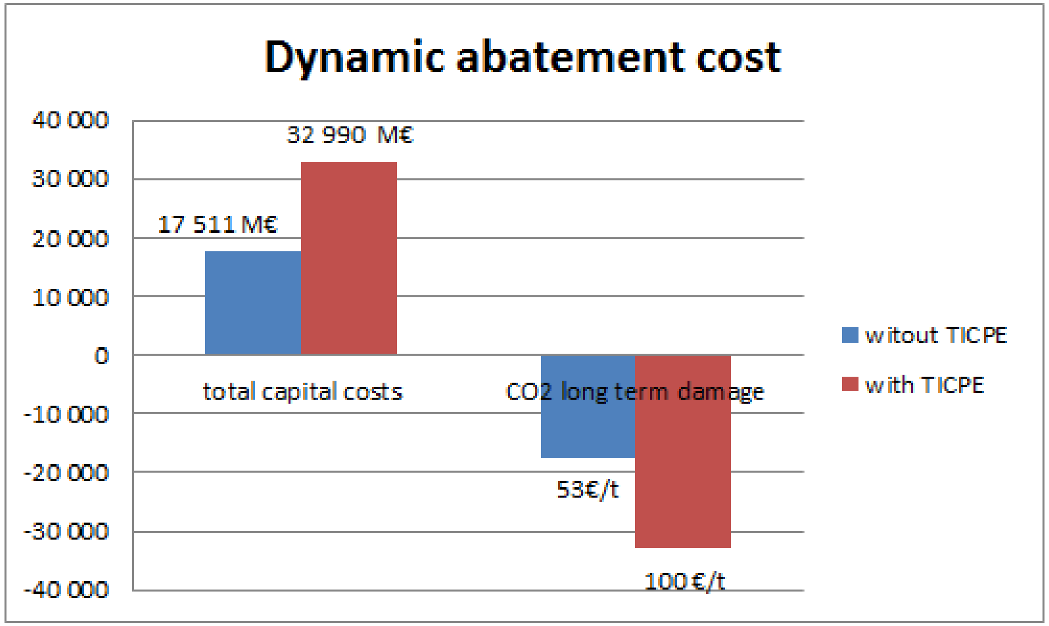
Static abatment costs for one car FCEV vs ICE



The SMAC at year n depends on the earlier deployment

How to take care of this inconsistency?

Dynamic abatment cost for the program



Methodology

- Take the deployment as a « green plant » to be launched in 2050
- Assume infinite life duration and no further cost (TCOs converge)
- Compute emissions avoided in 2050

Calculation
(no TICPE)
53 €/t = Capital cost* 4% /
13,2 Mt emissions avoided in 2050

The optimal timing is 2030

TICPE= gasoline tax

What if to launch the program in 2015

Table 2 Target analysis	unit	Base case	4 parameter target
Discounted cost for the scenario up to 2050	M€	17 511	10 582
Avoided CO2 emissions in 2050	Mt/year	13,2	14,1
Dynamic abatement cost	€/t	53	30
Market size in % of total car park	%	15%	**20%**
Gasoline price (yearly rate of increase)	%	1,4%	**1,8%**
Manufacturing cost (FCEV vs ICE in 2050)	%	11,3%	**9,8%**
Hydrogen production cost in 2050	€/kg	6,8	**6,2**

Base case

Suggested Target

Concluding comments

- The static abatement cost is a poor instrument for policy analysis; it decreases from 1600 €/tCO2 in 2020 to 650 €/tCO2 in 2030, is null in 2042 and then becomes negative

- Our methodology integrates learning-by-doing, provides a simple summary proxy for policy analysis and delivers an attractive framework for simulations

  - The dynamic abatement cost for the reference scenario is 53 €/tCO2 in 2015
  - Assume the normative social cost of carbon is 30 €/tCO2 in 2015 (Quinet 2009, Quinet 2013)
    - ✓ The optimal launching date should be postponed from 2015 to 2030
    - ✓ Or some key parameters of the scenario should be strenghtened

- Limitations and Extensions
  - Financing ; complementary innovations

Thank you!

anna.creti@dauphine.fr