Chair Energy & Prosperity

Workshop Extending the boundaries of environmental assessments: coupling of Life Cycle Assessment with economic modelling

Extending the limits of the abatement curve

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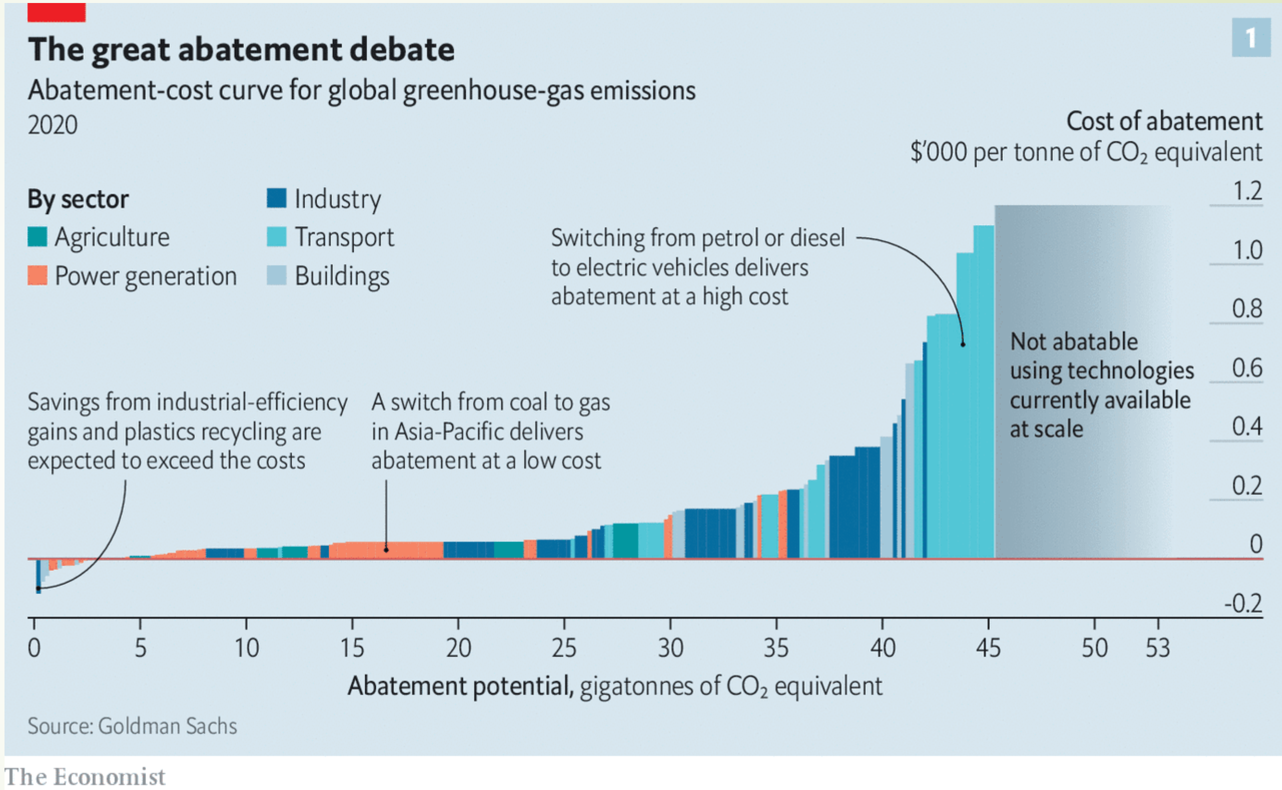
Outline of presentation

- ✓ This paper: Revisit and extend the abatement curve
  - Life Cycle Analysis
  - Sector interactions
- ✓ The abatement curve: a popular tool in cost benefit analysis
- ✓ A tool that attracted many criticisms

The Marginal Abatement Curve is popular tool

- McKinsey, Boston Consulting Group, Goldman Sachs…
- Ranking of MACs by increasing order is used to define a decarbonization trajectory
- **Giving up carbs**
  What is the cheapest way to cut carbon?
  The Economist [Feb 27th 2021 edition]



A tool that attracted many criticisms

Gillingham, K. and Stock, J. H., 2018. The Cost of Reducing Greenhouse Gas Emissions, *Journal of Economic Perspectives,* Vol 32-4, 53–72.

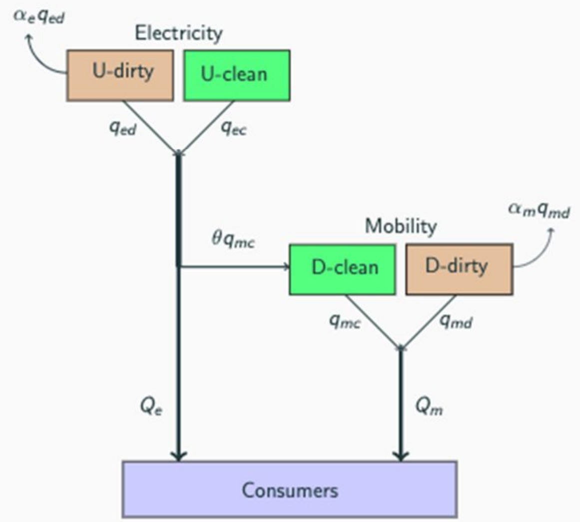
- Sector approach
  - Intersectoral aspects: upstream downstream, economies of scale
  - Intertemporal aspects: endogenous technical change (LBD, spillovers), inertia
  - Ancillary benefits: health, productivity
  - Local factors: competitive advantage, transaction costs, behavioral changes (rebound effects)
- Global approach (integrated assessment models)
  - Complexity
  - Lack of transparency

The benefit of a dual approach

The CBA framework	Sector Volontary scenario	Global Optimum scenario
Objective	Decarbonize mobility	Decarbonize the whole economy at the 2050 horizon
Scenario	Exogenously defined thru local constraints « gray » or « green » scenario	« optimal » under simplified global technological assumptions
Interactions	LCA with electricity	Horizontal+vertical thru an optimization model
Time horizon	Life time of the project 2030	Target NZE at 2050
Reference scenario	Business as usual (BAU)	Comparison of « admissible » scenarios

an illustrative example
based on Hoarau and Meunier, 2021

- Static partial equilibrium model
- Two sector: electricity (e) and mobility (m)
- Two technologies : "dirty" (d) and "clean" (c)
- Sector coupling: θ units of electricity per unit of clean mobility



Numerical illustration

Assumptions			
Parameter	Value		Definition
θ	0,5		upstream consumption of each clean downstream
αe	1		emission of each dirty electricity unit
αm	1		emission of each dirty mobility unit
ced	20		cost of each dirty electricity unit (constant)
cmd	20		cost of each dirty mobility unit (constant)
cec	20	200	cost of clean electricity (stepwise)
qecmax	25	125	maxmimum clean electricity production for each cost
cmc	60	150	cost of clean mobility (stepwise)
qmcmax	50	50	maxmimum clean mobility production for each cost
Qe0	100		electricity inelastic demand
Qm0	100		mobility inelastic demand

Discount rate is taken at 8%

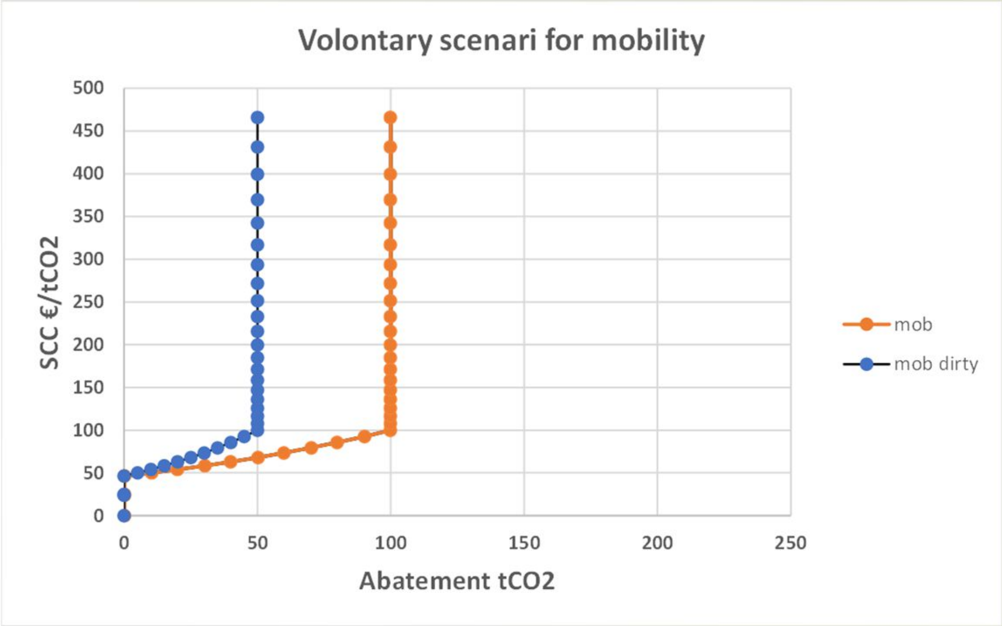
SCC 2020 = 46 €/tCO_2 growth rate also at 8% → SCC 2030 =100 €/tCO_2

SCC 2050 = 466 €/tCO_2

8

A volontary sector scenario for mobility over a finite horizon (10 years)

- **Two assumptions**
- Decarbonization by step
  - 10 more units each year
  - From 2021 to 2030
- Electricity with
  - Clean technology 2 ced + cec=220
  - Dirty technology ced = 20



CBA of the volontary scenario over a finite horizon (10 years) w.r.t BAU

$$- \sum C_n / (1+r)^n + p° \sum (1+r)^n \; A_n / (1+r)^n = - \sum C_n / (1+r)^n + p° \sum A_n$$

No discounting of abatements

$$MAC\ (mob\ 20\text{-}30 \mid BAU) = \sum C_n / (1+r)^n \; / \sum A_n < p°$$

Scenario	NPV € @2020 -2030	Abatements tCO2 2020-2030	Marginal abatement cost €/tCO2	SCC €/tCO2
Green mobility	77 949	550	114	46 @2020 117 @2032
Gray mobility	46 897	440	72	73 @2026
BAU	15 420			

The puzzle of extending the horizon

$$- \sum C_n / (1+r)^n + p° \sum (1+r)^n A_n / (1+r)^n = - \sum C_n / (1+r)^n + p° \sum A_n$$

No discounting of abatements

$$MAC\ (mob\ 20\text{-}30 \mid BAU) = \sum C_n / (1+r)^n / \sum A_n < p°$$

0

Bounded

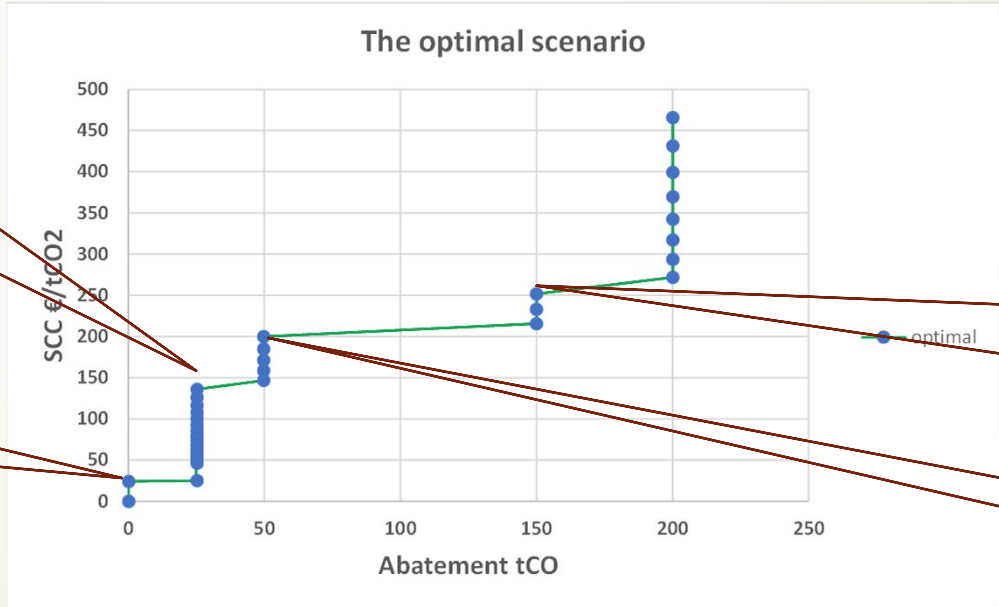
Unbounded

Any scenario should be implemented at once!

CBA of the optimal scenario thru a multi-sector model

Mac(mob1/L CA dirty)= (60 + 20/2)/(1 -,5) = 140

Mac(elec 1)= (20 + 20)= 40



Mac(mob2/L CA clean)= (150 + 220/2) = 260

Mac(elec 2)= (20 + 200)= 220

Comparison of two scenari over an infinite horizon: numerical illustration

The reference scenario = the global optimum through an optimization model thru 2050
The inferior « volontary » scenario extended from mob 20-30 to 2050

Scenario	NPV € @2020 Up to 2050	Abatements tCO_2 Up to 2050	Marginal abatement cost €/tCO_2	SCC €/tCO_2
Optimum	57 974	3 025		
Green mobility extended	184 820	4 225		
Green/optimum	126 847	1 450	87	46 @2020

Comparison of two scenari over an infinite horizon: numerical illustration

Select the « best » scenario from a portfolio

Special case: optimal timing of green mob (Creti et al. 2018)

Let *I* be the discounted of volontary versus BAU (including residual value)

and *A* the annual abatement in steady state (post 2030)

DMAC = *rI/A* = 8%(77 949 + 293 750)/100 = 297 €/tCO2 → 2045**

Using the abatement curve to dig out for the « best » sector scenario

Select the relevant time horizon?

- Life time of the project? **No**
- Time for complete decarbonization of the sector? **Yes**

Select the reference scenario?

- Business as Usual? **No**
- Rank admissible scenarios? **Yes**

Integrate the boundaries of the sector?

- Vertical (LCA)? **for the upstream sector (grid and local production such as ENR)**
- Horizontal (economies of scope)? **All local mobility usages to assess the economics of infrastructure; All regional deployments to assess LBD**
- Local constraints? **Introduce ancillary benefits (air pollution) and behavioral changes**

Plenty of applications for regional mobility projects

https://vighy.france-hydrogene.org/cartographie-des-projets-et-stations/

- **Projects partially analyzed thru dual approach**
  - **EAS-Hymob**
  - **ZEV**
  - **FCEB …**
- **Encouragements from the French hydrogen plan (to be done!)**
  - **AUXR_HUBH2, Cannes Lérins H2, DBeaut'Hy Truck, H2 Loire Vallée, H2 Nord Franche-Comté …**

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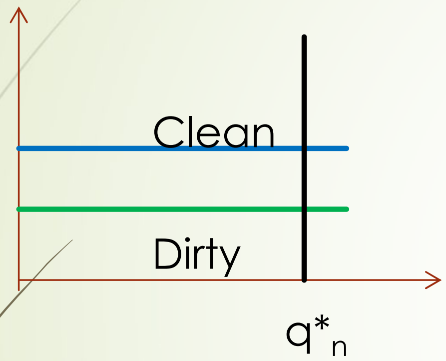
Thank you for your attention

http://www.chair-energy-prosperity.org/

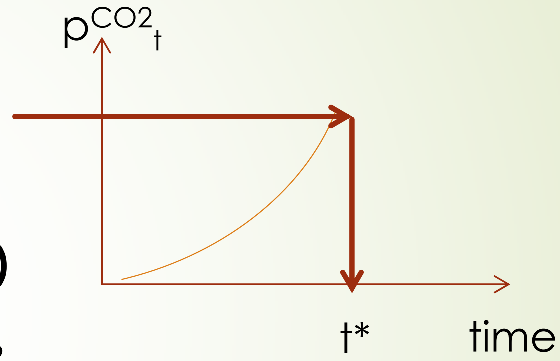
A familiar tool to capture the cost benefit of a technology, a project or a scenario… to decarbonize an activity, a sector, the economy…

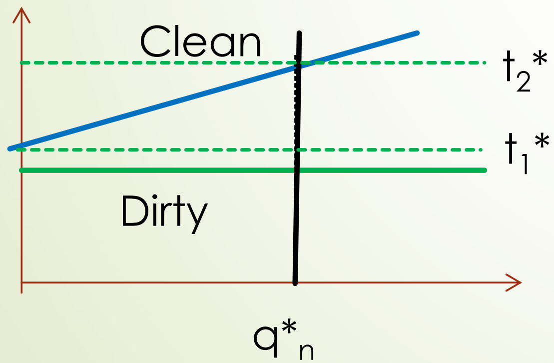


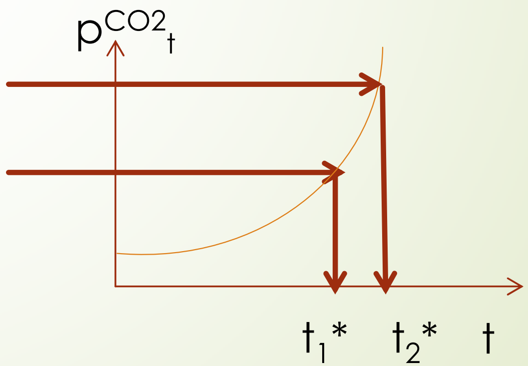
$\uparrow p^{CO2}_t$

MAC=$(C_n - C_o)/(E_0 - E_n)$

t* such that MAC=$p^{CO2}_{t^*}$







With convexity a range of static MAC's i.e. an abatement curve

CBA of a scenario over an infinite horizon

- **An admissible scenario includes a trajectory towards a zero net emissions (at 2050) (blue mob is excluded, green mob need be extended)**

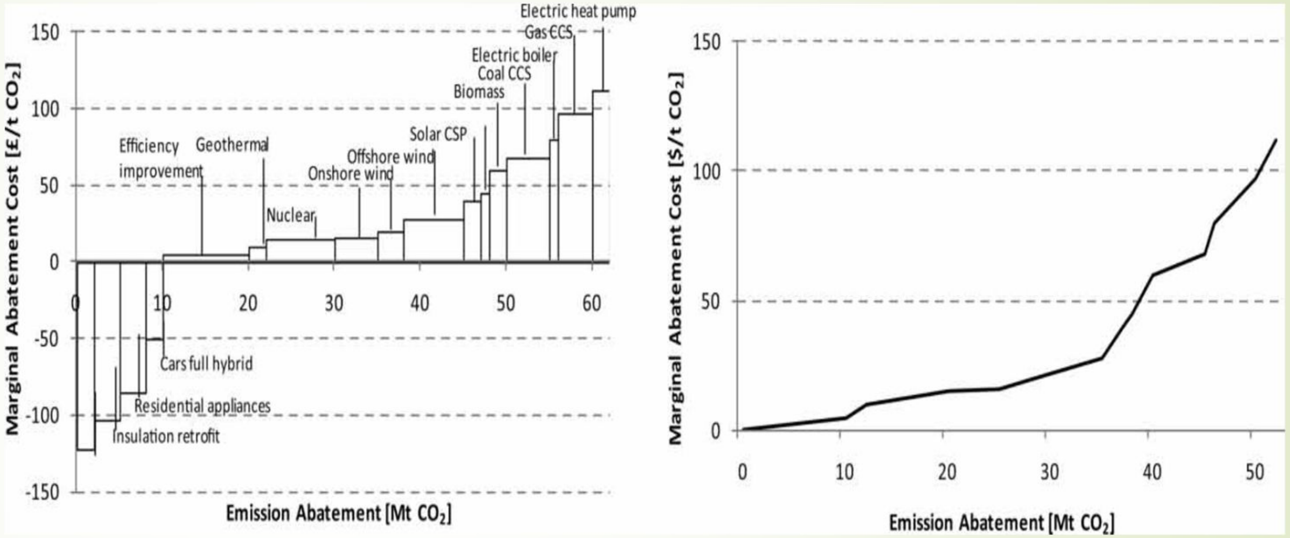
- **BAU can no longer be used as the reference since any admissible scenario would be better**

- **Two admissible scenari may differ**
  - **in the sequence de decarbonization**
  - **in the local factors for one sector**

- **The optimal scenario need be constructed for the whole perimeter under study including upstream downstream interactions**

The Abatement Curve

- Kesicki, F., and Ekins, P., 2012, Marginal abatement cost curves: a call for caution *Climate Policy*, vol. 12-2, 219-236.
- Ranking of static abatement costs by increasing order generates an abatement curve



Methodology for Static Abatement Cost

- Friedmann S. J., et al. 2020, *Levelized cost of carbon abatement : an improved cost-assessment methodology for a net-zero emissions world*. Columbia-SIPA, Center for Global Energy Policy
- LCCA = $(C_t - C_0)/(E_0 - E_t)$

Table 7: LCCA comparison for low-carbon steel alternatives

Comparison cases	Baseline	Carbon abatement (kg/ton-HM)	Carbon abatement fraction	Additional cost ($/ton-HM)	LCCA ($/ton-$CO_2$)
DRI-EAF new	BF/BOF (end-life*)	830	37.3%	114.32	137.73
EAF scrap new	BF/BOF (end-life*)	1383	62.2%	19.13	13.83
BF/BOF blue H_2 retrofit	BF/BOF	440	19.8%	53.08	120.64
BF/BOF green H_2 retrofit	BF/BOF	415	18.7%	182.46	439.66
DRI-EAF blue H_2 retrofit	DRI-EAF	438	31.4%	128.60	293.61
BF/BOF zero-C elec**	BF/BOF	164	7.4%	19.94	121.74**
DRI-EAF zero-C elec**	DRI-EAF	566	40.6%	68.94	121.74**
EAF scrap zero-C elec**	EAF scrap	422	50.1%	51.41	121.74**
BF/BOF CCS retrofit	BF/BOF	800	36.0%	38.4-56.8	48-71

**For replacing an existing steel production facility which is already capitally paid off, only OpEx is regarded as the original cost for LCCA calculation. This is a conservative assumption—early retirement and replacement of BF/BOF plants would add costs to the LCCA numerator.*

***Using zero-C electricity for iron and steel production, assuming electricity from the grid is zero-carbon and not subjected to additional retrofit cost with $120/ton-$CO_2$ LCCA.*

An application to a regional project for decarbonizing mobility
EAS-HyMob Normandy Project

https://eashymob.normandie.fr/fr/stations-recharge-hydrogene-normandie

- **Budget= 5M€**
- **Co-financed by EU (INEA)**
- **Duration: 2016-2018**

15 H2

250

5 years

Hyways

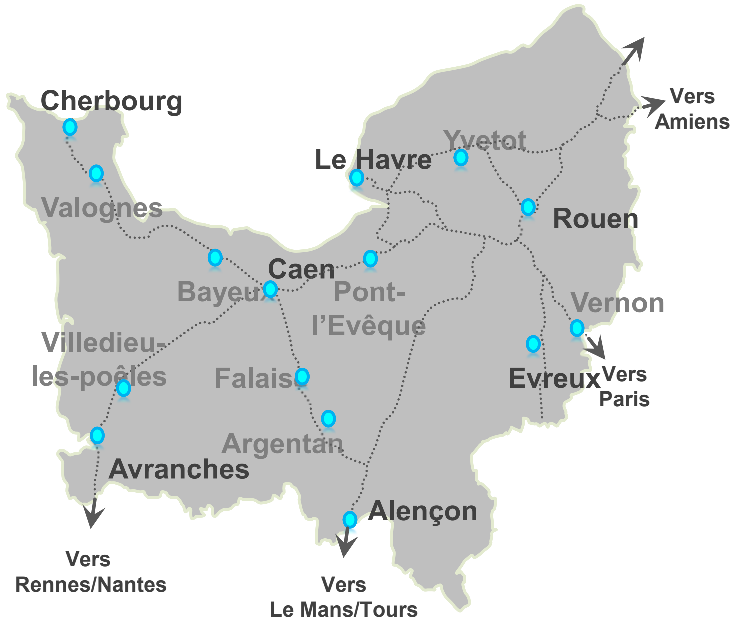
Partnership

RÉGION NORMANDIE

SERFIMGROUPE DEPUIS 1875

Symbio

HRS Network targeted for 2018



Co-financed by the European Union
Connecting Europe Facility

Policies and deployment for Fuel Cell Electric Vehicles an assessment of the Normandy project, Brunet, J. and Ponssard, J.-P. (2017). *International Journal of Hydrogen Energy* **42-7**: 4276-4284.

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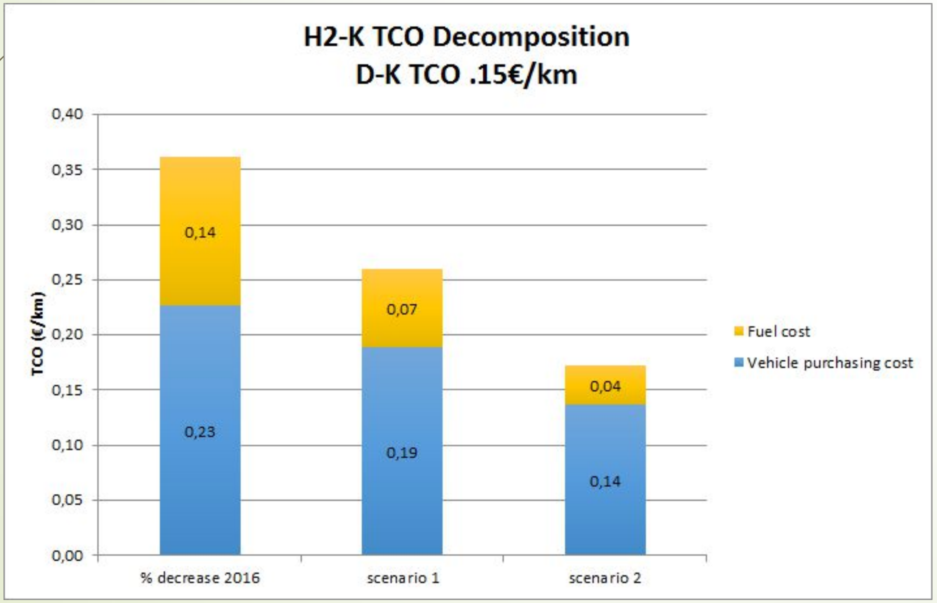
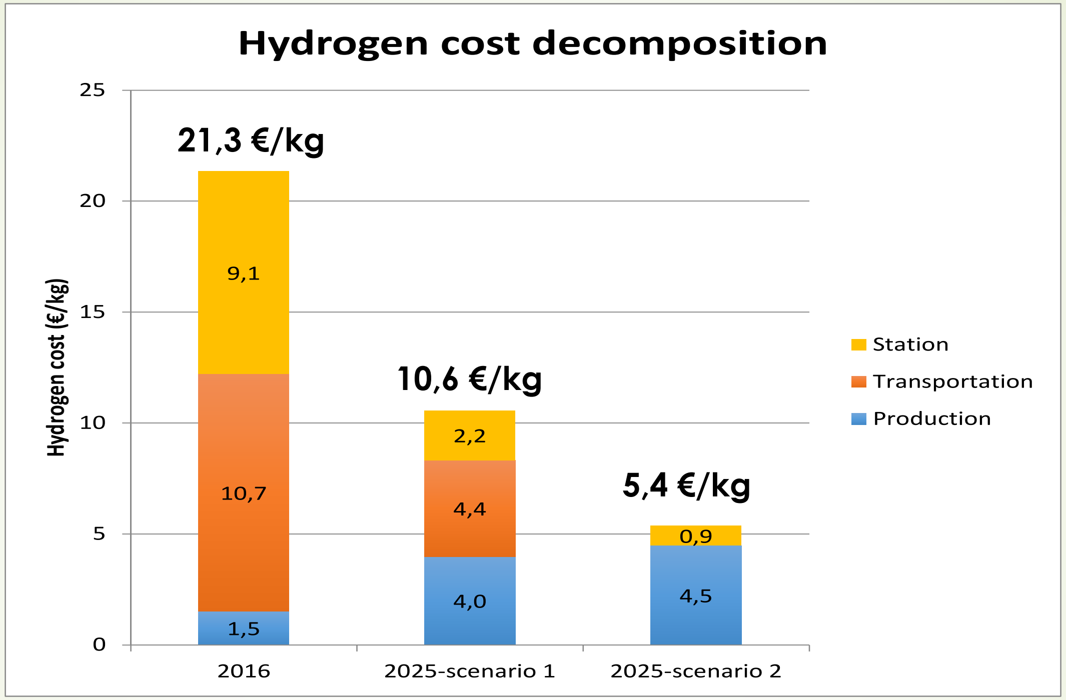
Total Cost of Ownership without subsidies		scenario 1	scenario 2
TCO Hydrogen kangoo	€/km	***0,26***	***0,17***
TCO Diesel kangoo	€/km	***0,15***	***0,15***
Delta TCO	€/km	0,11	0,02
Annual over cost	k€	3,68	0,65
CO2 abatement cost	€/tC02	***618***	***108***



% decrease 2016	scenario 1	scenario 2
Fuel cost	48%	74%
Vehicle cost	17%	40%



- **Scenario 1: 730 kg/year**
  - **Hydrogen is produced in two high powered electrolysers and the average distance electrolyser-station is 100 km. the utilization rate is 80%**
- **Scenario 2: 3 650 kg/year**
  - **Hydrogen is produced on-site by electrolysis. The utilization rate on the retail stations is of 100%.**

Result 1 Scenario 1 is not self sustainable

- **The CO2 abatement cost remains too high at 608 €/t**
- **The excessive cost comes from**
  - **Insufficient decline in purchasing cost**
  - **Insufficient decline in H2 production and distribution cost**

Result 2 Scenario 2 is self sustainable

- **The CO_2 abatement cost is within the range of expected social cost of CO_2 100€/t**
- **Two conditions**

  → A 40% decrease in vehicle cost through LBD and spill overs due to higher volumes in Normandy but also all accross Europe

  →A 74% decrease in H_2 delivery cost due to higher volume of H_2 consumption (more H2-K but also buses, trucks, sedans) resulting in a complete change in the network