Cost-Benefit Analysis of Hydrogen for Energy Transition in Container Glass Sector: A Case Study

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Table of Contents

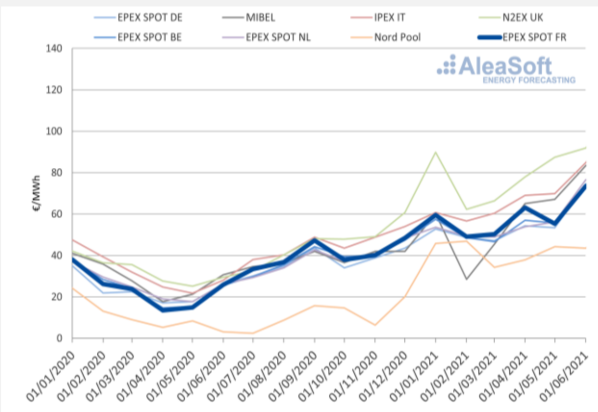
Context

- The **industry sector** accounted for **38%** (around 156 EJ) of **total global final energy use, 26%** (8.6 $GtCO_2eq$) **of global emissions,** and **24%** (70 $MtCO_2eq$) of **French national emissions** in 2020 (IEA, 2021).
- **Clean hydrogen** is a promising energy vector for carbon-neutrality of so-called hard-to-abate industrial sectors.
- In 2020, two-thirds of the European hydrogen production was consumed **on-site** due to the **high cost of transport** and **technical issues** (Hydrogen Europe, 2020).
- **Energy-intensive** industrial sectors need a **continuous energy supply**, which excludes the direct use of intermittent renewable energy sources.
- The continuous need for energy supply makes the on-site hydrogen production cost **depends on the grid electricity price.**
- The readiness of industries to switch from their polluting technologies is directly influenced by **fossil fuels and carbon market prices**.
- **Volatile and unfavorable electricity, fossil fuel, and carbon market** prices affect the private firms' decision-making.
- **CCfD** is seen as a support mechanism to eliminate the uncertainty of carbon market prices.

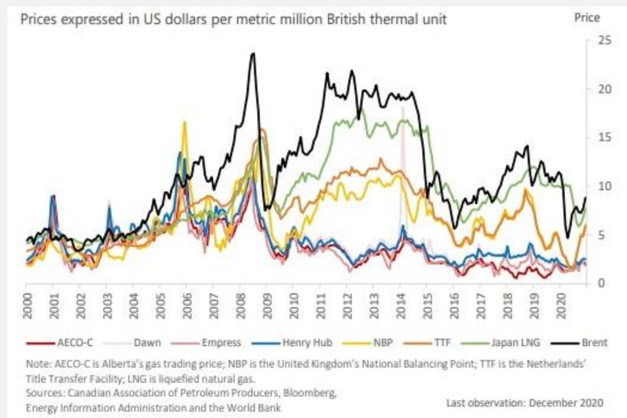
Research Question

- **The Challenge:** The production of most of the industrial materials is energy-intensive with a continuous process requiring a constant supply of energy fuels that poses the risk of uncertain and unfavorable energy and carbon market prices

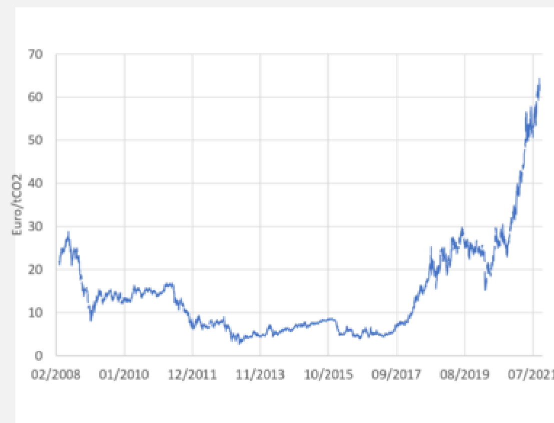
European Electricty Market Prices



Natural Gas Prices



EU ETS Carbon Prices

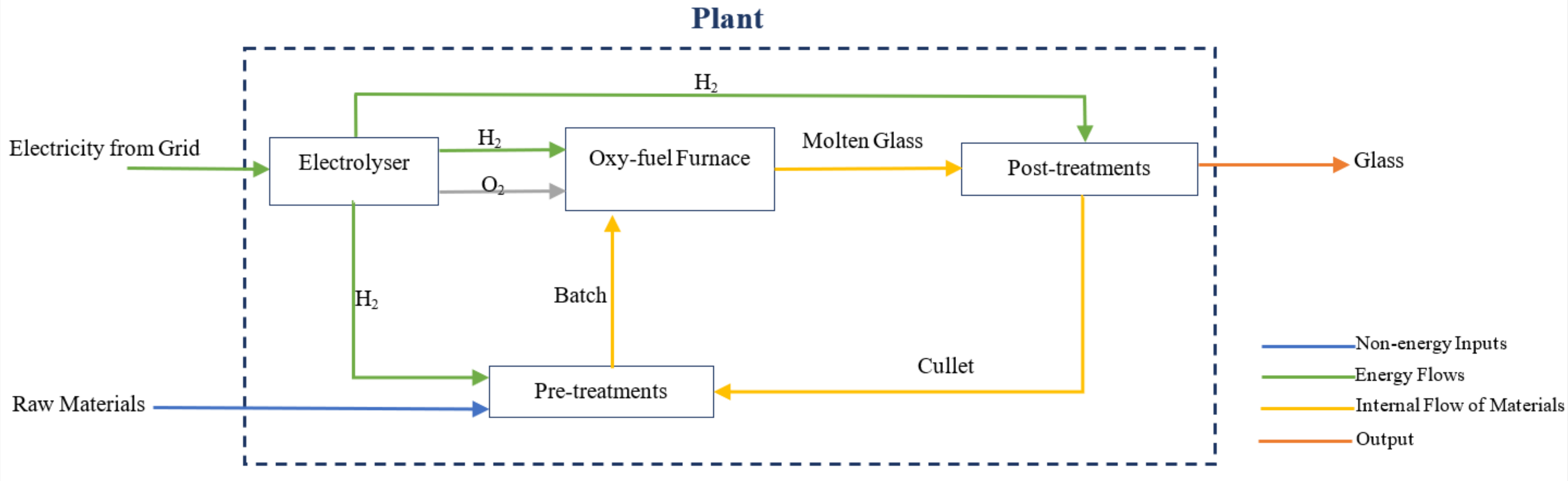


Source: European Commission and AleaSoft Energy Forecasting

- **Research Question:**
  - What are the impacts of energy and carbon market prices on the deployment of hydrogen?
  - What innovation policies exist to mitigate the risk of uncertain market prices?

Introduction to the Case-Study

- **Case-Study:** Container Glass Manufacturing Unit in North of France
- **Counterfactual Case:** Natural Gas as the Energy Fuel



Introduction to the Case-Study

- **Glass Industry in France**

Distribution and Production Volume of the National Glass Plants

Type	Number of Plants	Total Production (t/y)	Share of the Production Volume	Average Production per Plant (t/y)
Container glass	33	3 298 537	73.4%	~ 100 000
Flat glass	6	1 080 654	17.3%	~ 180 000
Fiberglass	7	381 686	8.5%	~ 55 000
Specialty glass	6	36 672	0.8%	~ 6 000
TOTAL	**52**	**4 797 549**	**100%**	-

Source: L'élémentarium - Verres

- GHG Reduction Targets in the Sector:
  - 24% reduction in Scope 1 & 2 GHG emissions in 2030 compared to 2015
  - 88% reduction in Scope 1 & 2 GHG emissions in 2050 compared to 2015
- So far, the glass sector has benefited from **free emission allocations** on EU ETS.

Introduction to the Case-Study

- Decarbonization Options in Container Glass Industry

	Hydrogen	Electrification	Biofuel
Pros	• Comptability with large scale furnaces • Longer furnace life-time (similar to NG fueled furnaces) • Direct use of oxygen or heat co-product if the production is on-site	• Already stablished technology • More efficient direct heating by using immersed electrodes • Zero or very low direct emissions of CO_2, thermal NOx or SOx	• Heat transfer properties similar to NG
Cons	• Properties of a H_2 flame is different than NG • Less efficient that electrification option • Possibility of NOx emission in the absence of oxy-fuel furnaces	• Available technology only at small scale • Shorter furnace life-time (lower than NG furnace) • It is not possible to melt higher temperature glasses (>1500C) • Concern of corrosion/erosion of electrode material • Recycled glass may be an issue that requires new handling methods	• Lack of clarity on the long-term availability, cost and technical viability of resources such as biomass and the degree to which it can be considered low carbon • Since biomass must be gasified to provide biogas fuel (i.e. bio-SNG) in the glass sector, it may be preferentially utilised in sectors that can use it directly as a substitute solid fuel

Methodology

Cost-Benefit Analysis (CBA)

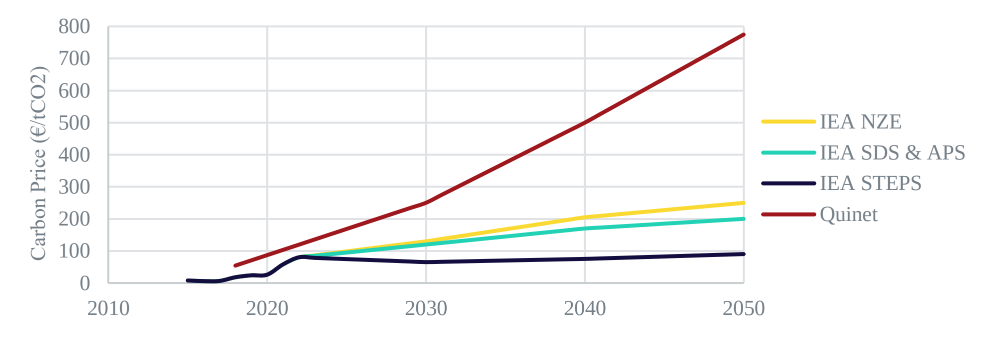
- **Main Objectives:** Determine the economic efficiency of the project and compare scenarios
- **Main Advantages:** CBA allows differentiation of 'Social' and 'Private' perspectives in:
  - **Choice of Discount Rates (DR):** a higher DR from a private perspective due to higher rates of uncertainty and risk
  - **Discrepancy in the social cost of carbon (SCC) and carbon market prices (EU ETS)**
  - **Monetizing of externalities:** from a social standpoint such as the environmental damage cost

Methodology

- **Choice of Discount Rates**

Perspective	Lower Value	Central Value	Upper Value
Social (DR_S)	1%	3%	5%
Private (DR_P)	8%	10%	12%

- **Discrepancy in social and market prices of carbon**



Source: IEA World Energy Outlook 2021, and Quinet Report 2019

- **Monetizing the Environmental Damage Costs**

Environmental Prices Handbook: EU28 Version by CE Delft 2018

Pollutant	Lower Value (€$_{2015}$/t)	Central Value (€$_{2015}$/t)	Upper Value (€$_{2015}$/t)
Carbon Monoxide (CO)	38.3	52.6	91.8
Nitrogen Oxides (NOx)	9970	14800	22100
Sulfur Oxides (SOx)	8300	11500	17900

Methodology

- **Input Data**

Data	Value	Unit	Parameter
Annual Demand of Natural Gas in the Reference Case	213	GWh/year	D_G
Glass Production Capacity	112000	tGlass/year	Q
Annual CO_2 Emission	26034	tCO_2/year	A_C
Annual NO_X Emission	263	tNO_X/year	A_{NOX}
Annual SO_X Emission	131	tSO_X/year	A_{SOX}
Annual CO Emission	44	tCO/year	A_{CO}

Input Price	Initial Value	Unit	Parameter	Cost/Benefit Function
Investment for Electrolyser	400	€/KW	p_{IE}	$C_{IE}(D_H, p_{IE})$
Investment for Conversion of Equipment	243	€/tGlass	p_{IC}	$C_{IC}(D_H, p_{IC})$
Electricity	70	€/MWh	p_E	$C_E(D_H, p_E)$
Natural Gas	35	€/MWh	p_G	$B_G(D_G, p_G)$
Market Price of Carbon	IEA Scenarios	€/tCO_2	p_{MC}	$B_{MC}(A_C, p_{MC})$
Social Cost of Carbon	Quinet Report	€/tCO_2	p_{SCC}	$B_{SCC}(A_C, p_{SCC})$
Oxygen	60	€/tO_2	p_O	$B_O(D_H, p_O)$
NO_X	Environmental Prices Handbook	€/tNO_X	p_{NOX}	$B_{NOX}(A_{NOX}, p_{NOX})$
SO_X	Environmental Prices Handbook	€/tSO_X	p_{SOX}	$B_{SOX}(A_{SOX}, p_{SOX})$
CO	Environmental Prices Handbook	€/tCO	p_{CO}	$B_{CO}(A_{CO}, p_{CO})$

Methodology

- **Decision Criteria**
  - **Social Viability:**
    - Positive 'NPV'

$$\mathrm{NPV}_S = \sum_{t_0}^{T} \frac{B_G + B_{SCC} + B_O + B_{NOX} + B_{SOX} + B_{CO} - C_E}{(1 + DR_S)^t} - C_{IE} - C_{IC} \geq 0$$

    - 'Social Abatement Cost' lower than 'Social Cost of Carbon'

$$SAC = \frac{\sum_{t_0}^{T} \frac{C_E - B_G - B_O - B_{NOX} - B_{SOX} - B_{CO}}{(1 + DR_S)^t} + C_{IE} + C_{IC}}{\sum_{t_0}^{T} A_C} \leq SCC$$

  - **Private Viability:**
    - Positive 'NPV'

$$\mathrm{NPV}_P = \sum_{t_0}^{T} \frac{B_G + B_{MC} + B_O - C_E}{(1 + DR_P)^t} - C_{IE} - C_{IC} \geq 0$$

    - 'Hydrogen Price' higher than 'Levelized Cost of Hydrogen' and less than industry's'Willingness to Pay':

$$\mathrm{LCOH}_2 \leq \mathrm{P}_H \leq \mathrm{WTP}$$

$$\mathrm{LCOH}_2 = \frac{\sum_{t_0}^{T} \frac{C_E - B_O}{(1 + DR_P)^t} + C_{IE}}{\sum_{t_0}^{T} \frac{D_H}{(1 + DR_P)^t}}$$

$$\mathrm{WTP} = \frac{\sum_{t_0}^{T} \frac{B_G + B_{MC}}{(1 + DR_P)^t} - C_{IC}}{\sum_{t_0}^{T} \frac{D_H}{(1 + DR_P)^t}}$$

Methodology

- **Scenarios:**

  - **Scenario1:** *'full deployment of hydrogen'* when the total energy demand of the site is supplied by on-site hydrogen production.

  - **Scenario 2:** *'hybrid solution'* when only 20% of the energy demand of the site is provided by hydrogen and the rest 80% of the energy demand is supplied by electricity to electric furnaces.

Results

		Unit	Scenario 1		Scenario 2	
			Social	Private	Social	Private
Costs	Investment Cost $C_{IE} + C_{IC}$	M€	-67	-67	-41	-41
	O&M Cost $\sum_{t_0}^{T} \frac{0.4(C_{IE}+C_{IC})}{(1+DR)^t}$	M€	-9	-6	-4	-3
	Electricity Cost $\sum_{t_0}^{T} \frac{C_E}{(1+DR)^t}$	M€	-331	-232	-225	-151
Benefits	Savings on NG $\sum_{t_0}^{T} \frac{B_G}{(1+DR)^t}$	M€	+96	+64	+96	+64
	Savings on CO_2 $\sum_{t_0}^{T} \frac{B_{MC}}{(1+DR)^t}$ *or* $\sum_{t_0}^{T} \frac{B_{SCC}}{(1+DR)^t}$	M€	+202	+27	+202	+27
	Benefits from O_2 Production $\sum_{t_0}^{T} \frac{B_O}{(1+DR)^t}$	M€	+39	+26	+5	+7
	Benefits of avoiding environmental damages $\sum_{t_0}^{T} \frac{B_{NOX}+B_{SOX}+B_{CO}}{(1+DR)^t}$	M€	+139	-	+139	-
Economic Indicators	**Social Net Present Value (NPV_S)**	M€	**+69**	-	**+172**	-
	Private Net Present Value (NPV_P)	M€	-	**-189**	-	**-97**
	Social Abatement Cost (SAC)	€/tCO_2	**270**	-	**64**	-
	Levelised Cost of Hydrogen production ($LCOH_2$)	€/kgH_2	-	**2.9**	-	**2.9**
	Industry's Willingness to Pay for Hydrogen (WTP)	€/kgH_2	-	**0.92**	-	**1.9**

Results

- **Sensitivity Analysis from Social Perspective**

Impact of Investment Cost of Electrolyser

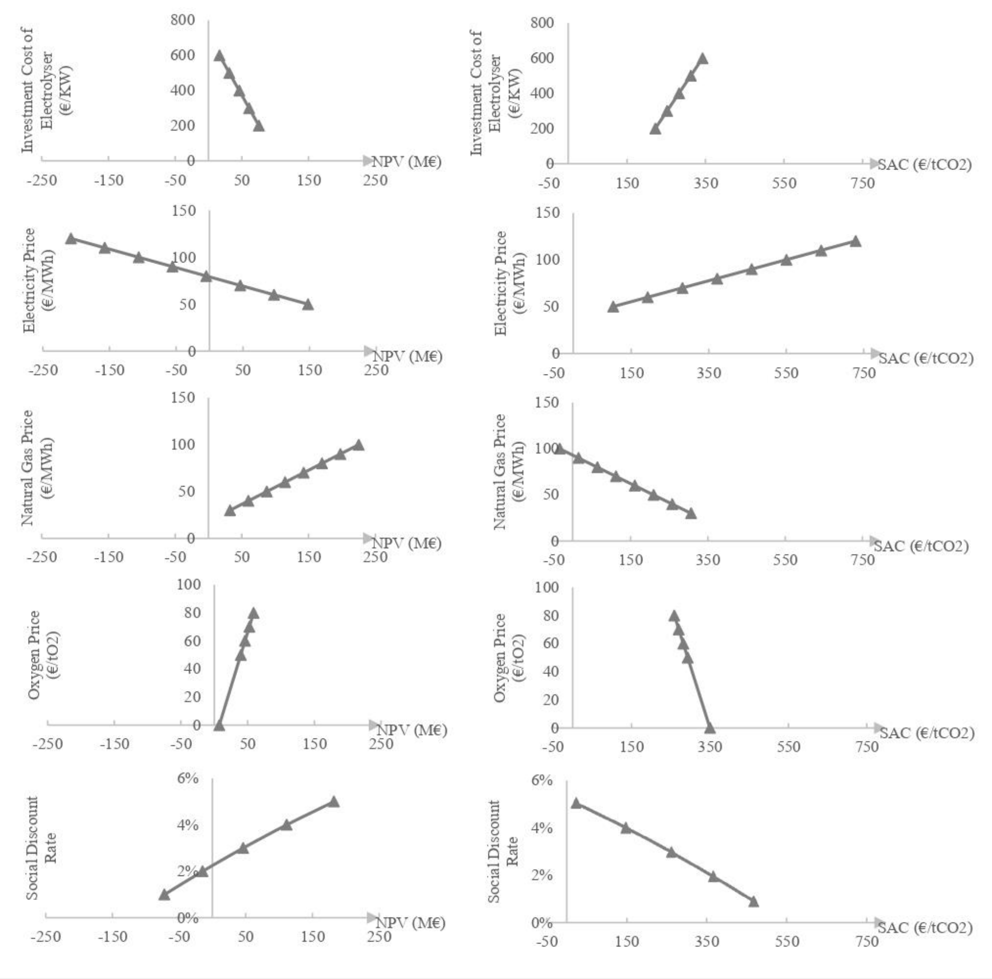
Impact of Electricity Price

Impact of Natural Gas Price

Impact of Oxygen Price

Impact of Social Discount Rate

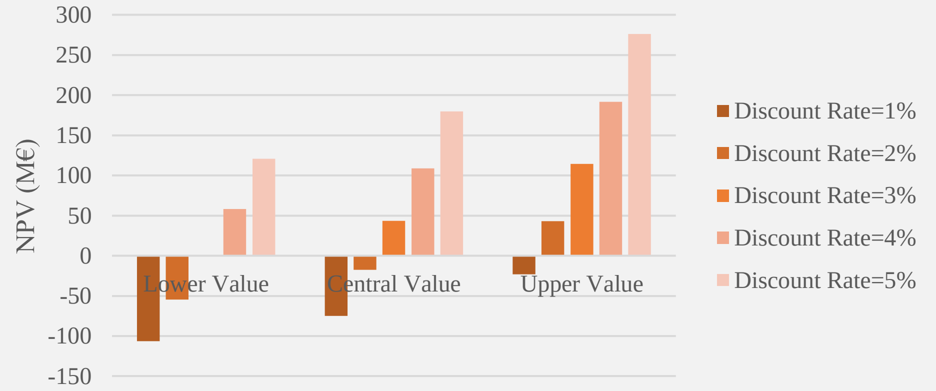
NPV | **Social Abatement Cost (SAC)**

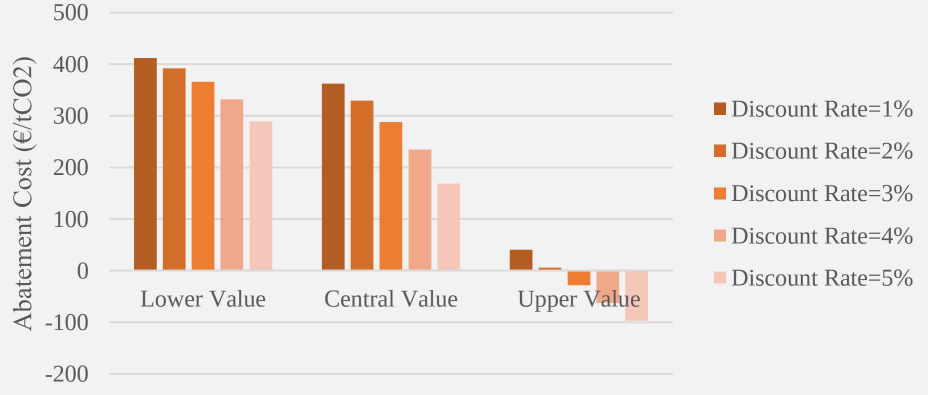


Results

- **Sensitivity Analysis from Social Perspective**

Impact of Externalities from Abatement of Environmental Damage Costs of NOx, SOx, and CO





Results

- **Sensitivity Analysis from Private Perspective**

NPV **Hydrogen Price**

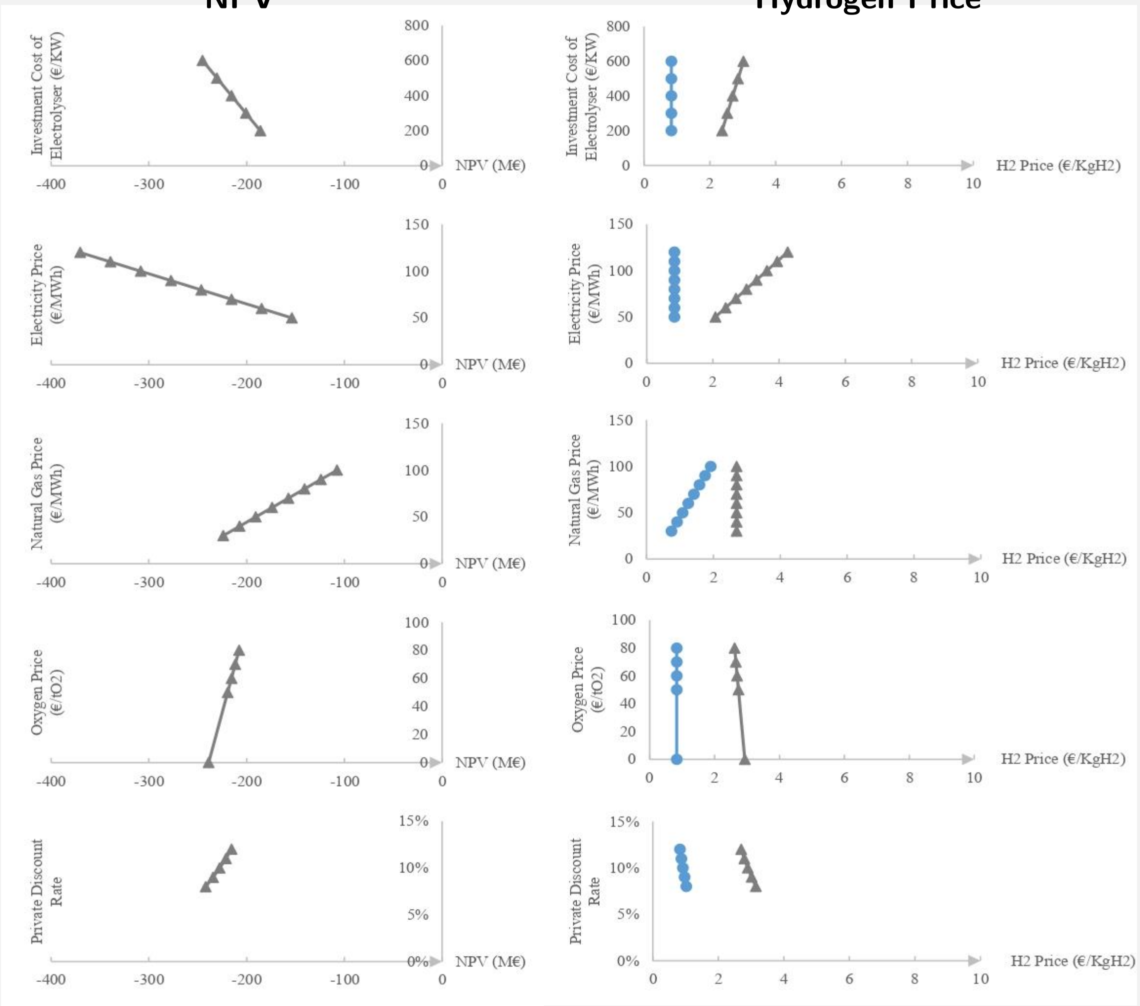
Impact of Investment Cost of Electrolyser

Impact of Electricity Price

Impact of Natural Gas Price

Impact of Oxygen Price

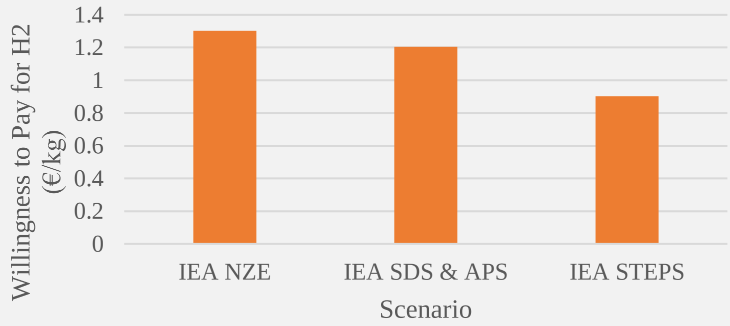
Impact of Private Discount Rate

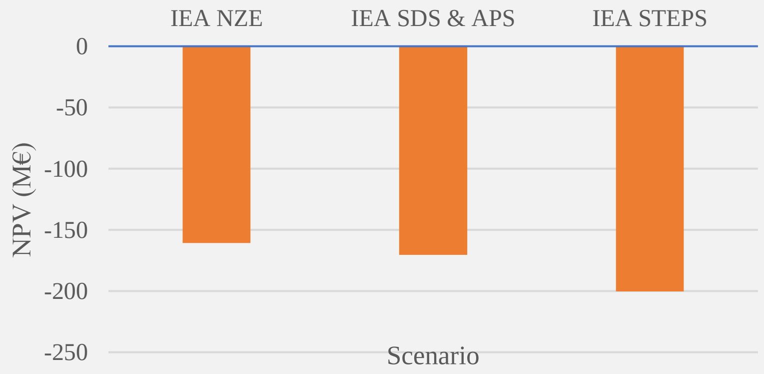


Results

- **Sensitivity Analysis from Private Perspective**

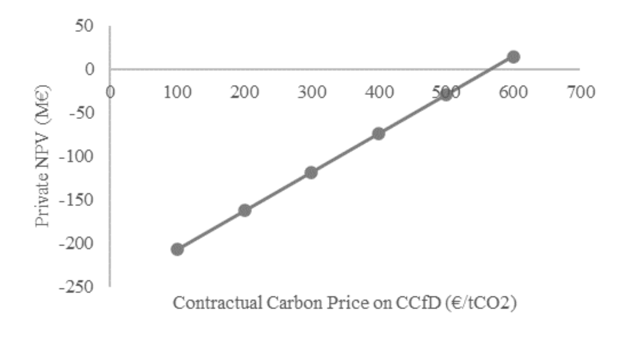
Impact of Carbon Market Price on EU ETS



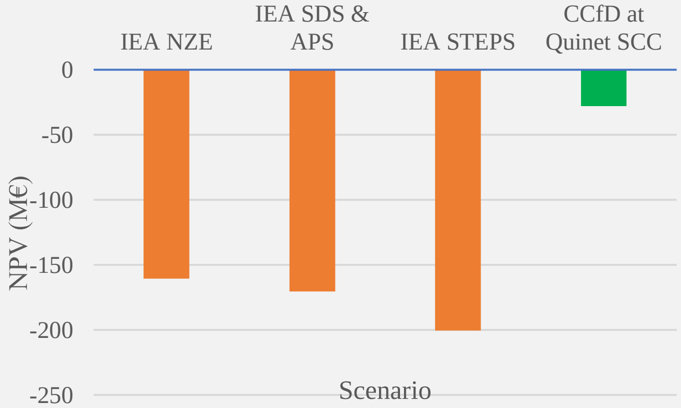


Results

- **Implementation of Carbon Contract for Difference (CCfD)**
  - Impact on the choice of the discount rate: lower DR due to a lower level of uncertainty
  - Fixed Carbon Contractual Price:



  - Carbon Contractual Price at the level of Quinet SCC



Conclusions

- The **social viability** is highly sensitive to the value of the *social discount rate* and the *prices of electricity and natural gas*. However, it is less sensitive to the investment cost of the electrolyser and the price of the oxygen.
- The **private viability** of the hydrogen deployment for the case study is the most sensitive to the *electricity and natural gas prices*. Nevertheless, the impacts of other variables are less significant.
- To reach a break-even point from a private perspective in the presence of **CCfD**, a fixed contractual carbon price of **570€/tCO_2** would be required.
- **CCfD at SCC levels** would still be not enough to make the project privately viable and it costs the public authorities around 60 M€.

Discussions

- The economic signals are not perceived similarly by public and private entities.
- A high share of operating costs in the cash flow of energy-intensive industries poses the risk of uncertain energy and carbon market prices.
- On one hand, achieving the ambitious carbon-neutrality targets requires high enough fossil fuel and carbon prices to keep the low-carbon products competitive with fossil-based ones. On the other hand, higher fossil fuel and carbon prices would result in high electricity market prices (in a merit order system) discouraging hydrogen production through electrolysis.
- As long as the electricity market is dependent on fossil-based power generators, the benefits of fossil fuel and carbon taxes are mitigated in the societies.
- It may take a decade or more until the governments are politically and economically ready to apply at scale a fully decarbonized grid and the benefits begin to flow.
- Project-based innovation policies such as CCfD are therefore essential to achieve the national decarbonization targets by 2050.

Suggestions for Further Research

- Taking into account the interdependency of the electricity, gas, and carbon market prices in the sensitivity analysis
- Analysis of the risk of the price fluctuations and diminishing of the marginal utility of the private investors contributing to the risk aversion
- Efficient designing of the CCfDs through a methodology that is technology-neutral
- Analysis of the combination of CCfD with other innovation policies

Thank You

Q&A Session