

# INDUSTRIAL PLANNING WITH INPUT-OUTPUT MODEL: EMPIRICAL EVIDENCE FROM LOW CARBON HYDROGEN IN FRANCE

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## Introduction – context

- French tradition of industrial planning for key economic sectors: telecommunications, railways, power generation (dams, nuclear program)...
- What are the links between H2 and industrial planning?
  - H2 as a GPT (General Purpose Technology) *a set of technologies with wide range of applications across all sectors which involve complementary innovation* (Bresnahan and Trajtenberg, 1995) ?
- → H2: a key energy carrier (Ball & Weeda, 2015; Brandon & Kurban, 2017; Maggio et al. 2019)
  - Industry (ammonia, refining, steel, chemicals...)
  - Heavy transport (direct use or e-fuel)
  - Electricity storage
- → H2 is also a enabling technology (electrolysis, Fuel Cell Vehicles...)
- If H2 is the next GPT, anticipation is crucial for industrial planning

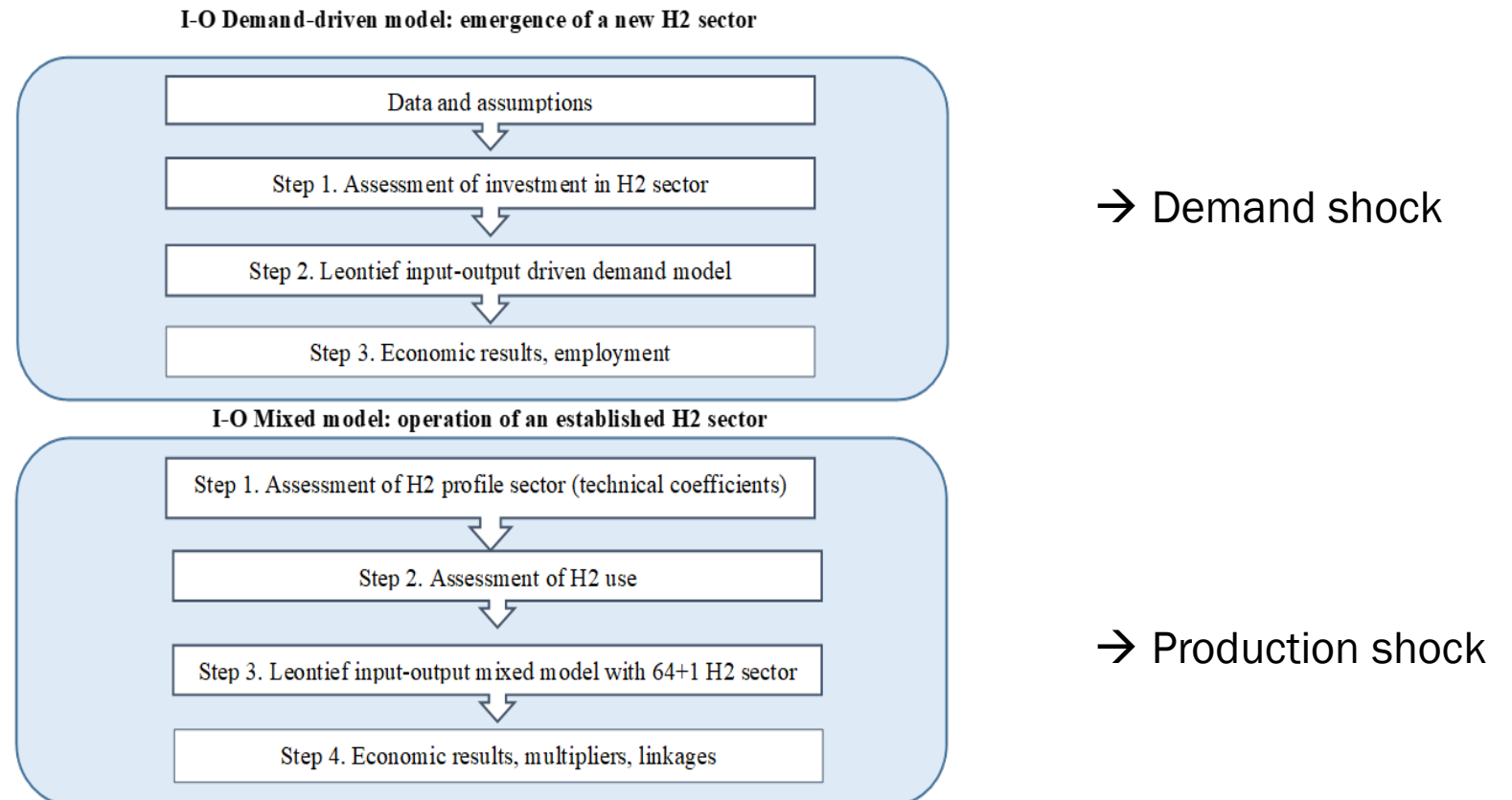
### Objectives of the paper:

- Estimate the economic impact of hydrogen development in France
- Anticipate the needs of a domestic hydrogen industry
- Simulate the emergence of a new sector within an economy

## Introduction – literature

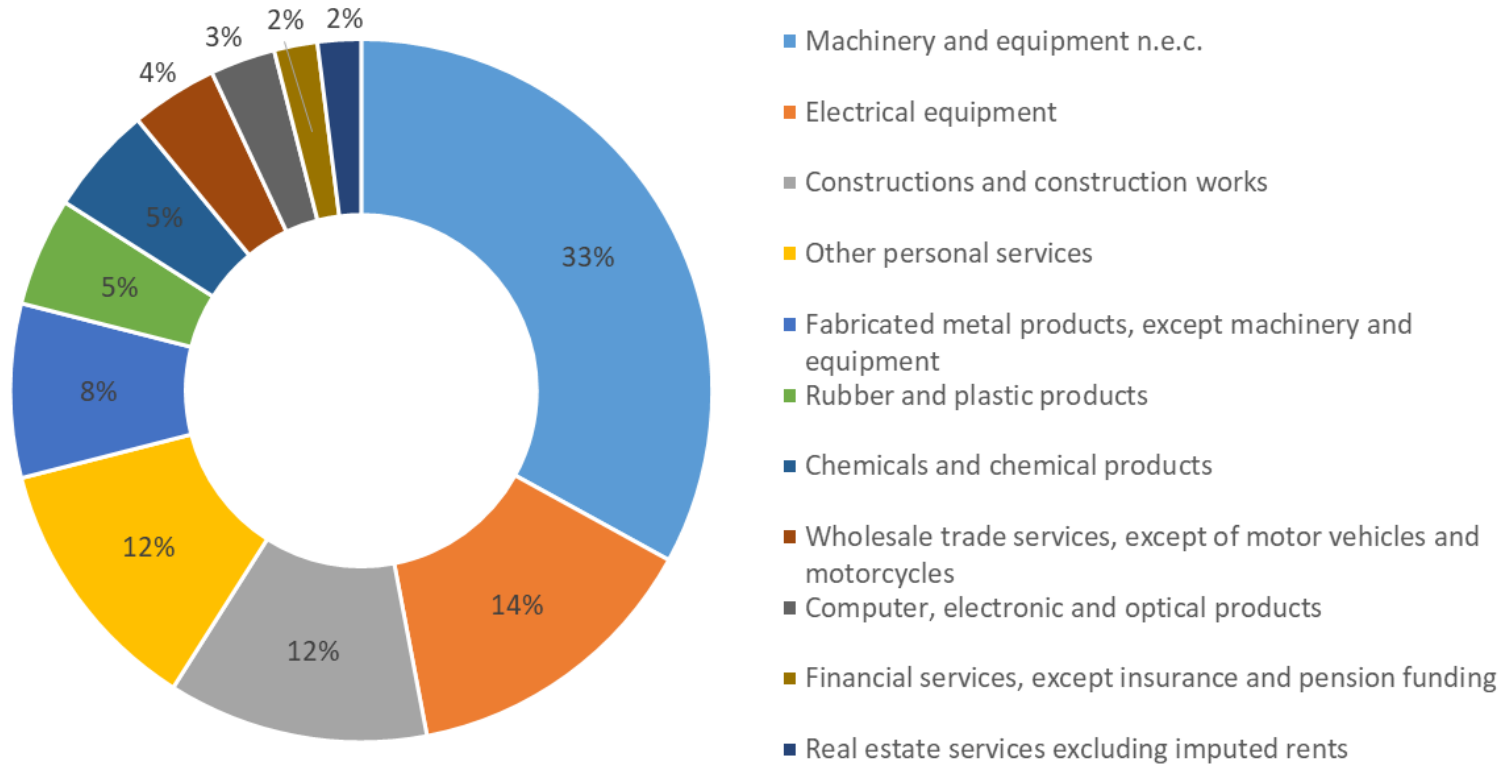
- Hydrogen literature: computable general equilibrium models (Espegren et al., 2021, Jokisch & Mennel, 2009 ; Lee, 2014 ; Silva et al., 2014).
  - Contribution of the article: assessment of inter-industry links
  
- Hydrogen literature using input-output models (IOM): hydrogen is analysed through transport sector (Wietschel & Seydel, 2007 ; Chun et al., 2014).
  - Contribution of the article: simulation for industrial uses with the creation of a new sector
  
- Remaining literature: investigating marginal technologies (biohydrogen) (Lee et al. 2011; Lee & Chiu, 2012)
  - Contribution of the article: we work on the most promising technology (electrolysis)

# Methodology: 2 steps with 2 input-output models



**Figure 1.** Methodology flow chart

# Methodology: 1<sup>st</sup> model (investment phase)



**Figure 2.** Sectoral view of investment in H2 sector

Source : author (based on IRENA, 2020 ; Lee, 2014 ; Wietschel & Seydel, 2007)

## Demand-driven model (Leontief)

$$x = (I - A)^{-1} \cdot f$$

$x$  : production vector

$I$  : identity matrix (64x64)

$A$  : technical coefficient matrix (64x64)

$f$  : final demand vector

$$x = L \cdot f$$

$L$  : Leontief inverse matrix

$$\Delta x = L \cdot \Delta f$$

## Employment

$$LC = \hat{E} \cdot \hat{X}^{-1}$$

$\hat{E}$  : diagonalised job matrix

$\hat{X}$  : diagonalised output matrix

$$LCL = LC \cdot L$$

$$\Delta e = LCL \cdot \Delta f$$

Assumptions: 70% efficiency, 93% load factor → 2.1 GW of electrolyser with 850k€/MW (RTE, 2022)

→ We calibrate the shock

# Methodology: 2<sup>nd</sup> model (operating phase)

**Table 1.** H2 consumption assumptions  
Sources : Ey & Hinico (2020), RTE (2022)

2 industrial consumers	
Ammonia production	Oil refining
220 ktH2	130 ktH2

**Table 2.** Operating costs  
Sources : IEA (2019) ; Lee et al. (2021) ; Nordio et al. (2021)

Input	Cost assumptions	Technical coefficient
Electricity	60 €/MWh	0.9466
Maintenance	2% CAPEX	0.0281
Labor	0.03% CAPEX	0.0042
Others	1.5% CAPEX	0.0211

Mixed model with output multipliers (Miller & Blair, 2009)

$$\Delta x_{65} = O_{65} \cdot \Delta p_{65}$$

$\Delta p$ : production shock vector (all elements are zero except for H2 output)

$O_{65}$ : output to output multiplier matrix (65x65) whose elements are calculated as follows :

$$o_{i,j} = \frac{l_{i,j}}{l_{j,j}}$$

### Multipliers and linkages

$$oto_j = \sum_{i=1}^n o_{i,j}$$

$oto$  : output to output multipliers

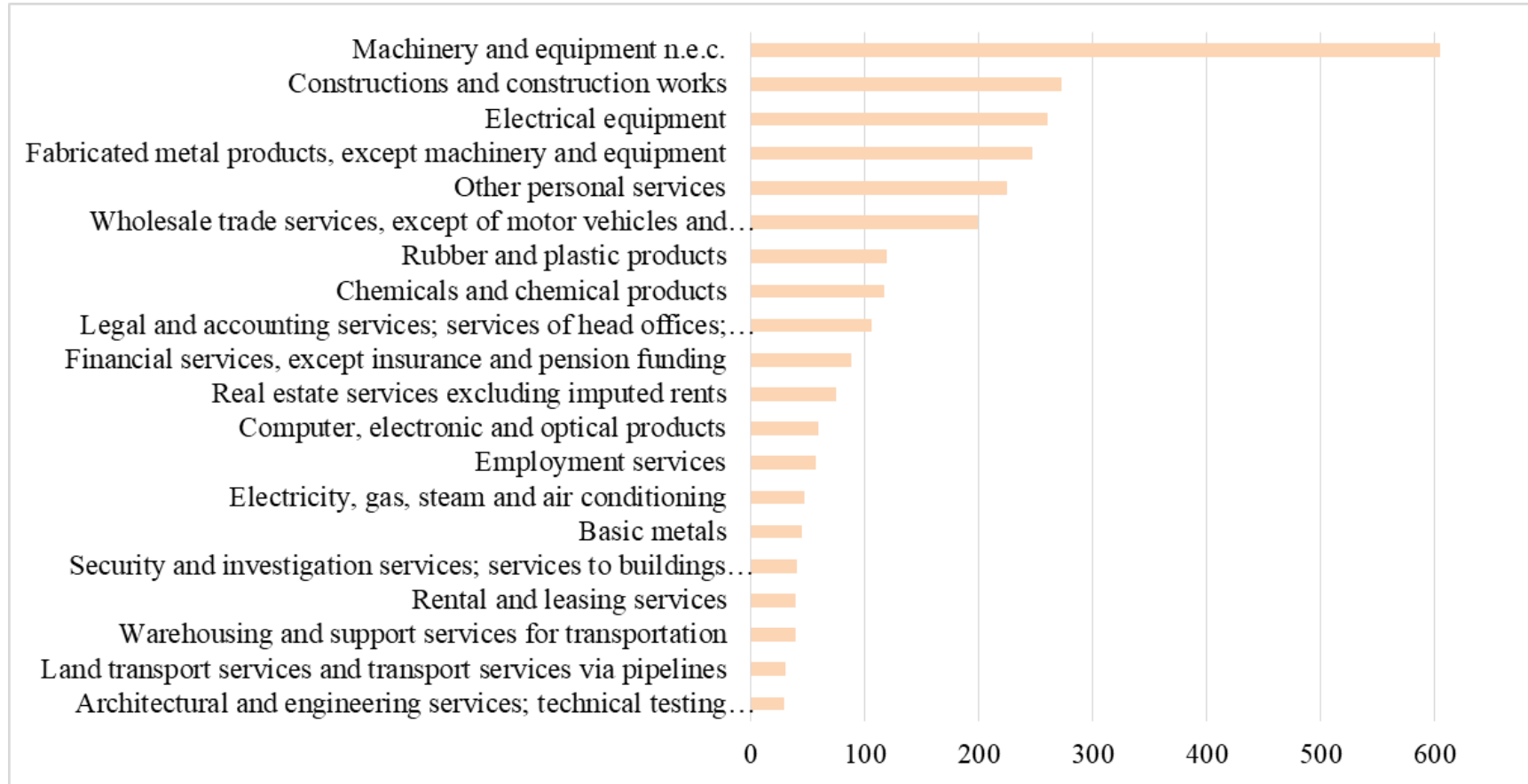
$$bli_j = \frac{bl_j}{\binom{1}{n} \sum_{i=1}^n bl_j} \text{ with } bl_j = \sum_{i=1}^n oto_{ij}$$

$bli$  : backward linkage indices

$$fli_j = \frac{fl_j}{\binom{1}{n} \sum_{i=1}^n fl_j} \text{ with } fl_j = \sum_{i=1}^n g_{ij}$$

$fli$  : forward linkage indices

# Results 1<sup>st</sup> model (investment phase): economics output



**Figure 3.** Output generated by sector (M€)

**Table 3:** Aggregated results

Final demand shock (M€)	1,785
GDP (M€)	1,271
Output (M€)	2,976
Employment	3,656

# Results 1<sup>st</sup> model (investment phase): jobs

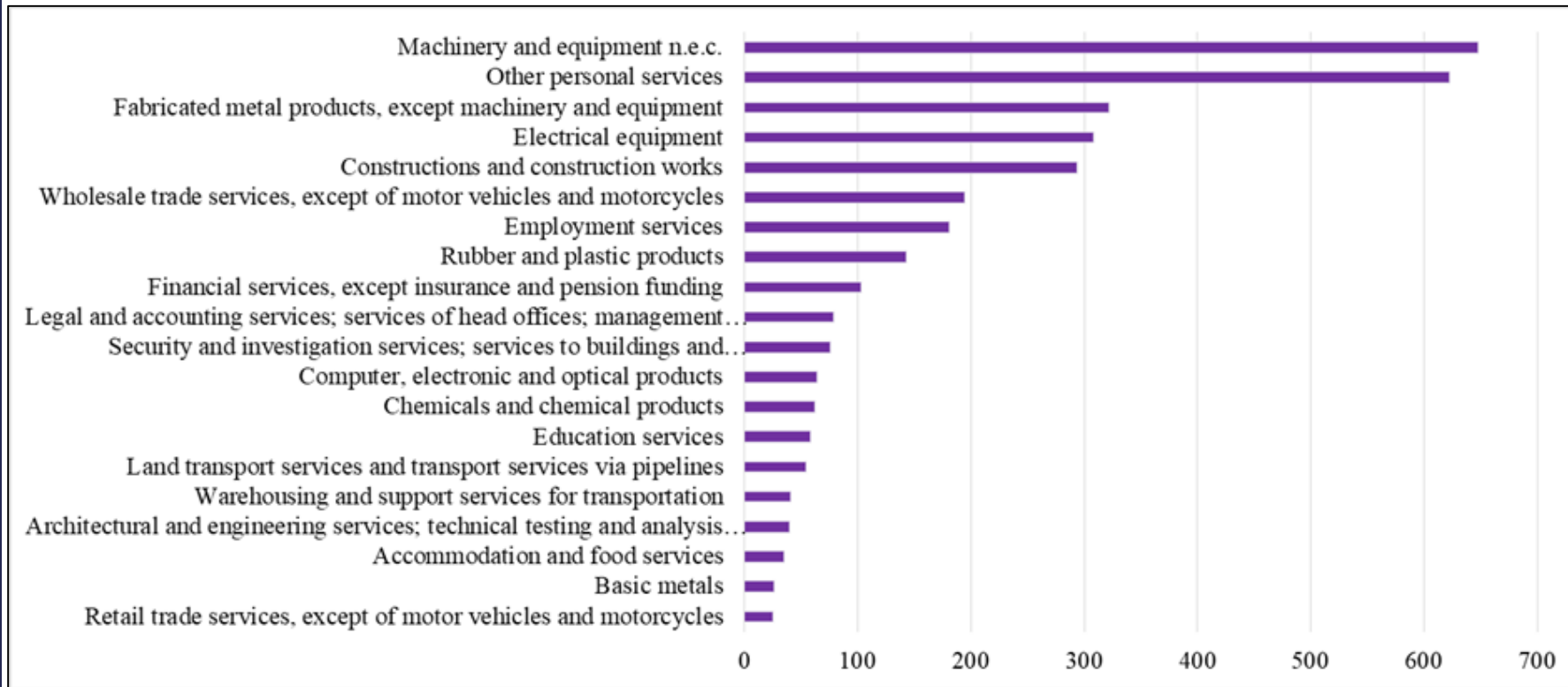


Figure 4. Job creation by sector

Table 3: Aggregated results

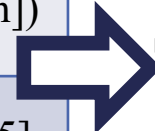
Final demand shock (M€)	1,785
GDP (M€)	1,271
Output (M€)	2,976
Employment	3,656



# Results 2<sup>nd</sup> model (operating phase) : main results

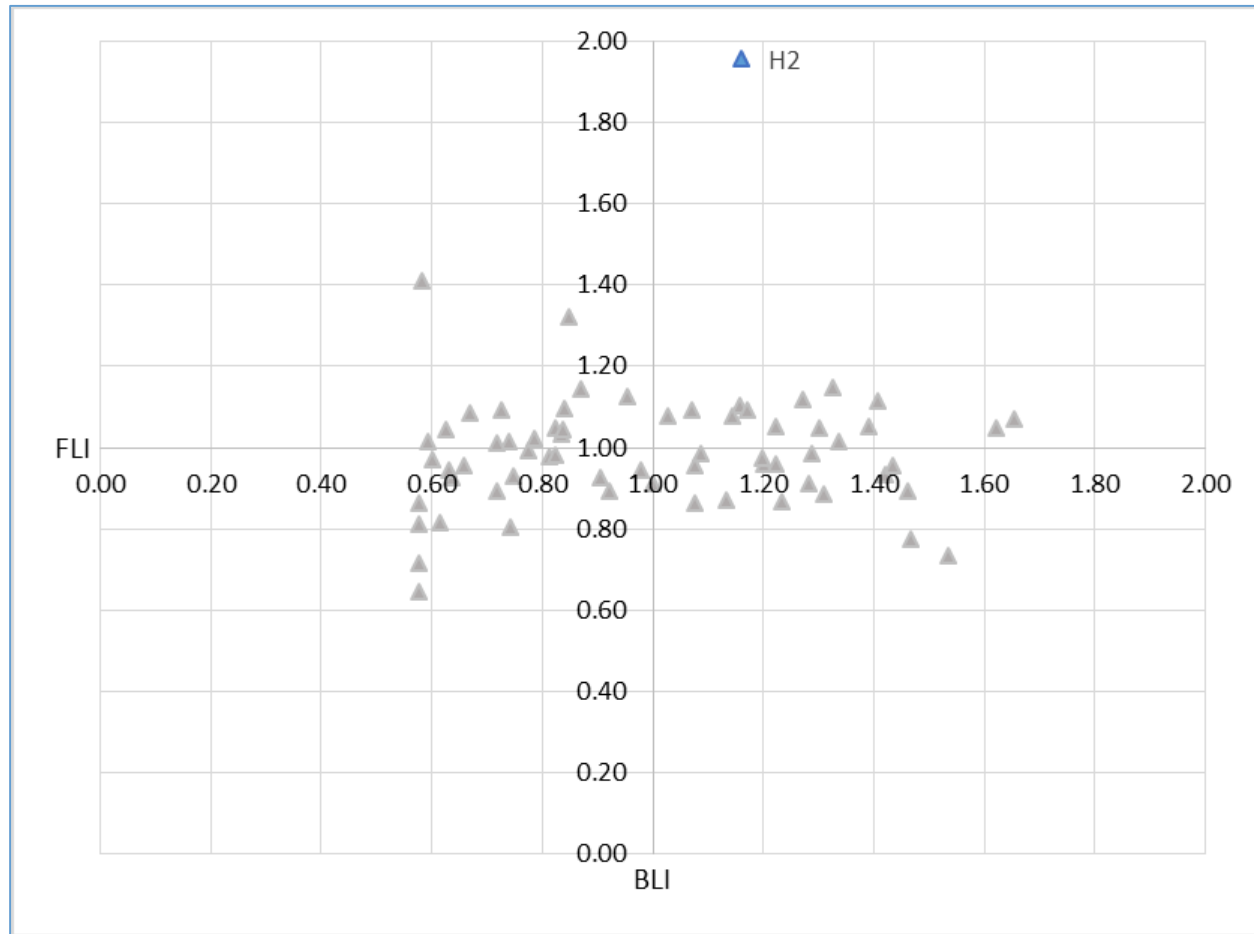
**Table 4: Main results**

	Annual GDP (M€)	Annual output (M€)	Annual hydrogen production (kt)	Avoided gas imports (M€, [TWh])
H2 sector	5	1,046	350	1,130 [16,5]
National economy	721	3,165	-	-



- Current grey H2 : 13 kgCO<sub>2</sub>eq/kgH<sub>2</sub>
  - Low carbon H2 (from grid): 3 kgCO<sub>2</sub>eq/kgH<sub>2</sub>
- Reduction in emissions: -3,5 MtCO<sub>2</sub>eq
- Hydrogen emissions in France (2021) : 11,5 Mt CO<sub>2</sub>eq – France total emissions: 604MtCO<sub>2</sub>eq RTE (2022)

## Results 2<sup>nd</sup> model (operating phase) : multipliers



**Figure 5** : Backward Linkage Indices (BLI) and Forward Linkage Indices (FLI) of the 65 sectors

- H2 sector :
  - Very high BLI → artificially "pulled" by his domestic intermediate consumptions
  - Average FLI → H2 sector only supplies two other sectors
- Atypical results related to the nature of the H2 sector (single product)
- H2 sector is purely domestic

# Policy recommendations (1/2)

- **Inter-industry dependence**
  - Industry is strongly stimulated but France has been facing de-industrialization since decades
  - Existing measures need to be reinforced, administrative procedures simplified and substitution of grey H2 more encouraged (tax credits, subsidies specifically for industrial actors and transport ecosystem)
  
- **Power sector scheduling,**
  - H2 sector is electricity highly intensive
  - Electricity sector in France faces challenges (nuclear reactors corrosion, lack of dispatchable power plants, RES development behind schedule...)
  - Map specific electricity capacities dedicated to H2 production and accelerate RES deployment
  - Subsidies and tax credits to incentivize industrial consumers to integrate additional power plants

## Policy recommendations (2/2)

### ■ Labor market planning

- Industrial jobs in the total workforce has fallen sharply but are crucial to build hydrogen infrastructure
- Jobs in industry and construction sector already know tensions for recruitment and suffers from bad image
- Focus on making these sectors more attractive (training, lowering labor costs, communication)
- Existing action applied to low wage earners should be extended since industry average wages are higher than the policy established threshold

### ■ Hydrogen development race

- Despite industrial difficulties, France features a number of strengths: industrial energy champion across the entire value of chain, gigafactories projects, large industrial projects, ecosystem development
- Public policies could more actively support consumption and distribution infrastructure projects to create favorable industrial fabrics and facilitate H2 emergence.

# Conclusion

Summary : 2 input-output models to assess the impact of an emerging H2 sector:

- First model (investment phase):
  - GDP = 1,2 Bln €
  - 3,600 jobs/year.
  - Stimulates the industry and construction sectors
- Second model (operating phase):
  - “Electricity, gas, steam and air conditioning” sector is the most solicited: very high BLI
  - H2 sector supplies only two sectors: average FLI

## Implications

- High industrial impact for two uses and modest production (350kt/year)
- Ambitious H2 policy:
  - substitution of all current uses of grey H2 (+1100 kt/year) *steel, chemistry...*
  - addition of other uses: (+2000-10 000kt/year) *heavy transport, freight...*

→ **major industrial program: challenges in labor force, technical resources and electricity availability**

→ **state intervention is crucial (Van der Spek et al. 2022)**

## Limits

- Intrinsic limits of IOM: static and linear models, fixed technical coefficients, assumed homogeneous sectors, etc.
- Starting assumptions influence the results.
- H2 is a sector with unique good → relevance of multipliers is challenged

# Thank you for your attention

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# APPENDIX

# Results 1<sup>st</sup> model (investment phase): final demand shock

**Table 5.** Final demand shock distribution by sector (M€)

Machinery and equipment n.e.c.	589
Electrical equipment	250
Constructions and construction works	214
Other personal services	214
Fabricated metal products, except machinery and equipment	143
Chemicals and chemical products	89
Rubber and plastic products	89
Wholesale trade services, except of motor vehicles and motorcycles	71
Computer, electronic and optical products	54
Financial services, except insurance and pension funding	36
Real estate services excluding imputed rents	36

**Table 3:** Aggregated results

Final demand shock (M€)	1,785
GDP (M€)	1,271
Output (M€)	2,976
Employment	3,656



# Results 1<sup>st</sup> model (investment phase): general output

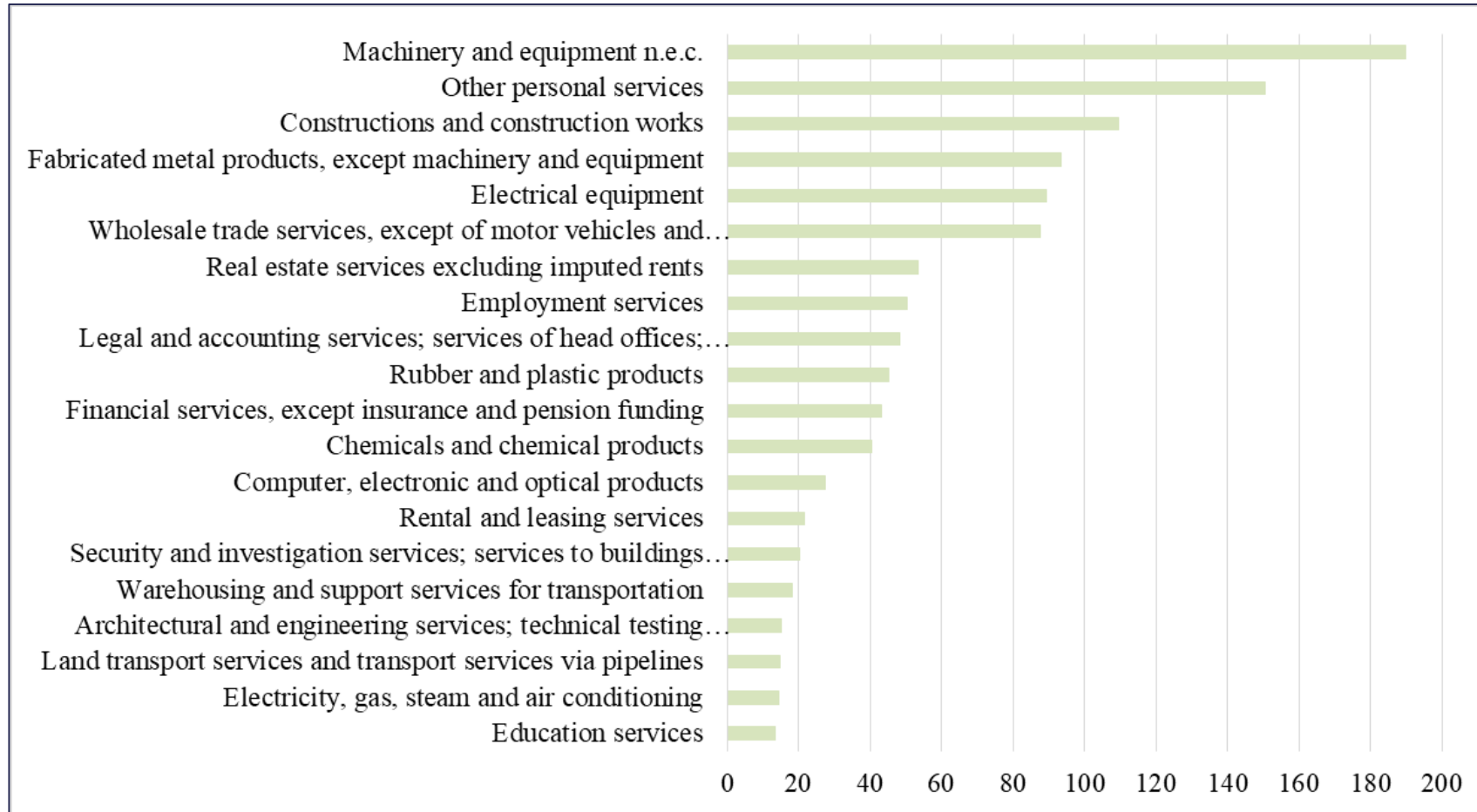


Figure 6. GDP generated by sector (M€)

Final demand shock (M€)	1,785
GDP (M€)	1,271
Output (M€)	2,976
Employment	3,656

Table 3: Aggregated results

# Results 2<sup>nd</sup> model (operating phase) : multipliers

**Table 6:** Output-to-output multipliers for the top 20 sectors

Sector	Output multiplier	Rank
H2	3.026	1
Water transport services	2.182	2
Insurance, reinsurance, pension funding services, etc	2.044	3
Wood and of products of wood and cork, except furniture	1.774	4
Food, beverages and tobacco products	1.773	5
Basic metals	1.742	6
Other non-metallic mineral products	1.729	7
Mining and quarrying	1.725	8
Paper and paper products	1.706	9
Accommodation and food services	1.697	10
Machinery and equipment n.e.c.	1.691	11
Motion picture, video and television programme services	1.690	12
Fish and other fishing products; aquaculture products; etc	1.688	13
Motor vehicles, trailers and semi-trailers	1.681	14
Wholesale trade services, except of motor vehicles	1.668	15
Natural water; water treatment and supply services	1.665	16
Services auxiliary to financial services and insurance services	1.655	17
Advertising and market research services	1.629	18
Other professional, scientific, technical services, veterinary	1.625	19
Printing and recording services	1.623	20

- Reading: if the H2 sector increases its output by €1, then the rest of the economy will increase its production by **€3.026** (direct and indirect effects)
- Output multiplier of H2 sector is overestimated: single activity sector VS diverse activities sectors

# Results 2<sup>nd</sup> model (operating phase) : multipliers

**Table 7:** Direct and indirect effects of H2 sector's output

Sector	Total effect	Rank
Electricity, gas, steam and air conditioning	1.621	1
Legal and accounting services; services of head offices; management consultancy services	0.043	2
Wholesale trade services, except of motor vehicles and motorcycles	0.031	3
Machinery and equipment n.e.c.	0.031	4
Electrical equipment	0.023	5
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	0.021	6
Chemicals and chemical products	0.021	7
Constructions and construction works	0.021	8
Financial services, except insurance and pension funding	0.016	9
Land transport services and transport services via pipelines	0.015	10
Rental and leasing services	0.015	11
Warehousing and support services for transportation	0.012	12
Fabricated metal products, except machinery and equipment	0.012	13
Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	0.012	14
Education services	0.012	15
Real estate services excluding imputed rents	0.010	16
Computer programming, consultancy and related services; Information services	0.010	17
Employment services	0.009	18
Architectural and engineering services; technical testing and analysis services	0.009	19
Services auxiliary to financial services and insurance services	0.007	20

- Electricity sector is most stimulated by the production of the H2 sector (→ electrolysis)
- Others sectors' benefits are marginal
- H2 sector is **dependant** on electric sector

# Results 2<sup>nd</sup> model (operating phase) : multipliers

**Table 8:** Direct effects of H2 sector's output

Sector	Technical coefficient
Electricity, gas, steam and air conditioning	0.9466
Machinery and equipment n.e.c.	0.0281
Electrical equipment	0.0211
Value added	0.0042

**Table 9:** Indirects effects of H2 sector's output

Sector	BLI	Rank
Electricity, gas, steam and air conditioning	0.675	1
Legal and accounting services; services of head offices; management consultancy services	0.043	2
Wholesale trade services, except of motor vehicles and motorcycles	0.031	3
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	0.021	4
Chemicals and chemical products	0.021	5
Constructions and construction works	0.021	6
Financial services, except insurance and pension funding	0.016	7
Land transport services and transport services via pipelines	0.015	8
Rental and leasing services	0.015	9
Warehousing and support services for transportation	0.012	10
Fabricated metal products, except machinery and equipment	0.012	11
Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	0.012	12
Education services	0.012	13
Real estate services excluding imputed rents	0.010	14
Computer programming, consultancy and related services; Information services	0.010	15
Employment services	0.009	16
Architectural and engineering services; technical testing and analysis services	0.009	17
Services auxiliary to financial services and insurance services	0.007	18
Telecommunications services	0.006	19
Coke and refined petroleum products	0.006	20

# Results 2<sup>nd</sup> model (operating phase) : multipliers

**Table 10:** BLI for the top 20 sectors

<b>Sector</b>	<b>BLI</b>	<b>Rank</b>
H2	1.956	1
Water transport services	1.411	2
Insurance, reinsurance and pension funding services, except compulsory social security	1.321	3
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	1.147	4
Food, beverages and tobacco products	1.146	5
Basic metals	1.126	6
Other non-metallic mineral products	1.118	7
Mining and quarrying	1.115	8
Paper and paper products	1.103	9
Accommodation and food services	1.097	10
Machinery and equipment n.e.c.	1.093	11
Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	1.093	12
Fish and other fishing products; aquaculture products; support services to fishing	1.091	13
Motor vehicles, trailers and semi-trailers	1.087	14
Wholesale trade services, except of motor vehicles and motorcycles	1.079	15
Natural water; water treatment and supply services	1.077	16
Services auxiliary to financial services and insurance services	1.070	17
Advertising and market research services	1.053	18
Other professional, scientific and technical services and veterinary services	1.051	19
Printing and recording services	1.049	20

# Results 2<sup>nd</sup> model (operating phase) : multipliers

**Table 11:** FLI for the top 20 sectors

Sector	FLI	Rank
Services auxiliary to financial services and insurance services	1.654	1
Printing and recording services	1.621	2
Employment services	1.534	3
Electricity, gas, steam and air conditioning	1.466	4
Legal and accounting services; services of head offices; management consultancy services	1.460	5
Financial services, except insurance and pension funding	1.433	6
Warehousing and support services for transportation	1.420	7
Mining and quarrying	1.407	8
Other professional, scientific and technical services and veterinary services	1.391	9
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	1.336	10
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	1.325	11
Postal and courier services	1.309	12
Travel agency, tour operator and other reservation services and related services	1.302	13
Rental and leasing services	1.287	14
Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	1.283	15
Other non-metallic mineral products	1.271	16
Products of forestry, logging and related services	1.234	17
Fabricated metal products, except machinery and equipment	1.224	18
Advertising and market research services	1.222	19
Products of agriculture, hunting and related services	1.201	20
...	...	...
H2	1.161	23

# Literature

- Input-output models (IOM) :
  - Linear meso economic model with empirical data (Leontief 1936)
  - IOM highlight links between sectors in an economy (Miller & Blair, 2009).
  
- Various extensions for IOM:
  - GHG emissions (Alcantara & Padilla, 2009; Hertwich & Wood, 2018; Wei et al., 2022)
  - Agriculture (Loizou et al. 2019)
  - Water management (Zhang et al., 2020)
  - Energy (Cellura et al., 2013; Llope, 2020)
  - ...
  
- New way to use IOM : to assess emergence of a new sector within an economy (Miller & Blair, 2009).