Scale up and Scale down issues of renewable Ammonia plants: Towards modular design

Antonio Sánchez, Mariano Martín
Department of Chemical Engineering. University of Salamanca

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New Paradigm

Power to chemicals

UE: Renewable energies 32% (2030)

Renewable energies
Intermittent and fluctuating character

Distributed Production

Modular design

Integrating chemicals into the electricity market as electricity ***storage*** option

Chemical Industry Challenges

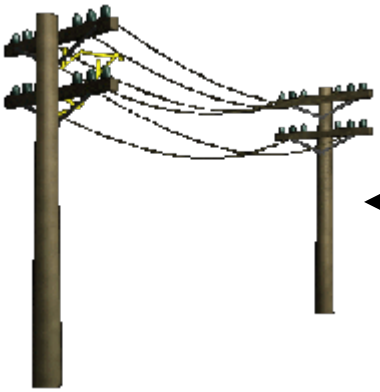
High dependent on hydrocarbons (raw materials/energy)

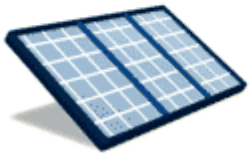
Target: ***Reduce Greenhouse emissions***

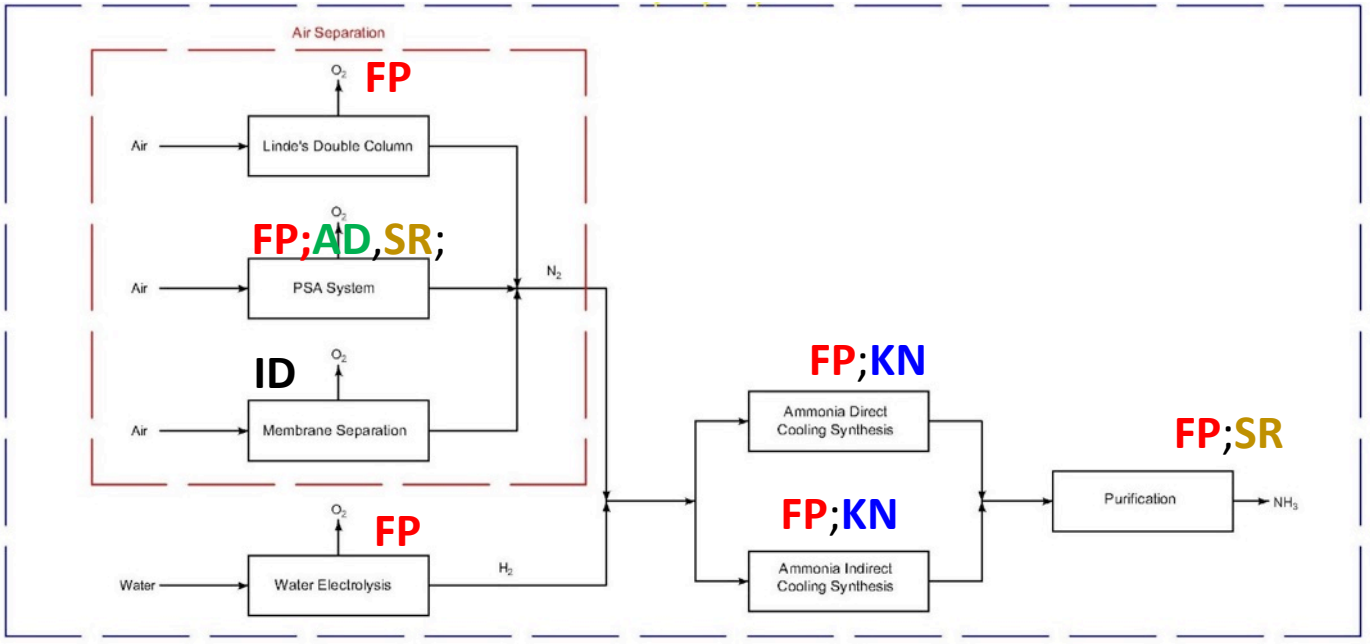
Avoid 2ºC temperature increase

New Synthesis Path

Cases of study



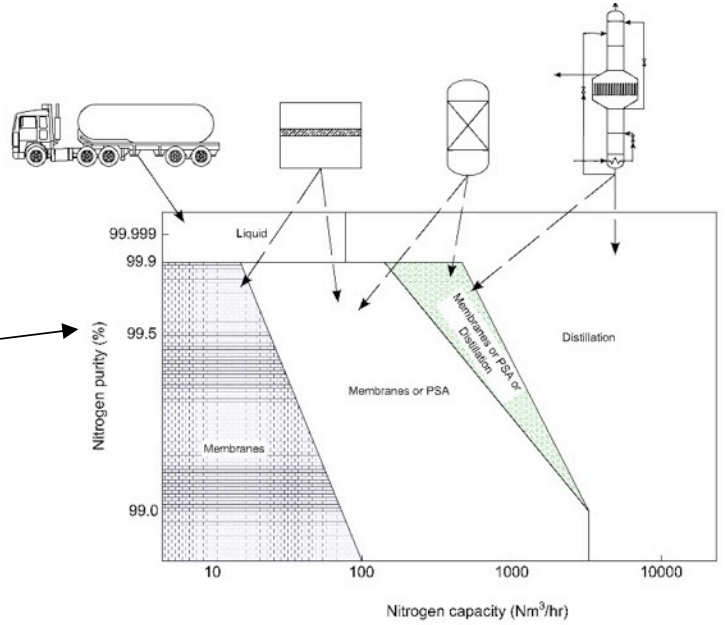


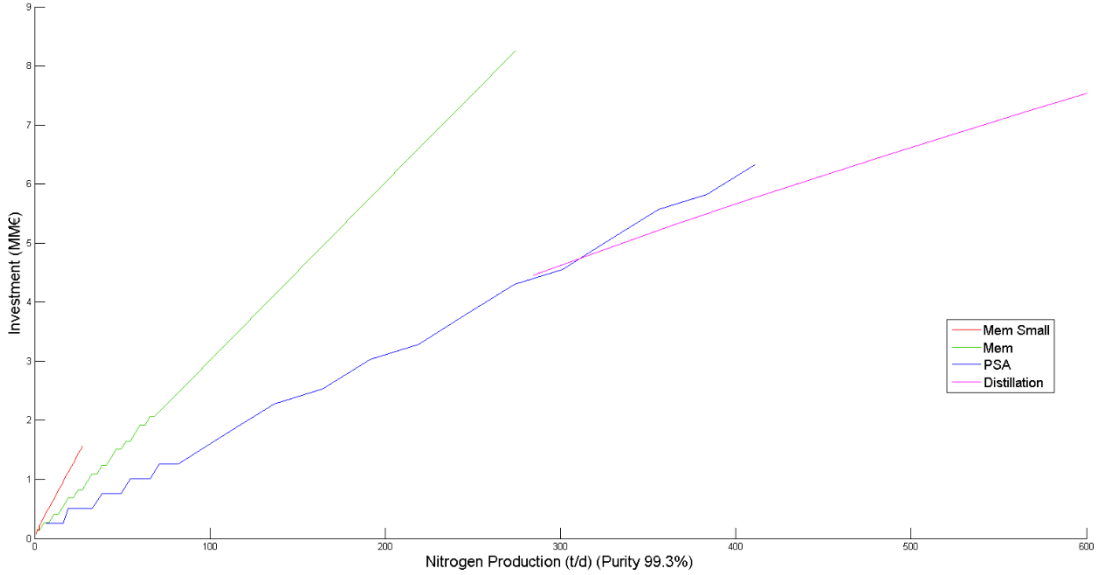


FP: First Principles; **AD**: Adsoprtion; **ID**: Industrial Data, **KN**: kinetics; **SR**: Surrogate models

Nitrogen production technology

Current State of Art for nitrogen production





Membranes: Very small capacities
PSA: Small capacities
Distillation: Large capacities

Only Investment Cost (Chemical Equipment)

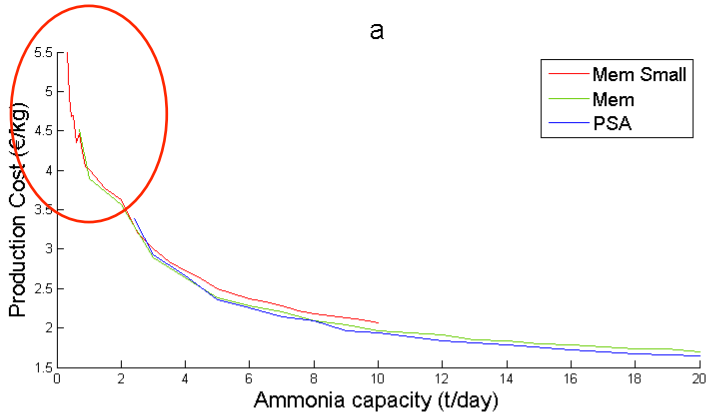
Non Modular:

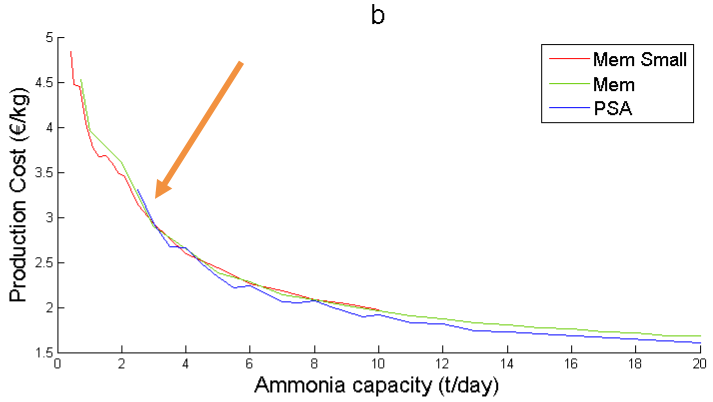
Direct vs Indirect Cooling

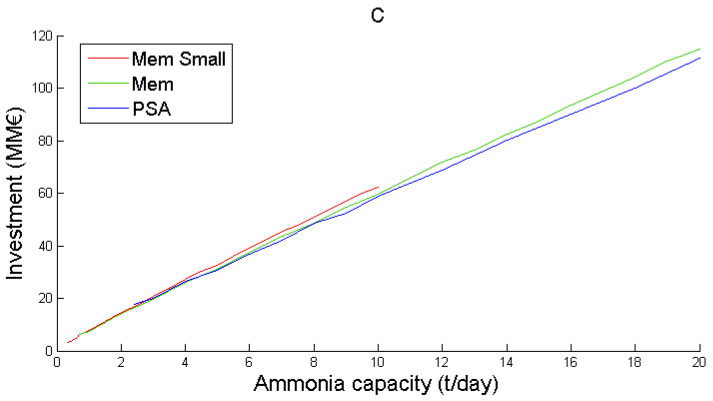
Small Capacities

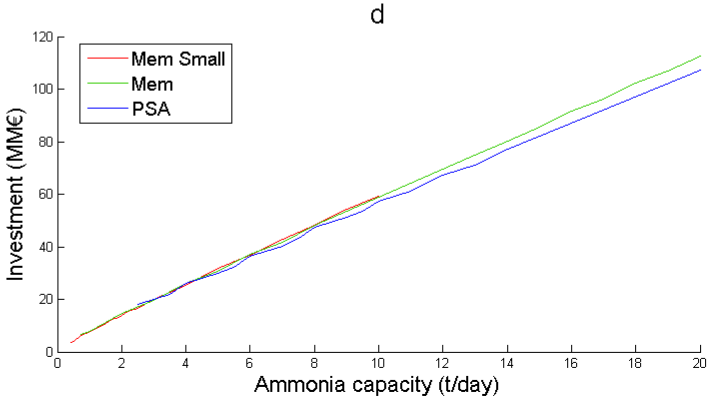
Solar energy is selected in a region in South of Spain

Investment and cost include the energy collection









a) Production costs Direct Cooling b) Production costs indirect cooling

c) Investment costs Direct Cooling d) Investment costs indirect cooling

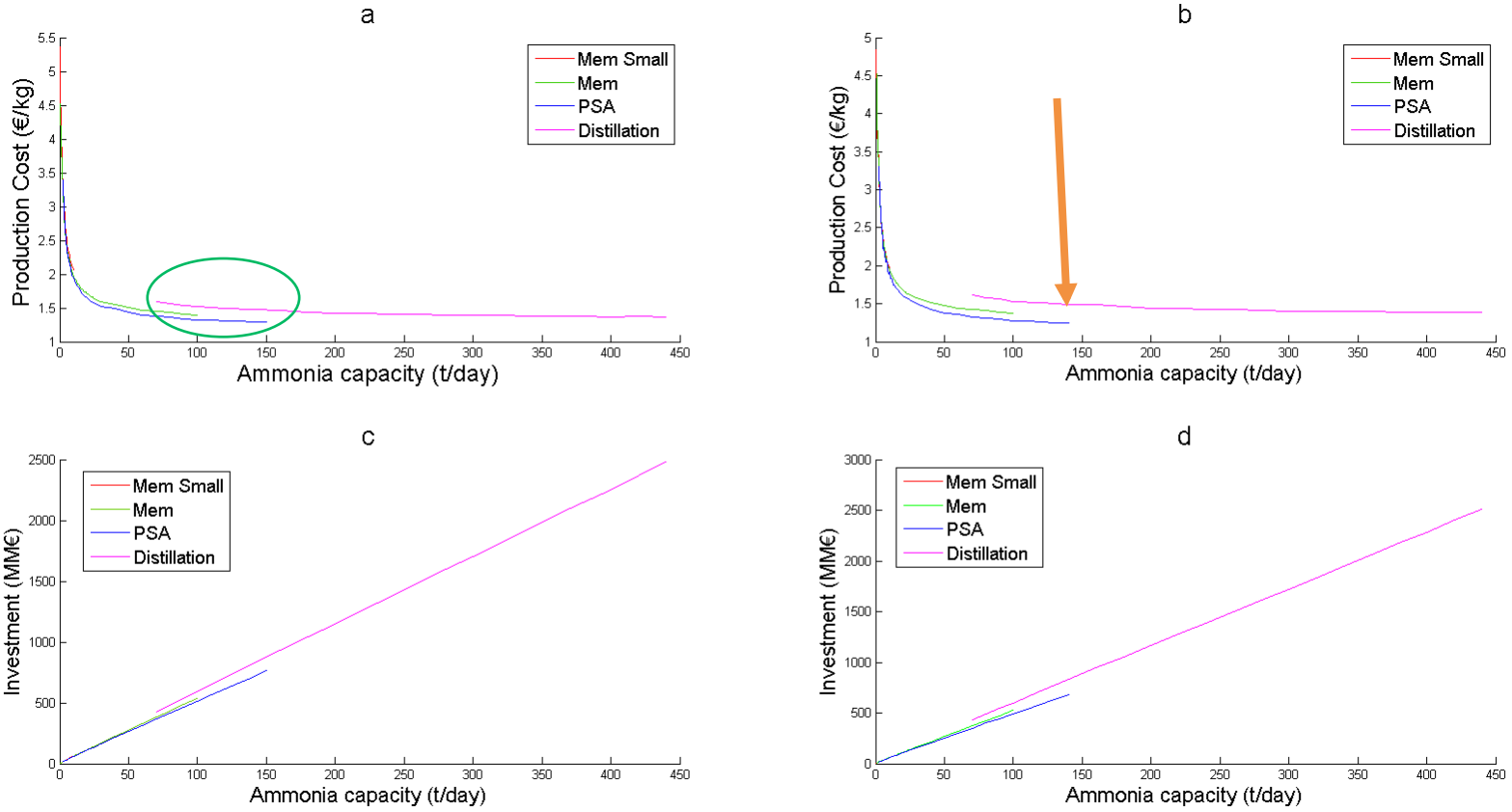
Non Modular:

Direct vs Indirect Cooling

Distillation included

Better cost in PSA respect to distillation with same capacity

Full Scale



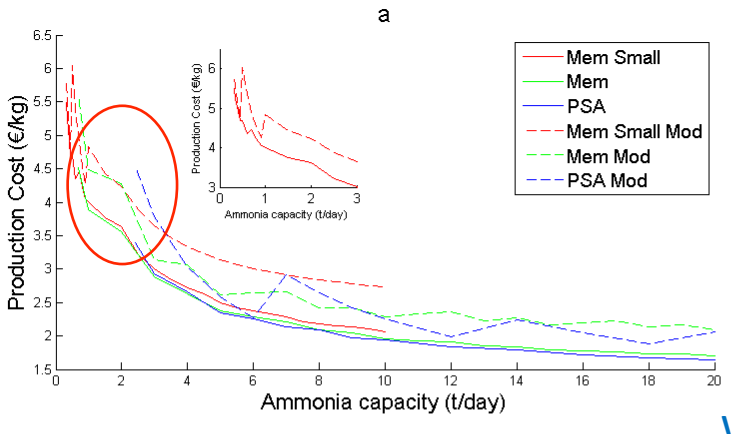
a) Production costs Direct Cooling
b) Production costs indirect cooling
c) Investment costs Direct Cooling
d) Investment costs indirect cooling

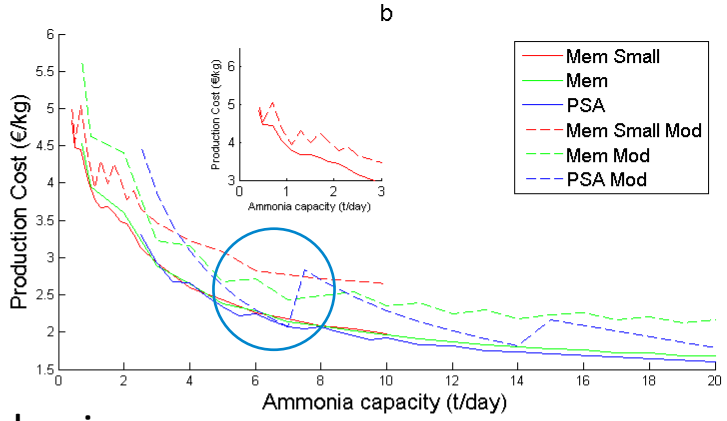
Modular Design:

Direct vs Indirect Cooling

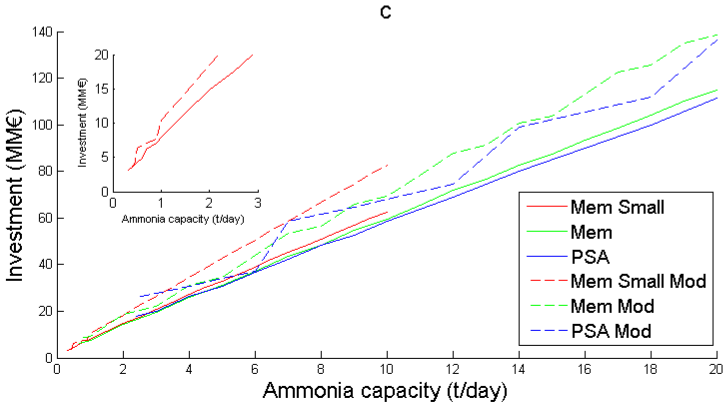
In general, modular present higher cost

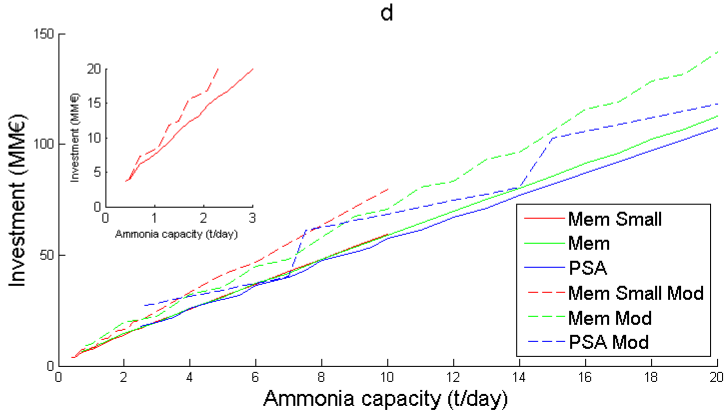
Advantages difficult to quantify





Waves behavior





a) Production costs Direct Cooling b) Production costs indirect cooling

c) Investment costs Direct Cooling d) Investment costs indirect cooling

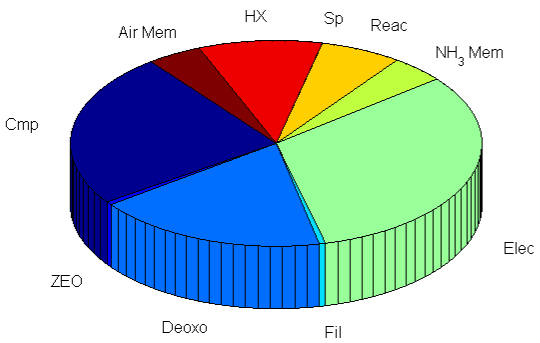
Equipment cost distribution

PV panels excluded

Electrolyzer, high cost

Mitigate the changes in nitrogen technology

a



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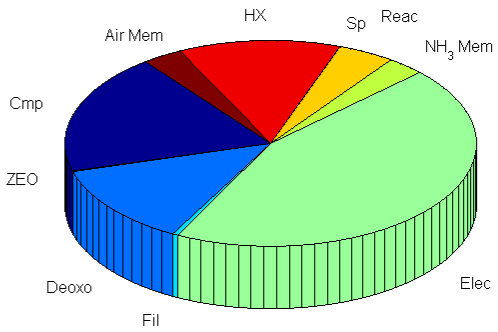
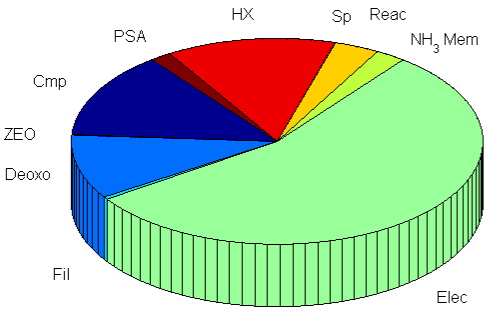


c



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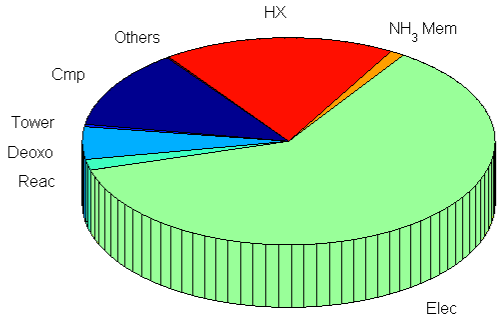
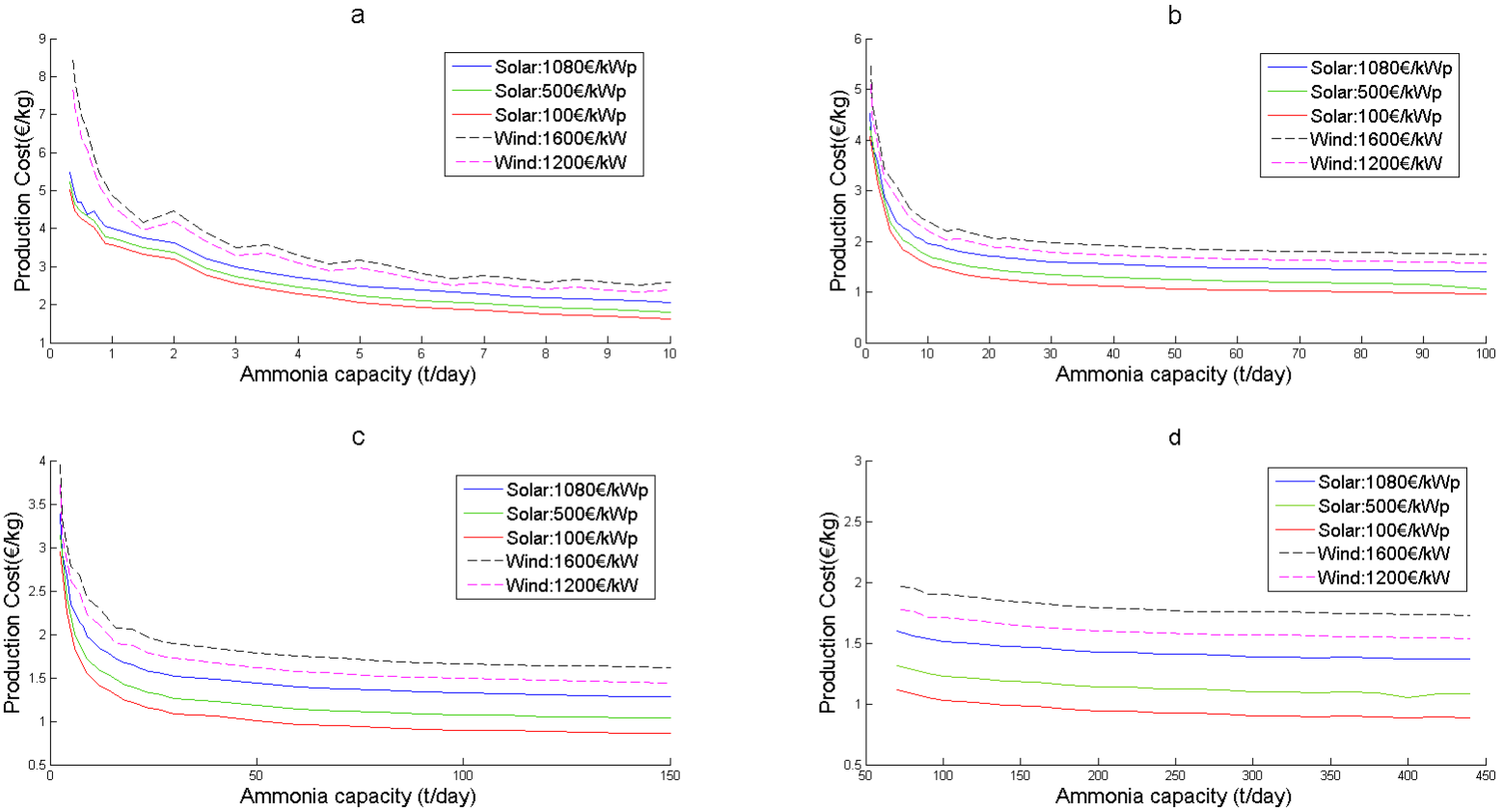


a) Equipment cost distribution (Small membrane)
b) Equipment cost distribution (Membrane)
c) Equipment cost distribution (PSA)
d) Equipment cost distribution (Distillation)

Sensitivity analysis

PV panels and Wind turbines

Around 1 €/kg is possible to achieve



a) Production Costs Direct Cooling (Small scale)
b) Production Costs Indirect Cooling (Small scale)
c) Production Costs Direct Cooling (Full scale)
d) Production Costs Indirect Cooling (Full scale)

Conclusions

- We **optimize NH_3** production from **water** and air using **renewable sources**

- Compare **three different technologies** in the nitrogen production for different production capacities

- Membranes are suitable for very small capacities, **PSA** for medium and **distillation** for large

- **PSA** are **competitive across scales**, limiting the number of unit required

- **Modular design** is cost efficient only at full capacity. Other advantages are not quantified

- Costs are currently high but **expected improvements** in power collection equipment can make it **competitive.**

- Further works: integration in a **supply chain** ammonia facilities, **detailed operation**