Low Carbon Energy mix challenge and balance with Renewable Energy

for countries operating or considering low-carbon energy technologies

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Managing Energy Transition in a BANI world

A new chaotic dimension to describe actual World

VUCA → **BANI**

Complexity and challenges

- volatile
- uncertain
- complex
- ambiguous



Chaos

- brittle
- anxious
- non-linear
- incomprehensible



DIE ZEIT — Abo testen

Feuerwehrleute kämpfen westlich von Bordeaux gegen die Flammen. © ALAIN JOCARD/AFP via Getty Images

Feuer in Südeuropa zwingen rund 300.000 Menschen zur Flucht

Flammen sind bis auf 15 Kilometer an Bordeaux vorgerückt. Der Bürgermeister lehnt eine Evakuierung bisher ab. Auch in Spanien sind weiterhin Waldbrände außer Kontrolle.

Quelle: DIE ZEIT, AFP, AP, dpa, vsp 27. Juli 2026, 5:50 Uhr

This summer, the fires in France are causing the largest exodus since the Second World War

BANI

- brittle
- anxious
- non-linear
- incomprehensible



Le Point

SAISONS Hebdomadaire En direct de la rédaction Palmarès des hôpitaux Séries d'été Guerre au Moyen-Orient

CRISE(S)

Iran : à Ormuz, le monde joue son équilibre énergétique… et économique

Entre envolée du brut et paralysie du détroit d'O… américaine contre Téhéran m… France, le cabi… majeu…

https://www… …pétrole-detroit-dormuz-bloque-et-risque-dinflation-en-france-LZMB5J2MB5

Iran: At Hormuz, the world is playing its energy and … economic balance.

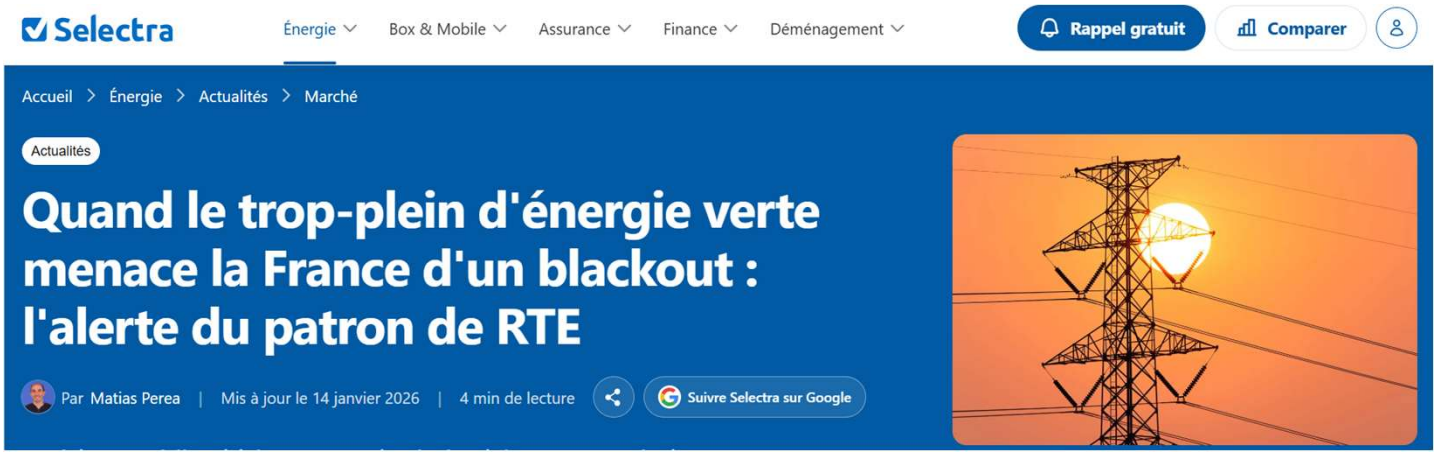
BANI

brittle

anxious

non-linear

incomprehensible



When an excess of green energy threatens France with a blackout: the warning from the head of French TSO – RTE

when Last April 1st, within a few minutes, 9 GW of renewable energy generation sold at a negative price shut down on the French grid."

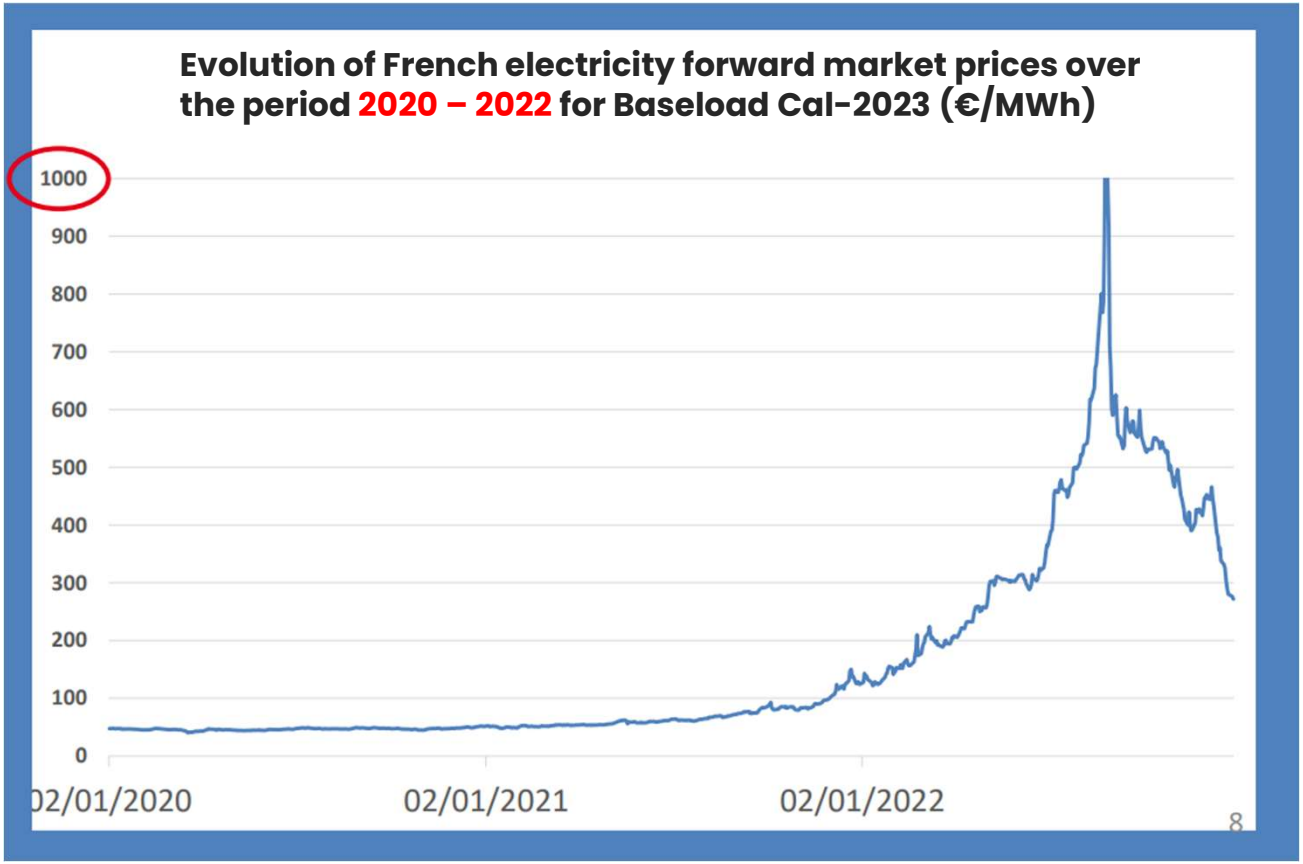
BANI

brittle

anxious

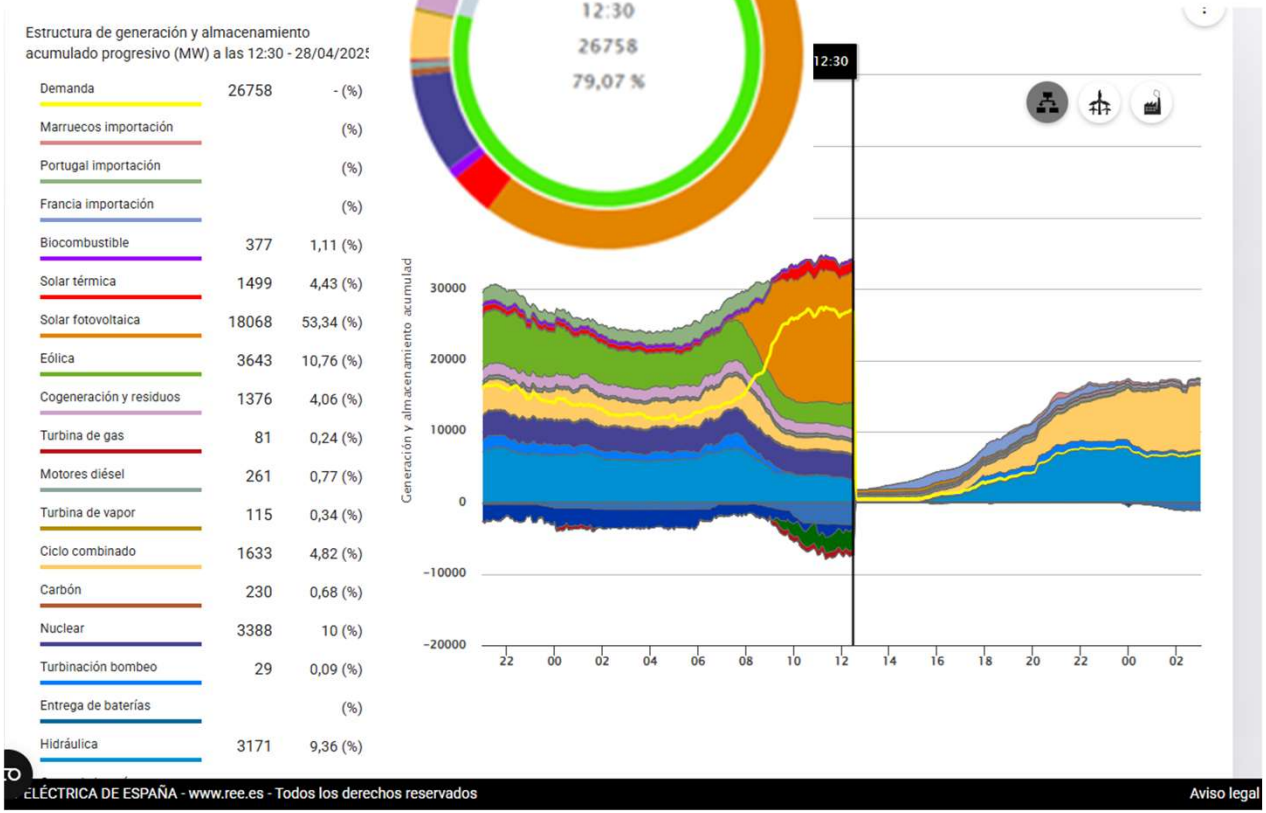
non-linear

incomprehensible



BANI

- brittle
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➔ 28 Avril 2025 – 12h33.17, the most severe blackout in 20 years in Spain & Portugal with Peak RE proportion @ 79%

➔ But 24 April 2025 - à 19h, higher peak without blackout !

100% Renewable Energy is it possible ?

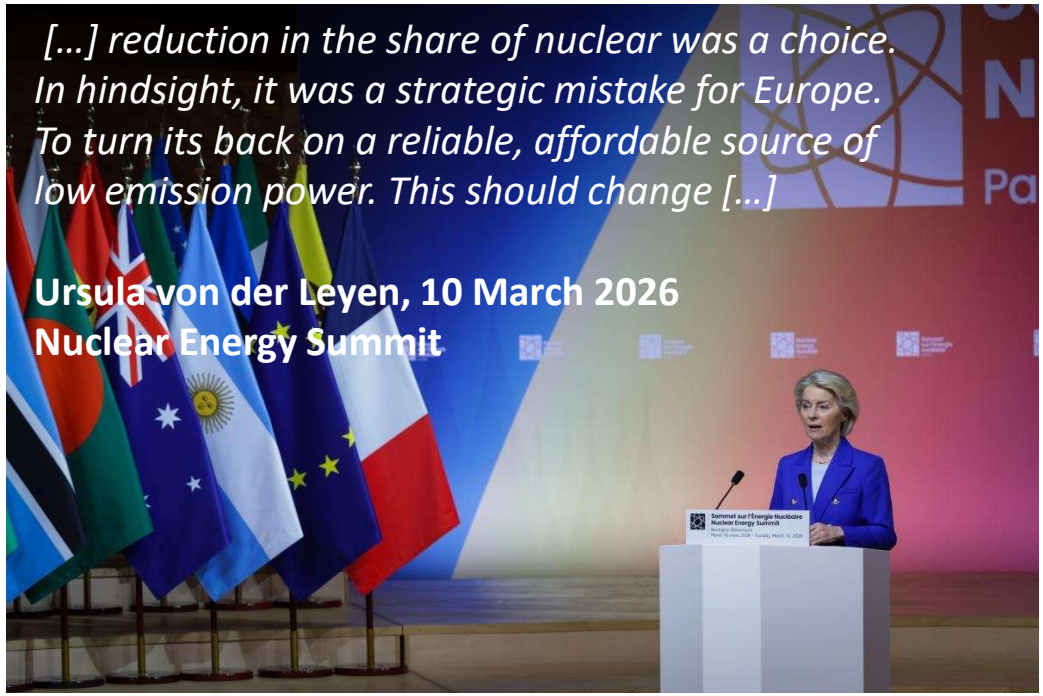
Theoretically YES but several conditions are request (source : RTE-ADEME report « Energetical Future 2050)

- Manage intermittent and versatile production **by IA use** (ie weather forecas) and **new flexible means (**storage, import/export
- Maintain and stabilize frequency with inertial system by **development of new electronic power devices**
- **Redesign electrical grid** to take into account abundance of decentralizes RE farm and social acceptance (ie Future OffShore wind turbine deployment in France allows to invest around 2 B€/y for 10 year to strengthen electrical grid)
- **Combination** dispatchable and intermittent energy sources is more viable

Nuclear and RE are of strategic importance for the UE

Several reasons (but not necessary replicable all over the world) :

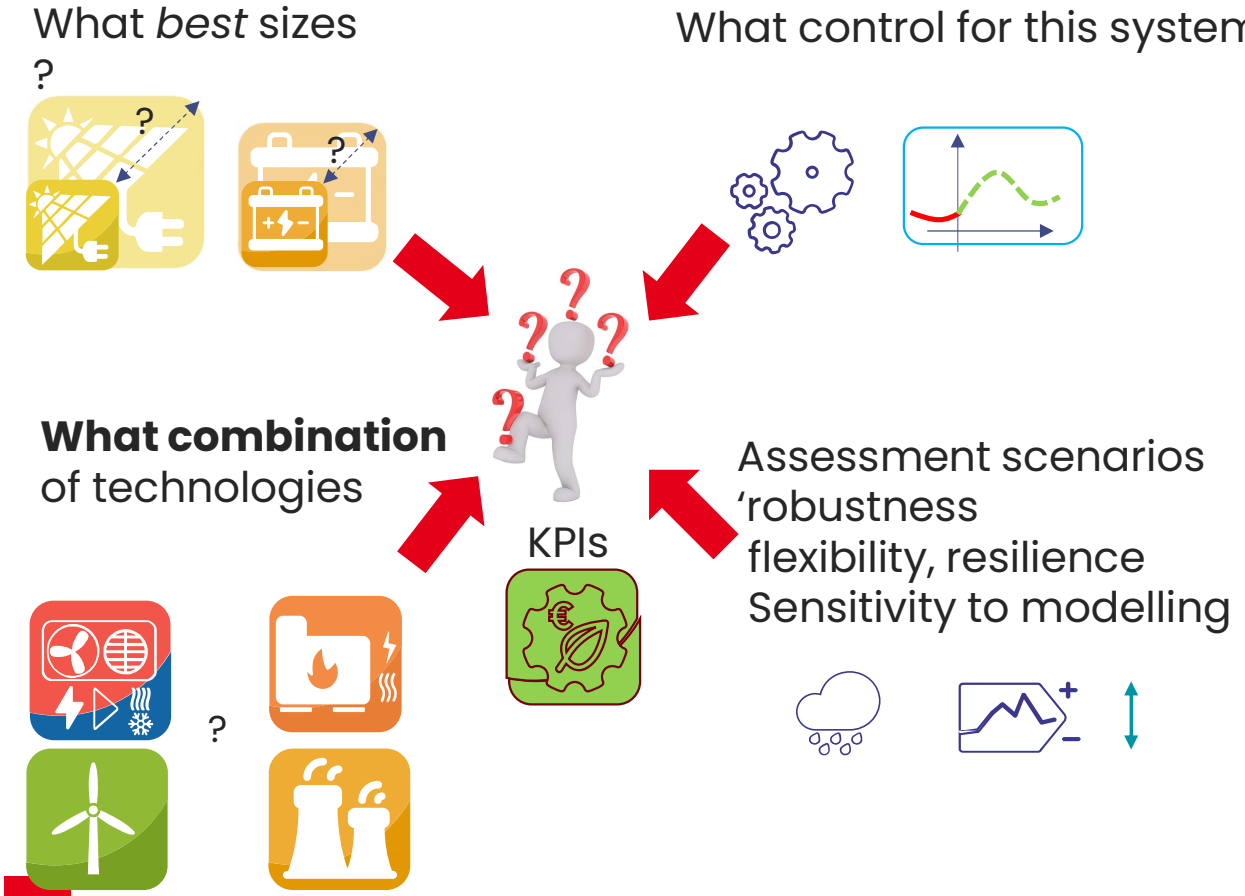
- the most efficient system for EU combines nuclear and renewables and is underpinned by storage
- Combination is subject to Multi-energy system modelling approach
- Europe has been a pioneer in nuclear technology and with Small Modular Reactor new business models to decarbonized Industry Sector producing High Valuable Molecule are available
- Fusion may be a game-changer but transition at lowest cost is affordable with EnR



Use of simulation model

Trilogy

to help make decisions about complex questions



« How to best integrate new technologies
like SMR, HTSE, RES
to reduce environmental footprint
at affordable costs,
at different time horizons »

A four step methodology

From opportunity study (step 1) to …
… demonstration (step 2) …
… and industrialization (step 3 - 4)
step-by-step, with go / no-go for each one

To perform energy mix optimization studies (even by non specialist of optimization)

To perform technology integration studies (MPC - XIL)

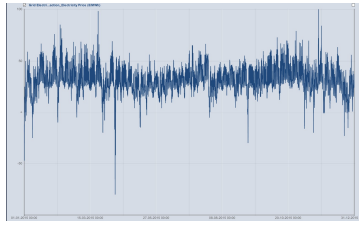
Several steps to model multi-energy system

https://cea.hal.science/cea-04681216

1 Collect Data And define KPIs

Define context

- **Time series** Loads, RES sources



- Time context and data
- Key performance indicators
  - Total cost,
  - CO2eq emissions
  - Resilience, robustesse

2 Identify possible components and system architectures

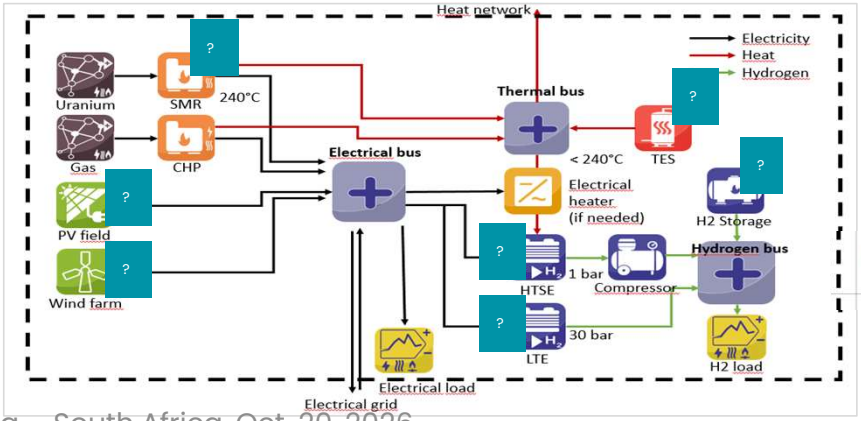
Define energy mix

- Site description
- Identify technologies to help improve energy efficiency and environmental footprint
- **Parametric data** Tec, Eco, Env

3 Build simulation model and compute system behaviour

Build an Optimisation Problem

- Model using CAIRN MILP library
- Optimize objective function,
- **Under technical and environmental constraints**
- **Using solvers Cplex, Highs…**

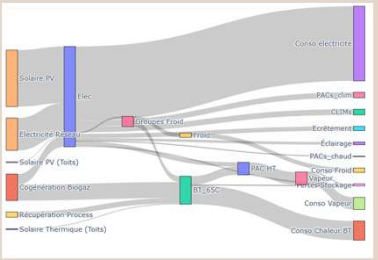


CAIRN Open by CEA

4 RESULTS Assess solution, KPIs robustness, resillience…

Analyze results

- **System dynamic behaviour** (flux-mass-energy values at each time)
- **Load satisfaction**



- **Optimal sizing of** components (RES, storages, converters)
- Key performance indicators **(KPI)**
- Sensitivity, robustness and resilience assessment
- **Viability studies: CAIRN control of NL simulation model**

Example of decarbonation of industrial port area

Complex energy hubs :

- Involve more than 100 industrial facilities
- Use Electricity, Heat, Cold, fossil fuels
- Produce Fatal heat, RES potential
- Possible large H_2 quantities

Examples of Dunkirk, Fos sur Mer

~ **40%**

of CO_2 industrial emissions in France

What opportunities for their decarbonation pla

TANDEM

Typical question raised in https://tandemproject.eu/

Can new technologies help decarbonize industrial harbour ?

What optimal energy supply chain could be used as the direct CO_2 emissions will be reduced by 2035, by 2050 ?

At what costs ?

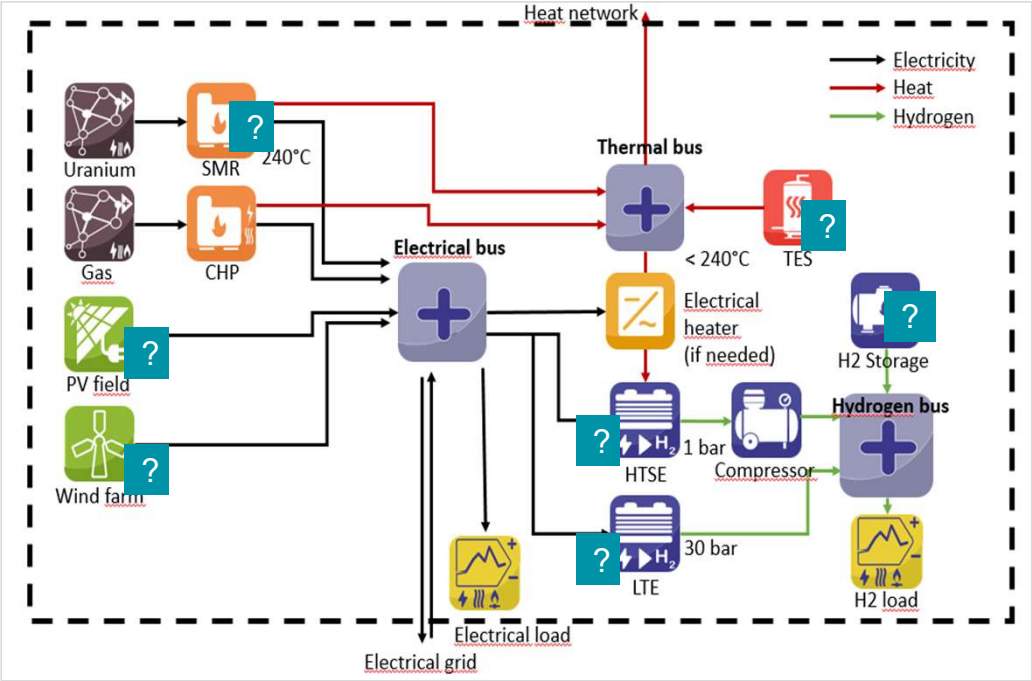
Simulation approach needed

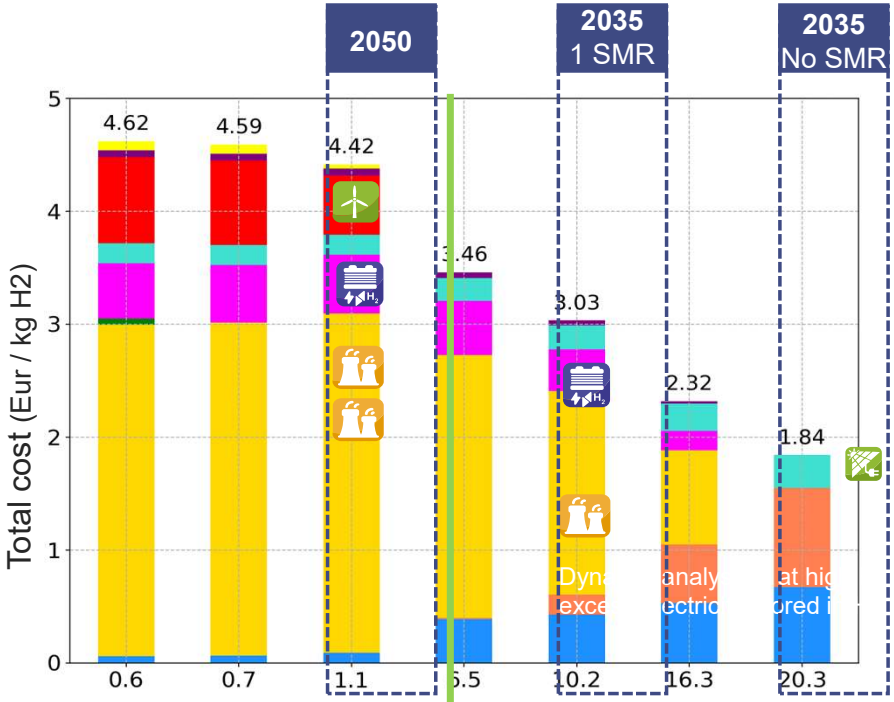
Modelling, Simulation & Numerical Assessment

Hydrogen production decarbonization plans

Can new technologies help decarbonize industrial port area

» Possible optimal energy mixes : minimal Total costs / CO2 content



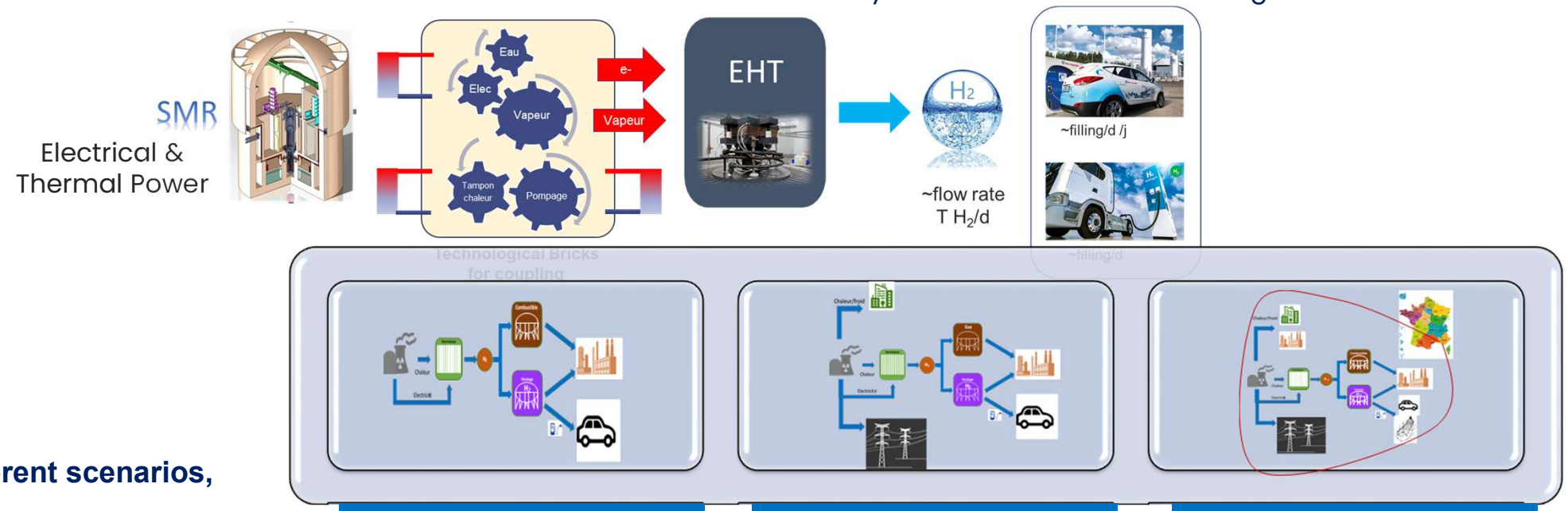


what optimal size under what optimal operation ? (KPIs !)

CCGT, SMGR, SMR, LTE, HTSE, PV_Field, Wind_Farm, Compressor, H2_HP_Storage, Thermal_Storage, Heater

SMR to X : Nuclear Energy to produce H2 and beyond Chemical Sector

Increase of efficiency compared to the reference where HTE unit is solely connected to the electrical grid



3 different scenarios,

3 technical configurations

3 tech-eco evaluations

Use Case n°1: H2 production only Driver: Maximizing H2 output for a given system	Use Case n°2: Flexible H2/power Driver: Maximizing RoCE* by switching between power and H2 markets	Use Case n°3: Service to Community Driver: Maximizing response to specific energy supply of an area

*Return of Capital Employed

Four research priorities for a low-carbon mix

01 Technology complementarity

Assess nuclear flexibility alongside renewables, storage and controllable demand.

Country-specific combinations

02 Lower energy needs

Improve efficiency and design services that use fewer resources.

Adoption and distributional effects

03 Demonstration

Fund demonstrators with explicit performance criteria and shared results.

Evidence before wider deployment

04 Hard-to-abate uses

Test solutions for industrial heat, materials and long-distance transport.

Lifecycle emissions assessment

Islands and NIZs: sentinels of global change



Non-interconnected electrical systems by nature — exposed first to climate change and resources stress,

Every kilowatt counts: stability, continuity of service requiring real-time supply-demand balance renewable integration and robustness must be achieved **simultaneously**

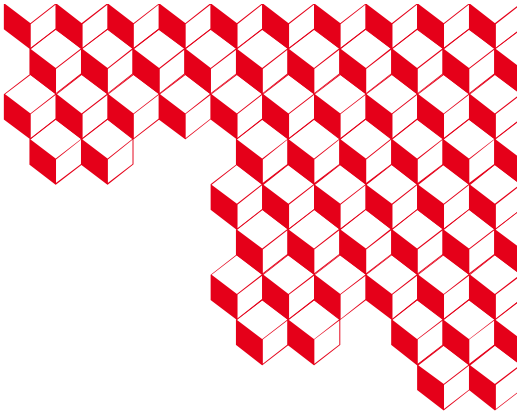
Structural vulnerabilities: energy dependence (fuel essentially), limited economies of scale, exposure to climatic hazards

The island paradox: constraint → no interconnection backup · visibility → impacts appear here **first** · opportunity → **full-scale laboratory** for the energy systems of tomorrow: **create ideal full-scale innovation testbeds**

In conclusion…

- Research and Innovation for net zero in a BANI world are capital
  - ☞ Research to clarifies uncertainties and the limits of technologies (Tests assumptions against models, experiments and observations)
  - ☞ Innovation to Turns knowledge into solutions that people can use (Includes technology, organisations and public policy)
  - ☞ Manage an Hollistic Approach thanks complex modelling and simulation
- Balance “End of the month vs. end of the world”
- **Combination** dispatchable (as nuclear) and intermittent energy sources is depend on country specificity
- RE is crucial for short time horizon
- Energy Island may be a laboratory subject to replicability





Thank you for your attention