Model taxonomy for hydrogen energy systems

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Agenda

2-minute version of the work

Longer version with more details

Approach

Define a model taxonomy for archetypes of hydrogen models

Define the archetypes of hydrogen models commonly used in literature

Characterize the archetypes using the taxonomy

Identify **commonalities, gaps, and challenges**

Key messages

1. **No single model can cover all** the perspectives and **soft-linking** multiple models **is necessary** to give a holistic answer

2. **Hydrogen** is a versatile energy carrier that **requires special features for modeling**. These include system-wide scope, flexibility to the power sector, need for high temporal resolution, no end use GHG emissions, consumer behavior, among others

3. **Some** of the modeling **categories** (e.g., renewable hydrogen production) **are well covered across all archetypes**, while others (e.g., environmental impact) are only covered by one or few archetypes

4. The characterization allowed identifying **correlations between the archetypes** to identify which ones are the most **complementary** to each other

5. In terms of **gaps, environmental impact**, the **innovation** cycle, **market design** and **policy** levers to promote deployment are much less covered

6. Hydrogen technologies are relatively new in some archetypes (e.g., IAM) and a **consistent and validated set of data for use across models is lacking**

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There are 6 major categories that can be used to characterize the most important features of an energy model

This taxonomy is applicable to any energy model

Complexity

Factors that make the model more realistic

- Irrationality of agents
- Uncertainty analysis
- Market representation

Spatio-temporal features

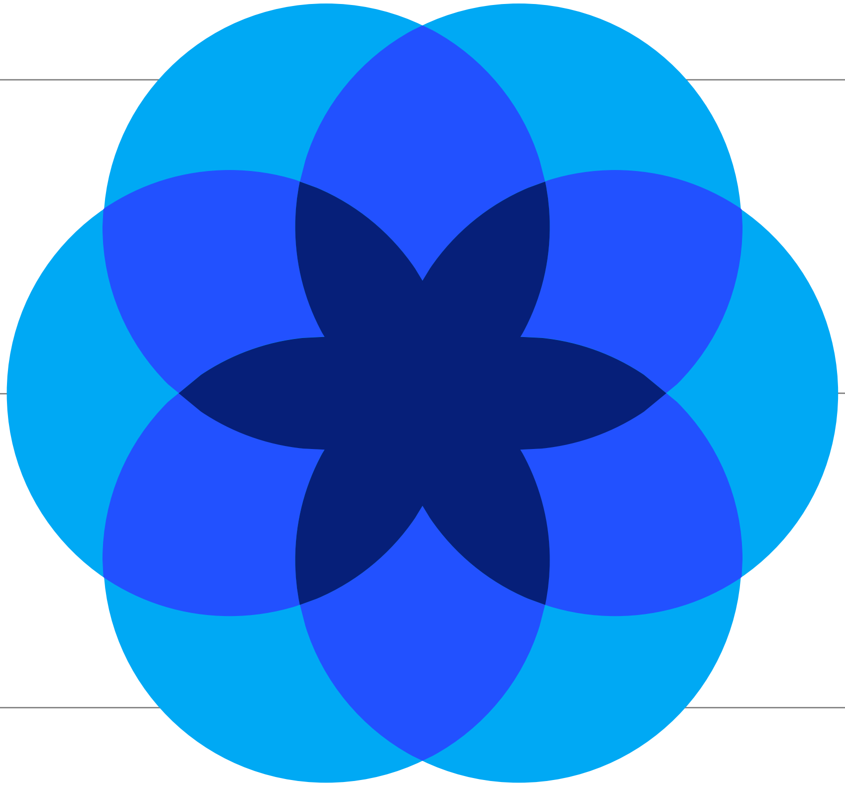
Coverage and resolution across space and time

- Spatial resolution
- Spatial coverage
- Temporal resolution
- Time horizon

Structure (topology)

Conversion pathways covered and input data

- Renewable technology
- Thermal plants
- Hydrogen conversion
- Demand technologies
- Sectors covered
- Input data
- Constraints



Purpose of the model

Main intended use of the model

- Policy
- Market
- Environmental
- Forecasting
- Backcasting
- Exploratory

Solution methods

Approach to solve the problem and reach the final state

- Analytical approach
- Mathematical approach
- Methodology
- Programming language

Use and accessibility

How easy is to access the code and make changes? Is training available?

- Transparency
- Licensing
- Training

Modeling features required to model hydrogen

System-wide scope

Trade-offs across feedstocks and end uses

Possibility to convert to other carriers

Flexibility for power system

Electrolyzers compete with other flexibility options such as storage, transmission, demand response

Spatio-temporal resolution

Fine resolution to capture flexibility benefits and model infrastructure expansion

No end use GHG

Need to use lifecycle assessment to quantify the upstream impact and beyond GHG emissions

Systemic drivers

Role of hydrogen is influenced by role of other cross-cutting tech like CCS, bioenergy, nuclear

Consumer behavior

Hydrogen might arise (e.g., FCEV) when other factors beyond cost are considered

Development uncertainty

Cost decline over time, availability of renewables, CCS can all affect the role of hydrogen

Climate variability

Wind is fundamental for H_2 production and it is affected by the climate year and patterns

Taxonomy is adapted to 4 categories when considering the main modeling features that hydrogen requires

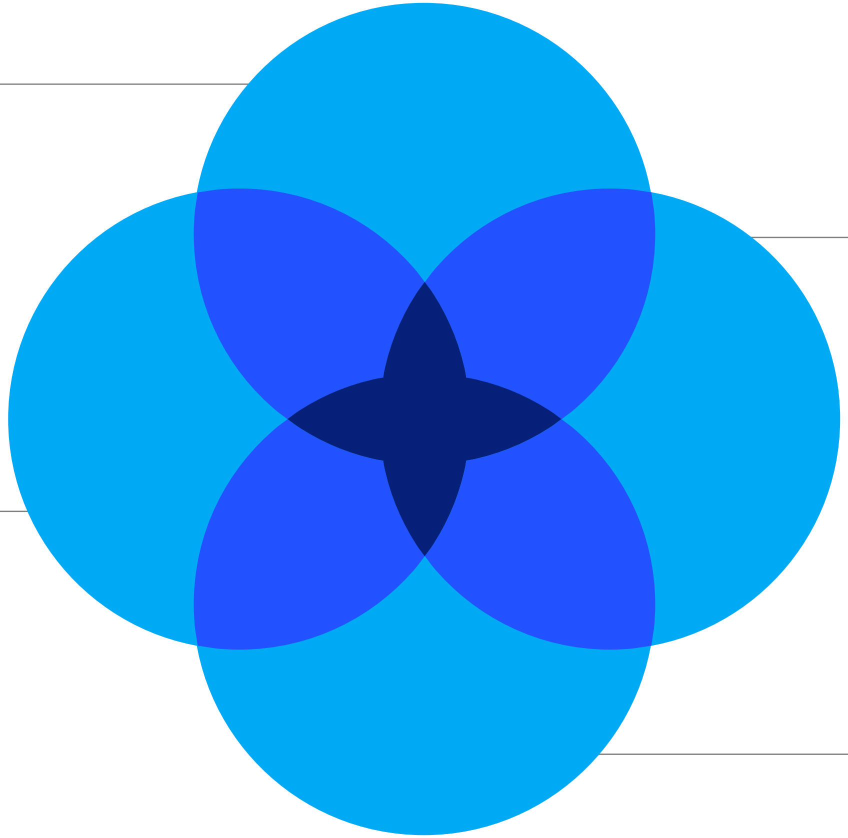
Methodology

Role of hydrogen will depend on this

- Optimization vs simulation
- Macro vs micro-economic
- System dynamics
- Multi-criteria

Complexity

Hydrogen technology are mostly at an early stage making **innovation (tipping points)**, clear **policy signals and market formation** critical. These are complex aspects that most models do not cover. **Behavioral aspects** could also favor hydrogen and are also overlooked by most models



Spatio-temporal resolution

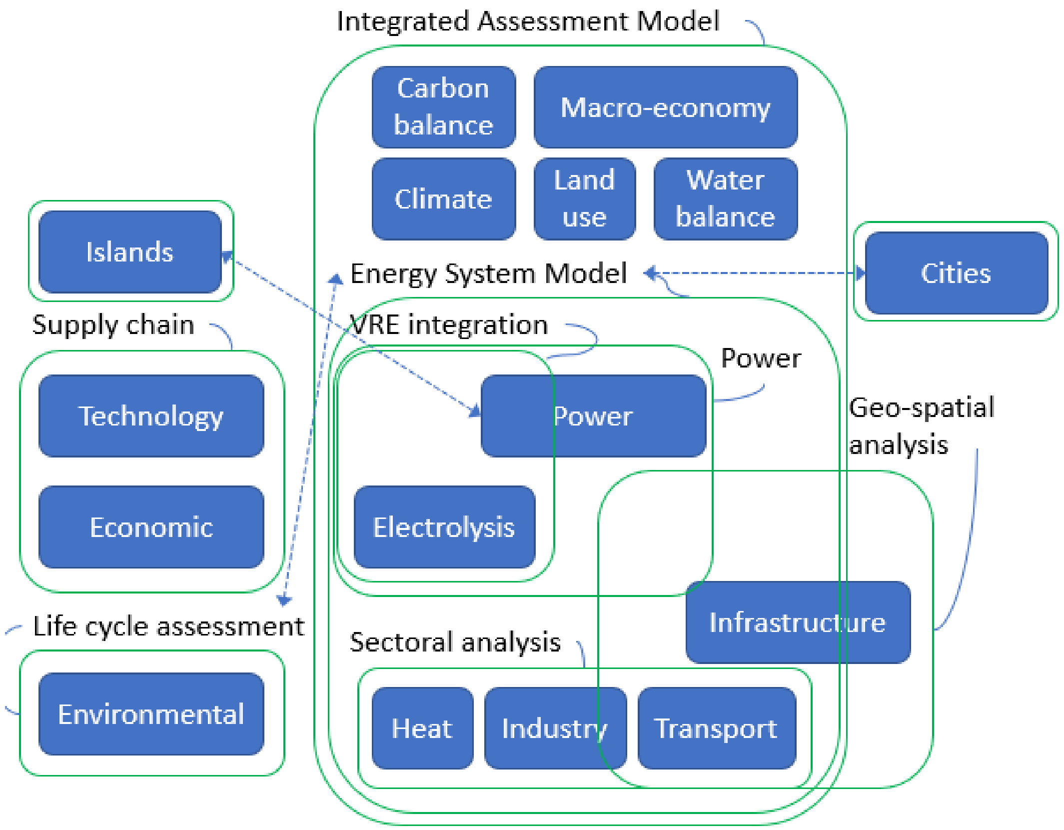
Need for models that can model with at least **hourly resolution** to be able to account for the **flexibility** of electrolyzers and with high spatial resolution to make choices about **infrastructure expansion** and consider the specific **renewable potential**

Model topology

Full hydrogen potential can only be assessed when **all the conversion pathways (to derivatives)** are considered, and **all the end uses** (for those derivatives) are included. Multiple feedstocks and trade are also relevant for its full potential

There are 9 archetypes for hydrogen models

Boundaries and relationships between hydrogen model archetypes



Archetype	Description
IAM	Used for **IPCC reports** covering the natural system, the human system, and climate
Energy	Used to outline decarbonization pathways for the **entire energy system**. Usually exclude economy and land
Power	Focus on **electricity sector** with (at least) hourly resolution
VRE integration	Off-grid optimization of **plant configuration** (including unit sizes, storage, and hourly operation)
Sectoral models	Have a better representation of a **single sector** but omit the interaction with the rest of the energy system
Cities	Similar to **energy models** but **applied to a city**, potentially with a higher spatial resolution
Islands	**Isolated systems** with more limited choices for 24/7 electricity supply and storage technologies
Supply chain	Identify the **spatial location of assets** (renewables, pipelines, HRS) with fixed assumptions for the rest of the system
LCA-based	Expand energy model to cover **sustainability aspects** with more data needed and soft-linking required

There are trade-offs to consider for each archetype and selection should be done based on modeling objective

Specificity for hydrogen Low ○ ◔ ◑ ◕ ● High

Archetype	Advantages	Challenges	Specificity for H_2
IAM	Cover land use, economy, climate, and the entire energy system	Slow update cycle (IAM). Focus on H_2 for road transport. Limited PtX representation. Perfect foresight assumed	○
Energy	Consider trade-offs for feedstocks and end use across the entire system and constraints can be added to cope for shortcomings		◔
Power	Captures flexibility and representation of the power market	Limited representation of hydrogen transport and use. Limited to a single year	◑
VRE integration	Closer to business model of PtX plants with high temporal resolution	No alternative uses for the renewable energy or coupling with hydrogen use	◕
Sectoral models	Broader set of criteria and range of business models can be included	Omit technologies with multiple output (e.g., CHP). No possibility of demand curves with multiple sectors	◑
Cities	Complement urban planning and closer to implementation	Availability of granular data. Behavioral aspects	◔
Islands	Explore pathways towards 100% RES	Modeling high VRE systems with seasonal storage. Full energy system coverage with high temporal resolution	◑
Supply chain	Individual sites for renewables and H_2 use can be identified	Exogenous assumptions on hydrogen demand and willingness to pay and fixed renewable input	●
LCA-based	Enriches cost and energy dimensions with environmental impact	Consistency in inventory data (e.g., electricity) and limit to expanding geographical scope	◔

No single model covers all the features that are needed

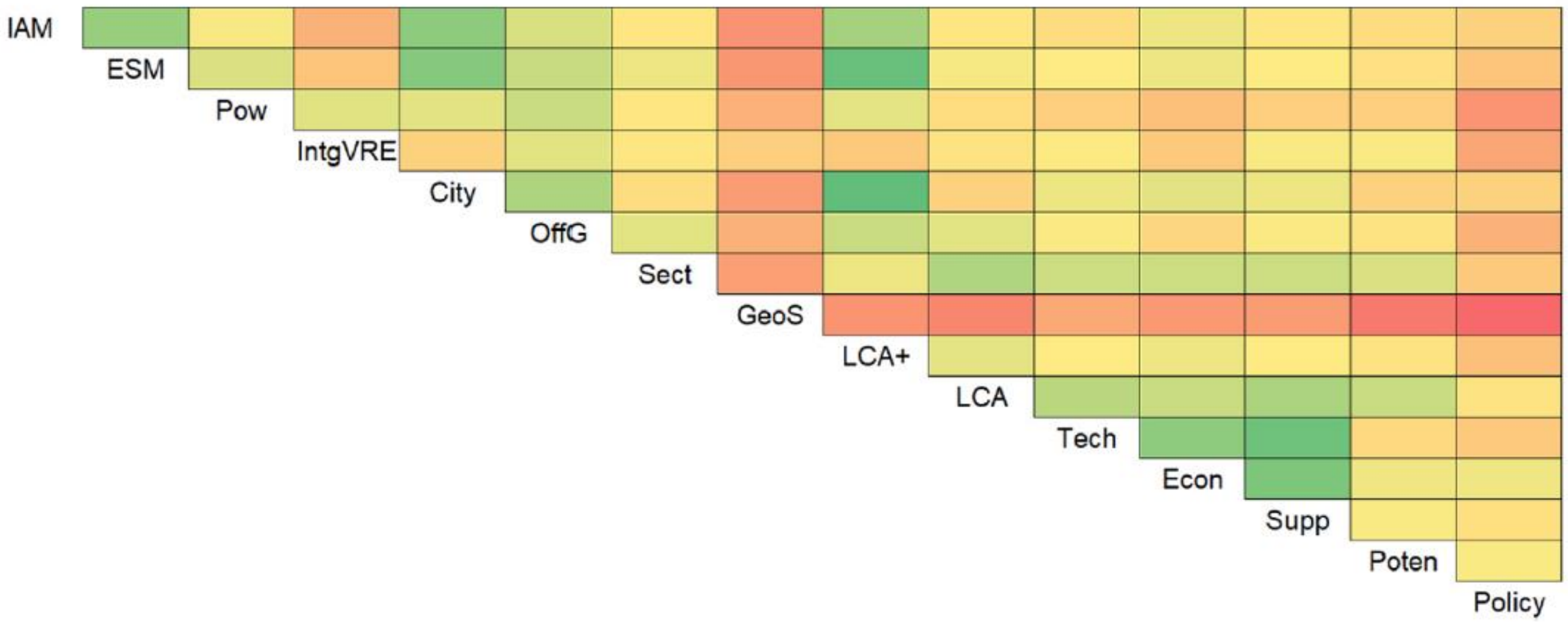
Archetypes \ Features required for hydrogen	All energy sectors	All pathways	H_2-derived carriers	Flexibility (power)	Non-rationality	Spatial / temporal resolution	Beyond climate change	Technology / system drivers
Power model				●		◐		◐
Behavioral model					●			
Life Cycle Assessment							●	
Spatial analysis						◐		
Hydrogen supply chain						●		
Technology model		●						
Energy model	●	●	●					●

Source: Blanco H. (2019). ISBN: 978-94-034-2170-4

There are archetypes that are close to each other and choice will depend on the study objective

Correlation between archetypes Low — High

Correlation between hydrogen model archetypes based on similarities across dimensions of the hydrogen taxonomy



Key insights

- **LCA, energy, and spatial analysis can be complementary**
- **Geospatial analyses** for renewable potential and infrastructure **are the least correlated to other archetypes** so there are limited choices if that is critical aspect of a study
- **IAM, ESM, power model, city, and off-grid models are highly correlated** given their reliance on cost optimization and the representation of (a part of) the energy system. The specific choice among them will depend on the specific objective of the study

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