Course: Global Energy Transitions and Climate Policy

lecture 5 Modeling of Energy Transitions: Pathways, scenarios and tools

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The Agenda Today

Pathways, scenarios, and tools for planning energy transitions

- Timeseries and targets
- Pathways and scenarios
- Tools for modelling energy transition
- Modelling for policy making

Energy Transitions (reminder)

Energy transitions:

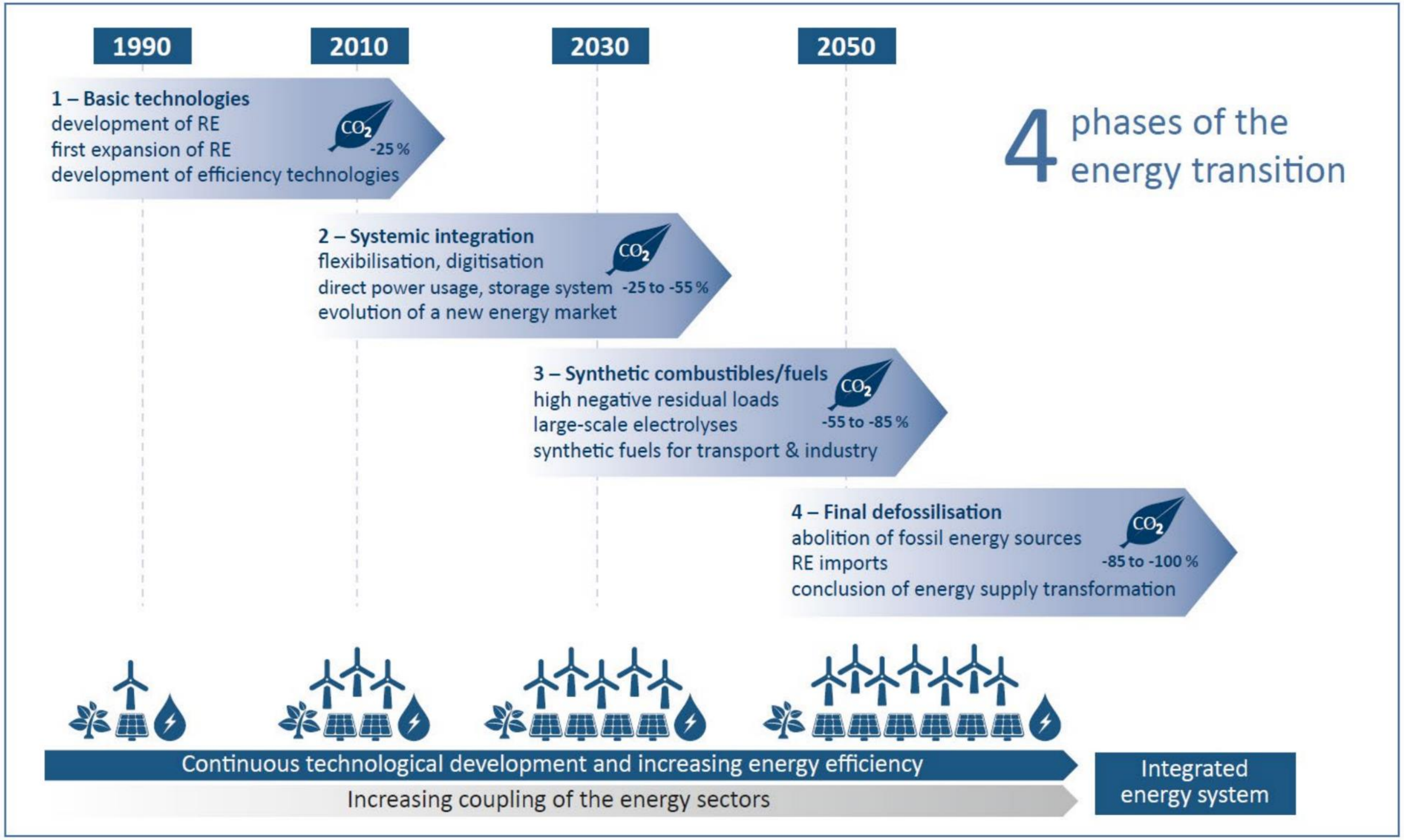
- are affected by international energy markets (oil, gas, coal, etc.)
- are impacted by lifestyle change, behavioural change, and societal change.
- induce technological change, and technological change make transitions possible.
- shape new energy trade relationships between different countries.
- may impact geopolitics, by creating winners and losers.

Group Work (20 + 10 min)

- Divide in groups of 4-5 with at least one stakeholder in each group
- Your country has a target to reach “Net-zero” CO_2 emissions by 2050
- This includes the energy sector, i.e., electricity, heating/cooling, and other energy carriers (fuel for transport)
- Highlight different measures and policies to achieve the goal (yellow colour)
- Mention both supply-side and demand-side solutions
- Develop at least three alternative ways to achieve the target
- Document your main assumptions, considerations, input arguments (different colour)
- Possibly develop a timeline, or roadmap, or waterfall …

Energy Transitions: Happen over (long) time

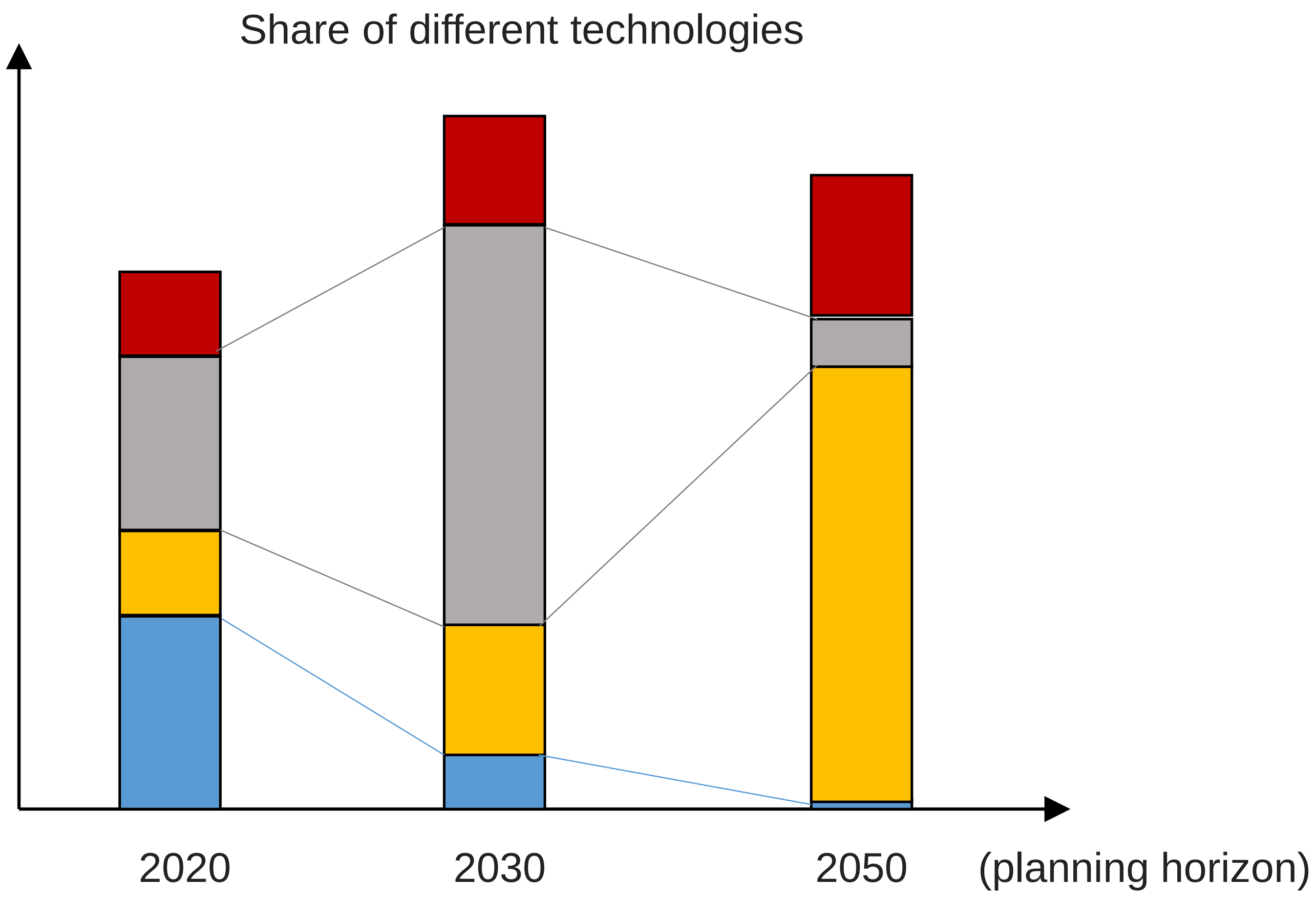
- Transitioning from a current state to a future state, based on a target.
- Different measures that can take place in different time scales.
- Timing defines the level of ambition, i.e., how fast the target must be achieved.
- Timing also defines technology portfolio (based on maturity, commercialization, etc.)



Mostafa, M.; Varela, C.; Franke, M.B.; Zondervan, E. Dynamic Modeling and Control of a Simulated Carbon Capture Process for Sustainable Power-to-X. *Appl. Sci.* **2021**, *11*, 9574. https://doi.org/10.3390/app11209574

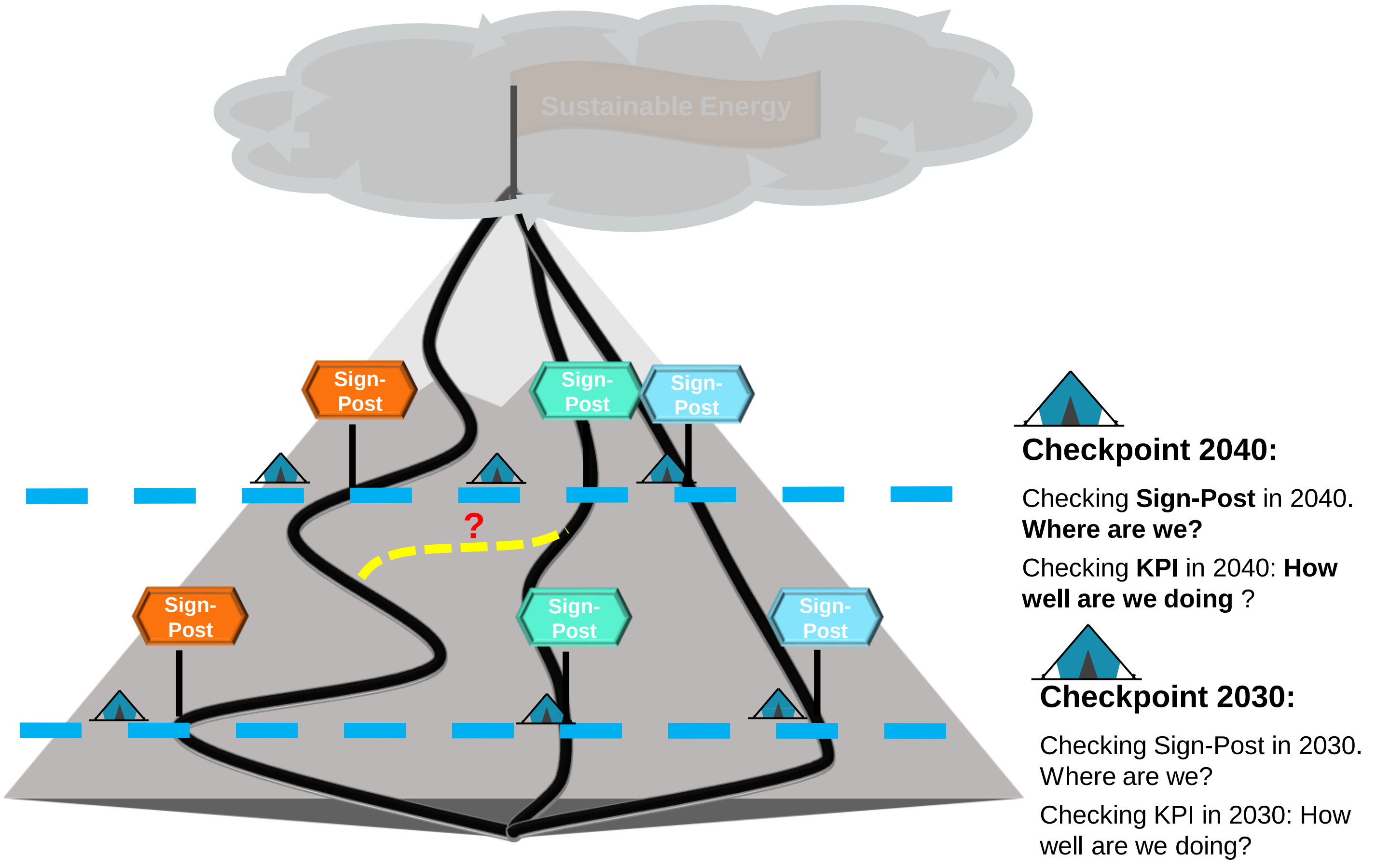
Energy Transitions: State of change

- **Technological change** at different stages of transition, what new technologies can do and cannot
- **Phase in and phase out** (diffusion rates, learning rates, growth rates)
- **Interdependency** of technologies and sectors: one cannot penetrate without others being prepared
- **Bridge technologies:** helping to reach the target, appear mostly at intermediate stages
- Social, institutional, behavioral requirements for scaling up new trends and technologies



Energy Transitions: Alternative pathways

- **Alternative pathways** with the same starting point and target.
- **Sign-posts** identify the scenario that we are in. The most characteristic results of each scenario serve as sign-posts in order to identify the path we are on.
- **Key performance indicators (KPI)** assess the sustainability of the system. KPIs are to likely differ by scenario and over time.
- **Early warning systems** to prevent delay and cost overruns
- **Changing pathways:** if needed, due to difficulty/challenges, change in potentials, etc.



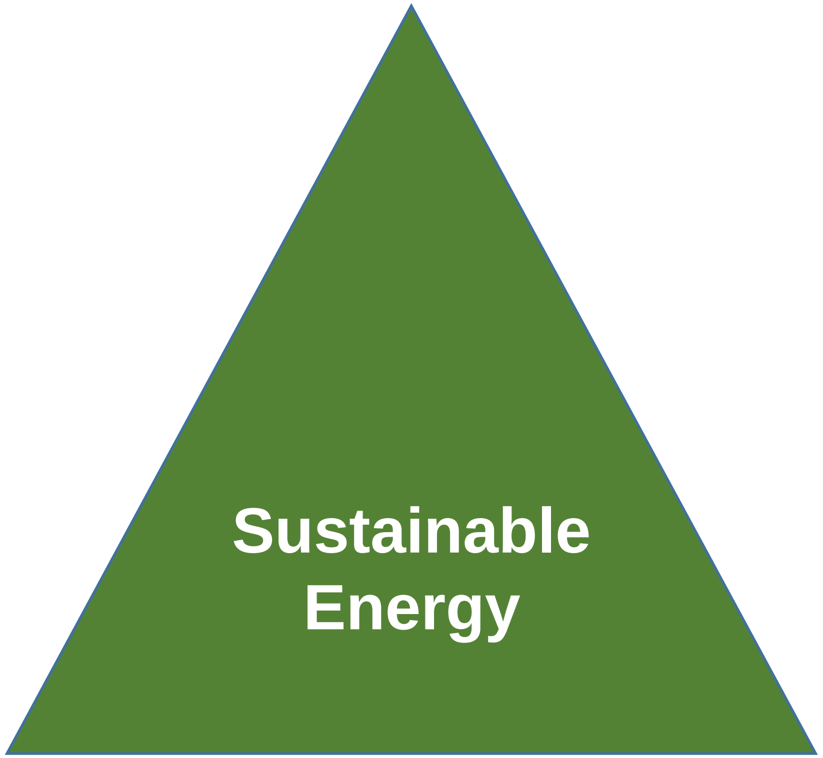
Same starting point - different pathways represent different policy options

Energy Transitions: Key Indicators

Energy Security

Securing the energy needed for economic development

- **Energy Efficiency:**
  - Energy intensity of economy
  - Rate of improvement of energy intensity
  - Conversion efficiency
- **Fuel Mix (Energy, electricity)**
- **Net energy trade**
- **Investment requirements**



- **GHG emissions from the energy system**
- **Energy implications**
  - air pollution
  - water use & water stress

Energy and Environment

Minimize adverse energy system impacts on climate, ecosystems & human health

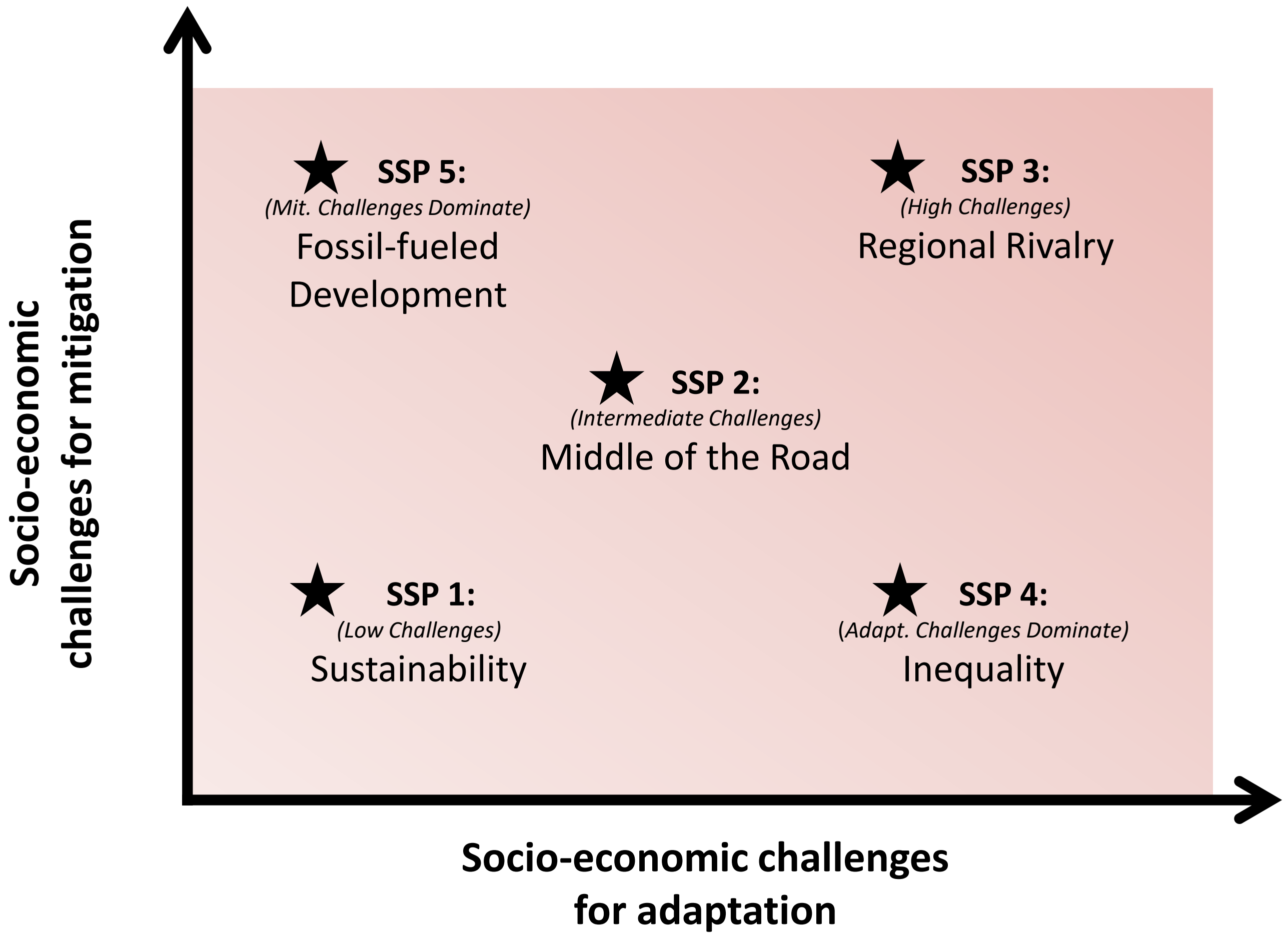
- **Access to energy services**
- **Energy affordability**
- **Food security (biomass use)**

Energy for Quality of Life

Provide affordable energy for all at all times

Shared Socio-economic Pathways (SSPs)

- Depicting **five different world futures**
- **Pathways** to examine how global society, demographics, resources, technological change and economics might develop over the next century
- A broad view of a “business as usual” world without future climate policy
- Developed by a large group of scientists for making assumptions and definitions a bit more consistent.



Narrative

Qualitative description of broad patterns of development

Riahi, K., Van Vuuren, D.P., Kriegler, E., Edmonds, J., O’neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O. and Lutz, W., 2017. The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview. *Global environmental change*, *42*, pp.153-168.

Shared Socio-economic Pathways (SSPs) (II)

SSP5: Fossil fueled development

- Rapid economic growth, free trade fueled by carbon-intensive fuels
- High technology development
- Low regard for gobal environment and SDGs
- Technology fixes Low population and high mobility

Markets first

Clash of civilisations

SSP3: Regional rivalry

- Competition among regions
- Low technology development
- Environment and social goals not a priority
- Focus on domestic resources
- High population growth
- Slow economic growth dev. countries

SSP2: Middle of the Road

SSP1: Sustainability

- Global cooperation
- Rapid technology dev.
- Strong env. policy
- Low population growth
- Declining inequity
- Focus on renewables & efficiency
- Dietary shifts
- Forest protection

UN world

Have's and have not's

SSP4: Inequality

- Inequality across and within regions
- Social cohesion degrades
- Low technology development
- Environment priority for the few affluent
- Limited trade

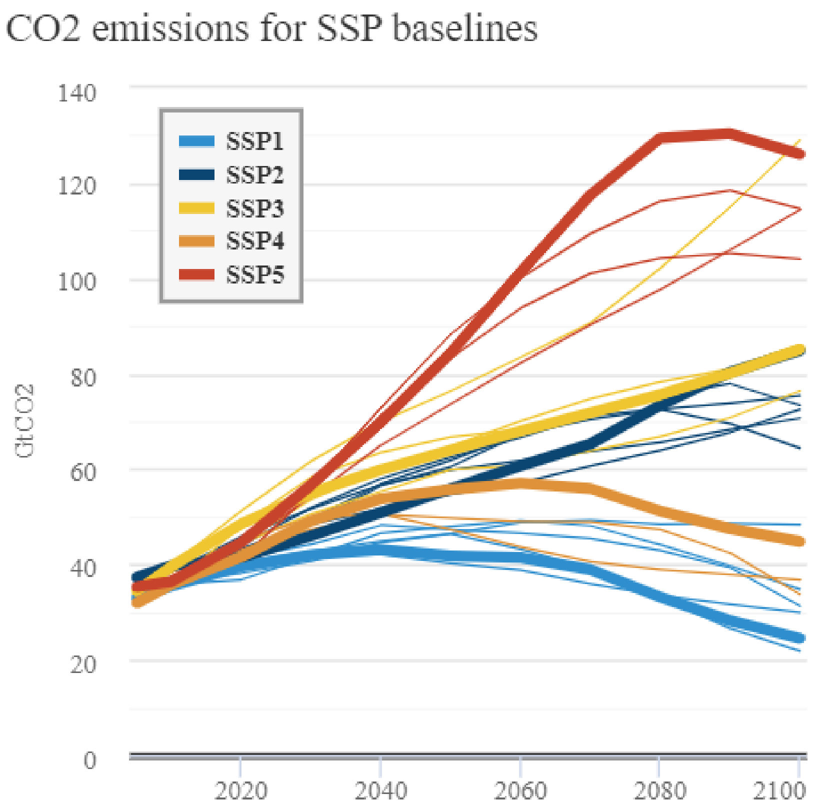
Challenge to mitigation

Challenge to adaptation

Pathways vs. Scenarios

- Have been used alternatively in the literature.
- **Pathways** depict a broader path in energy transition, without specifying details in steps that should be taken and timing.
- Each pathway can include several **scenarios**.

Narrative ➔ Pathways ➔ Scenarios



Scenario: **“**A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change, prices) and relationships.” (IPCC)

- Example of scenarios: business as usual, high-growth, low-demand, accelerated RE policies, high electrification, etc.
- Scenarios are neither predictions nor forecasts, but are useful to provide insight on the implications of decisions

Scenario Development for Energy Planning

Step 1: Define the Issue/Target

- What should be achieved? In what timescale?

Step 2: Input Data and Assumptions

- Identifying the key trends, factors, and uncertainties that may affect the plan, including the political, socio-economic, technological, e.g., energy demand, available resources, etc.

Step 3: Identify Uncertainties

- Some assumptions may be relatively certain, e.g., the cost of a mature technology. Certain trends will continue in a predictable way.
- Uncertainties define a space of possible futures. For example, energy prices, cost of emerging technologies, population growth and demand.

Step 4: Develop Scenarios

- Developing scenarios based on consistent assumptions, e.g., high energy demand may not happen in a scenario with low economic growth, or low urbanization/education/income, etc.

Scenario Assumptions

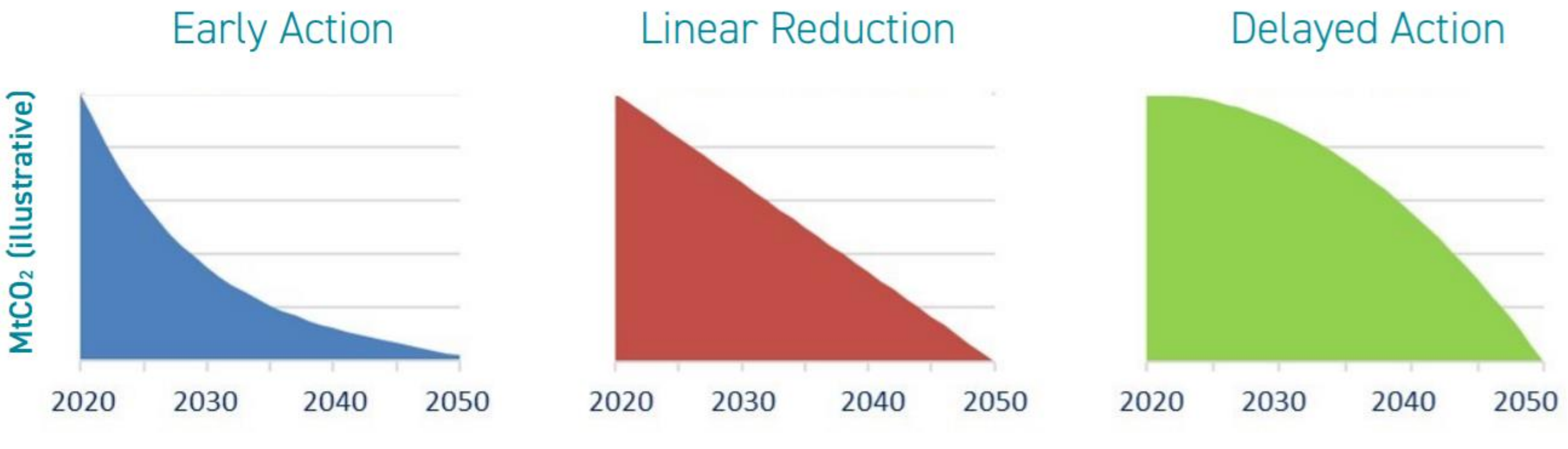
- Identifying key trends and assumptions as of today to 2050 or until 2100.
- **Adaptive pathways or myopic (short-sighted) scenarios** can account for the short-cycle of policy making ➔ revisiting the progress after 4-10 years and refining assumptions and updating the scenario.
- A target can be achieved with multiple scenarios with completely different designs.
- Scenarios should not be biased by optimism or pessimism of the scenario developer.
- Scenarios exhibit different levels of ambition in different years: **early action vs. late action.**

Early action:

- Higher capital cost
- More dramatic change

Late action:

- May be cheaper
- Higher risk of failure



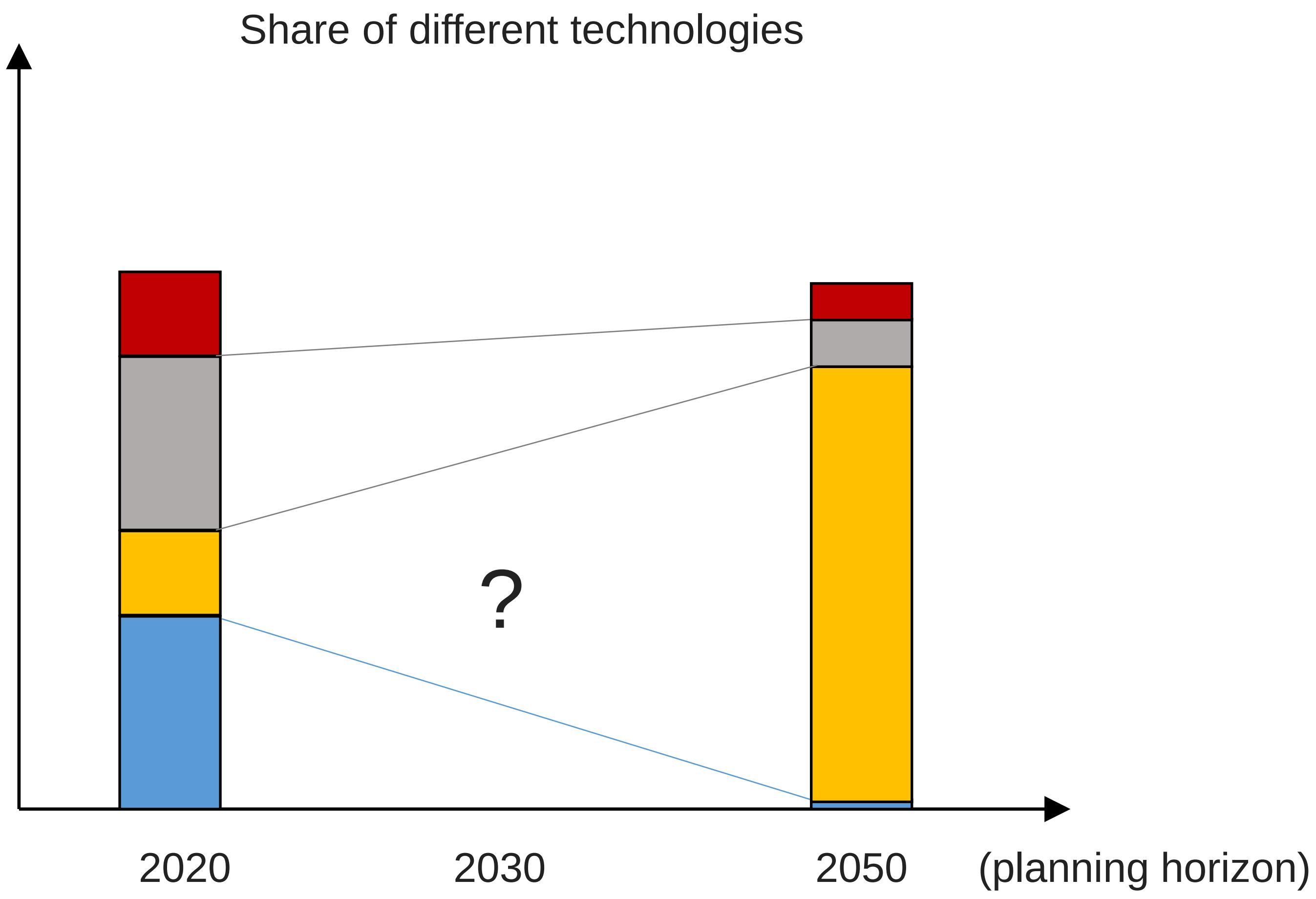
Source: https://www.skillnetireland.ie/

Feasibility of Scenarios

- Can the **target be achieved** in the planned time?
- Will the **expected growth/penetration** rates happen?
- What if one technology fails to **phase in/out?**
- Do we have enough **energy resources/potentials** for this plan?
- Can **past trends** be extrapolated to the **future**?

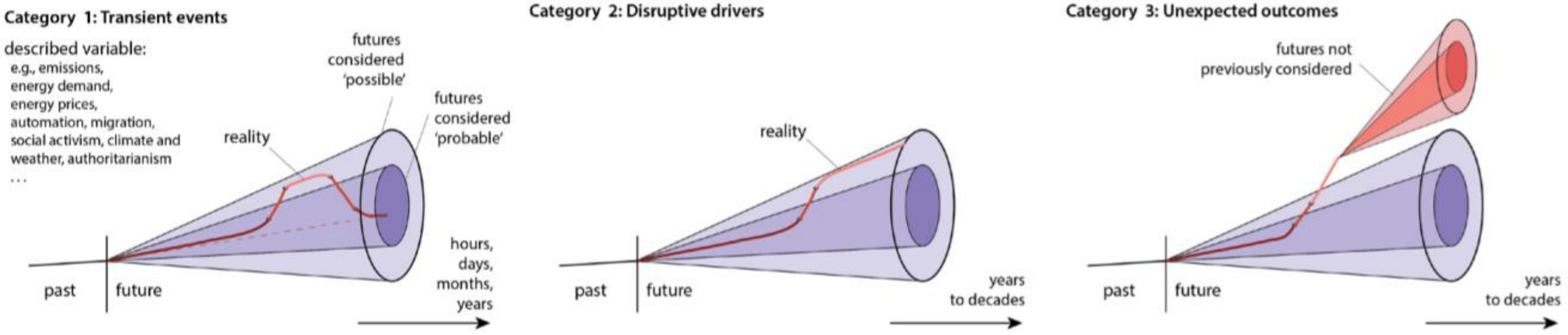
Beyond techno-economic:

Is the society, government, institutions, people have enough capacity to make the transition happen?



Scenarios and the Unknown World

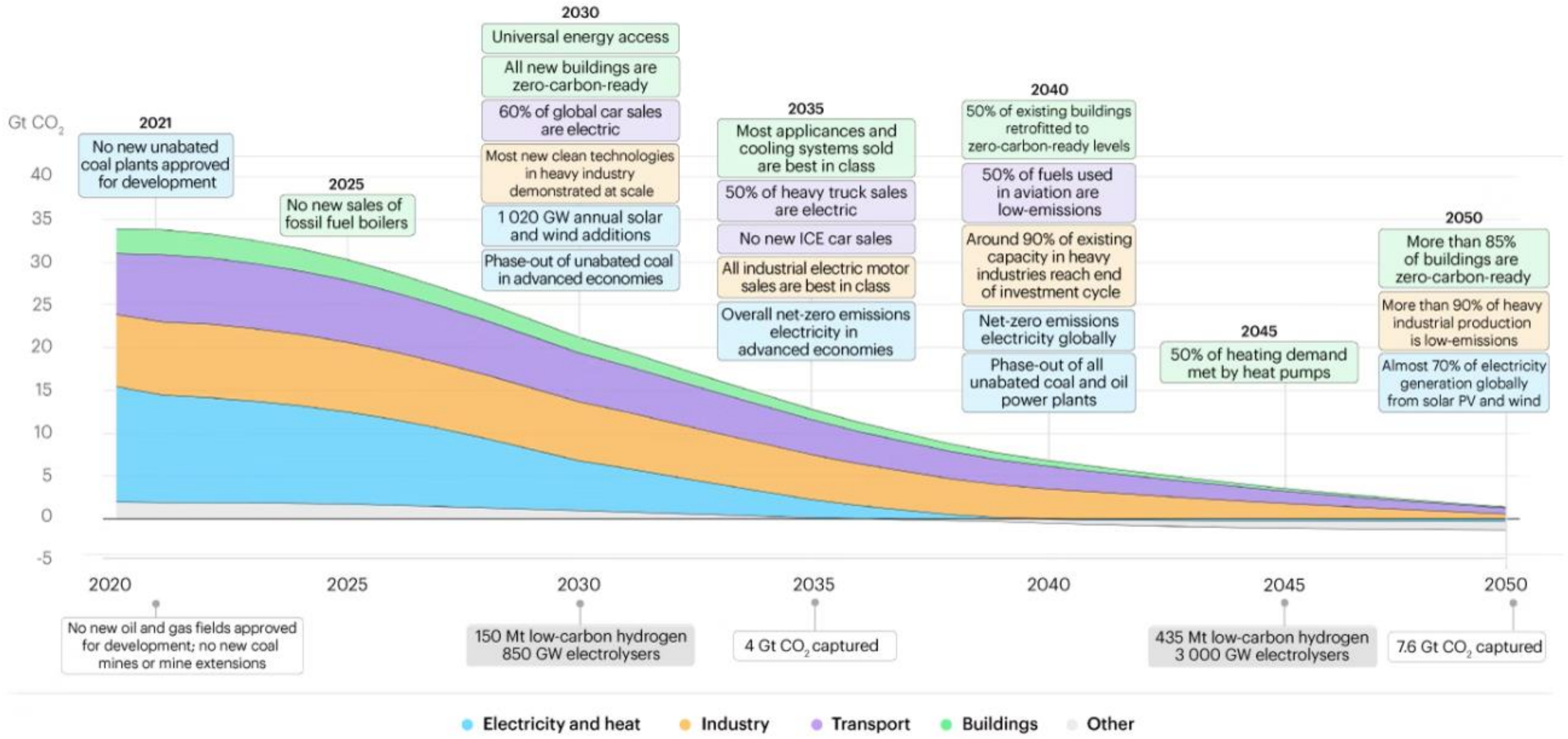
- Scenarios specify what is possible (feasibility zone) and what is probable (likelihood zone)
- Scenarios can explore a broad range of futures, yet they may fail to foresee the unexpected
  - Solar PV boom was not foreseen in many scenarios
  - Smart phones, do we know what will be the next technology revolution and when?
  - Scenarios cannot expect disruptions such Covid-19
- Is it worth and how to explore the unexpected outcome?



McCollum, D.L., Gambhir, A., Rogelj, J. and Wilson, C., 2020. Energy modellers should explore extremes more systematically in scenarios. *Nature Energy*, *5*(2), pp.104-107.

Modeling of Energy Transition

Representing sectors, relationships, developments in a quantitative way using mathematical equations.



Source: https://www.iea.org/reports/net-zero-by-2050

Why Modeling of Energy Transition?

Modelling:

the process of building **a simplified/reduced representation** of a **complicated system** using **computer software** in order to analyze that system.

- Large amount of data and complex relationships ➔ **Difficult or impossible** to analyze and understand
- Models can be used to simplify the real world by representing the **key sectors and relationships.**
- The implications of decisions are massive in terms of **the impact on the society and economy ➔** Decision must be analyzed before being made.
- Energy path dependency: decisions today will impact future generations.
- Models can help to reduce the risk of failure.
- Models can compare implications of different scenarios.

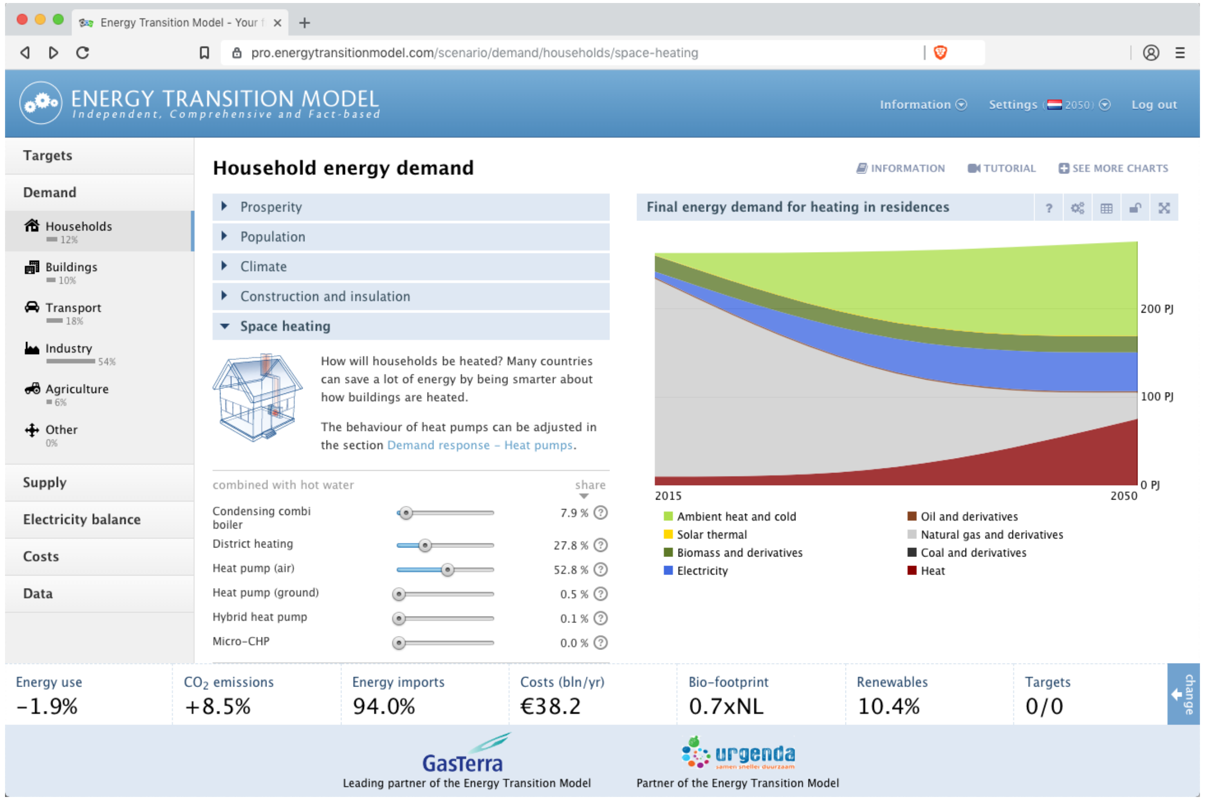
"All models are wrong, but some are useful." ***George Box***

Tools for Energy Planning

Modelling tool:

computer software to build, simulate, and analyze **a simplified/reduced representation** of the energy system and its possible transition scenarios.

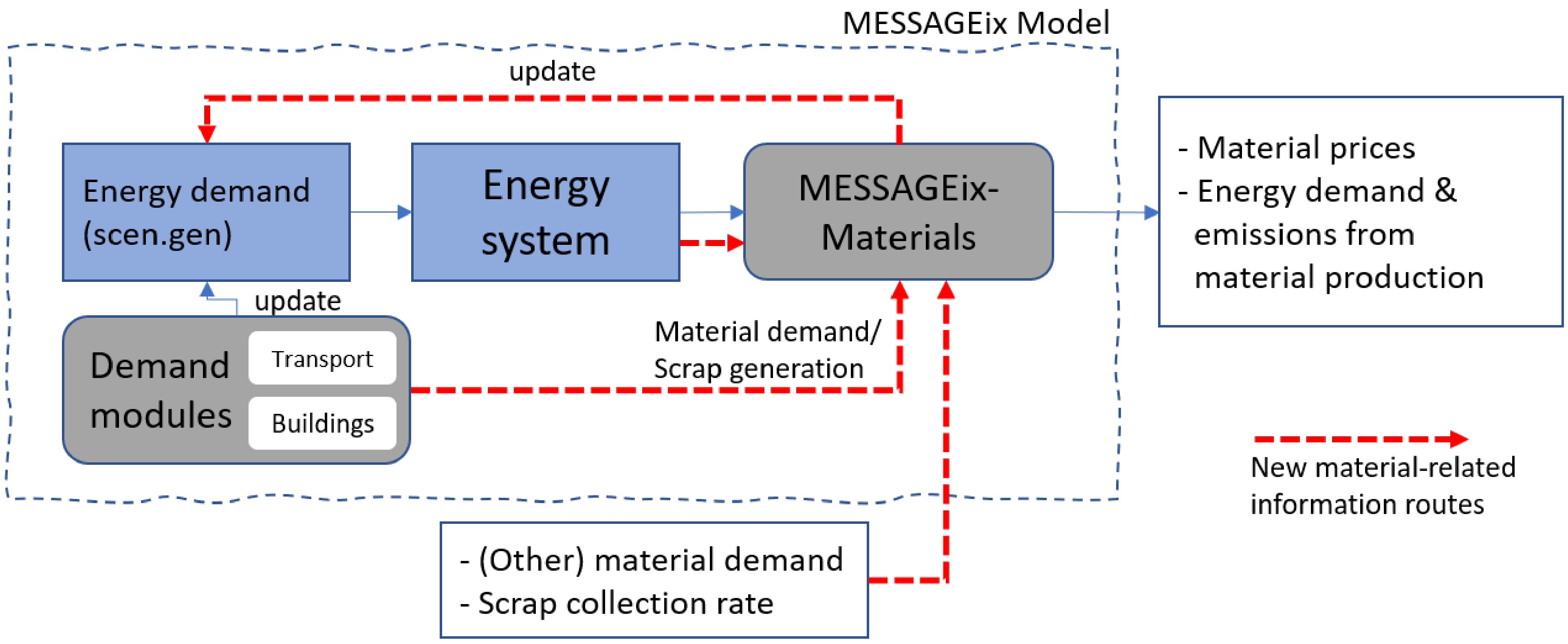
- A wide range of tools exist with various
- modeling logic
- sectoral coverage
- spatial resolution (sub-national to global)
- temporal resolution (hourly to multi-decade)
- Some tools are open-source and/or free
- Some tools have data for selected countries
- Learning a tool from 2 weeks to a few months
- Some tools have graphical user interface



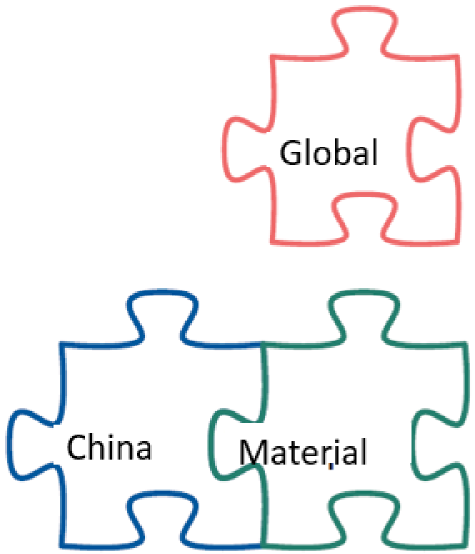
Source: https://www.energytransitionmodel.com

Integrated Assessment and Model Linkage

- Example: modeling of material requirements within energy systems transitions



* No iterations. Arrows mean one-time, one-directional information transfer.



Modeling of Energy Transition: Criticism

- **Energy transitions are too complex** to be modeled: a wide range of technologies, interdependencies, actors, institutions, etc.
- Future is full of uncertainties: modeling creates a false impression that we know “what” may happen.
- Quantitative modeling of many relations in the energy transition is not possible without over-simplifications (e.g., relationship between agents, or the attitude of people to a new trend).
- Models have failed in the past to simulate trends; how should we trust them for **the (long) future**?
- Models cannot always represent **disruptions, technological revolutions**, etc.
- Societal and individual behavior and lifestyle changes are not easy to quantify (how many people adopt a new technology and at what rate?)
- Modeling includes many assumptions that may be biased by the view of individual or institution doing the modeling work.
- Energy transition models are so complex that even modelers themselves may not understand the cause-effect relationships.
- Other: many models are “black-box”, are not validated, different models produce different insights (which one to trust), models lack practical view (too theoretical) etc.

Energy Planning: Final Notes

- Energy Scenarios can **support planning**, but they do not replace the planning process
- A range of scenarios should be explored, representing different realities and future developments
- Considering uncertainties in input data and assumptions
- (Early-stage) Stakeholder engagement in the scenario design process
- Opening the “black-box” of modeling: open source tools and open data
- Models generate insights and not plans: the results are indicative
- Models can be used to assess the implications of different scenarios (costs, emissions, sectoral change, etc.)
- Collaborative modeling practices instead of relying on one model or one modeling group.
- How much are we willing to pay for models/modeling?

Further reading

- *Net Zero by 2050 (IEA): https://www.iea.org/reports/net-zero-by-2050*
- *A tool for analysing some energy transitions: https://pro.energytransitionmodel.com/*
- *Riahi, K., Van Vuuren, D.P., Kriegler, E., Edmonds, J., O'neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O. and Lutz, W., 2017. The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview. Global environmental change, 42, pp.153-168. https://www.sciencedirect.com/science/article/pii/S0959378016300681*
- *Criticism to modelling: Debating the bedrock of climate-change mitigation scenarios https://www.nature.com/articles/d41586-019-02744-9*
- *McCollum, D.L., Gambhir, A., Rogelj, J. and Wilson, C., 2020. Energy modellers should explore extremes more systematically in scenarios. Nature Energy, 5(2), pp.104-107. https://www.nature.com/articles/s41560-020-0555-3*
- *Chang, M., Thellufsen, J.Z., Zakeri, B., Pickering, B., Pfenninger, S., Lund, H. and Østergaard, P.A., 2021. Trends in tools and approaches for modelling the energy transition. Applied Energy, 290, p.116731. https://www.sciencedirect.com/science/article/pii/S0306261921002476*

- Thank you for your attention!