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Introduction to scenarios and modelling for energy planning

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science for global insight

What is energy planning?

- Preparing for an uncertain future in a comprehensive, organized and transparent manner
- Longevity and capital-intensity of energy infrastructures
- A prerequisite for informed decision making
  - Understanding future demand developments
  - Evaluating options & reviewing different ways to meet those needs
  - Identifying risks and benefits
  - Exploring “what if..” questions
  - Understanding trade-offs
  - Investment requirements
  - Optimal energy mix & resource allocation
  - Compliance with policy constraints
  - Testing the effectiveness/feasibility of policy measures
- Avoiding sequential stop-gap measures

Why energy planning?

- Energy is strategic in the key dimensions of sustainable development: Economic, social and environment
- Energy security
- Energy is integrated: One part of the system affects other parts
- Energy is intra-grated: Energy policies affect and are affected by a myriad of other decisions/developments
- Energy planning is about choices & dealing with uncertainty
    - Technology
    - Fuels and prices
    - Policy
    - Demand
- Communication tool (public, investors, stakeholders, neighbors)

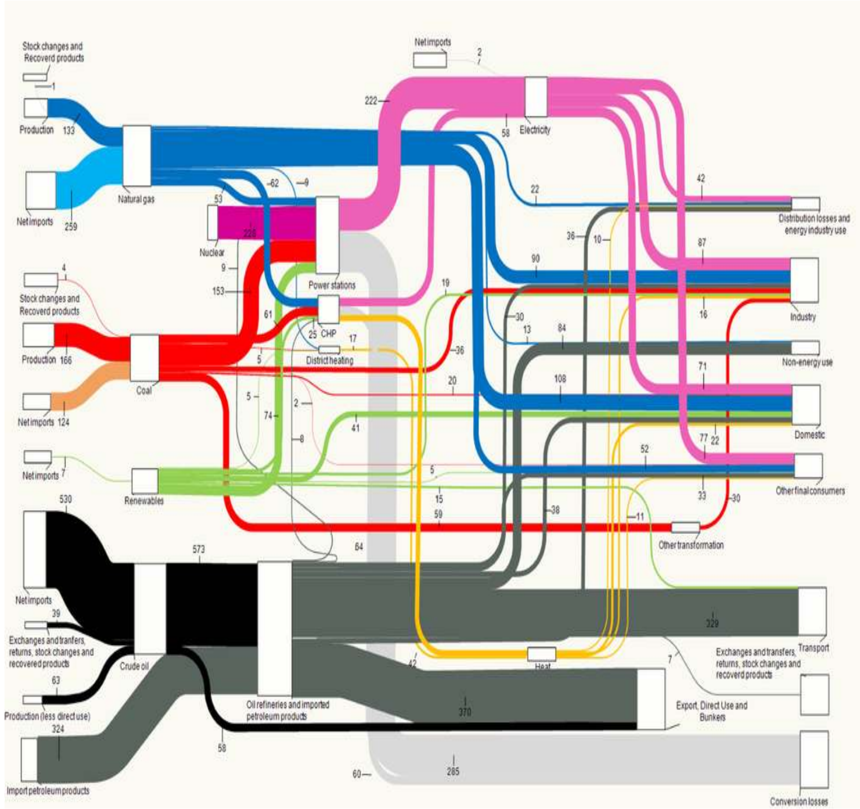
Energy modelling – what is it and what is it not

- Energy models create simplified images of real life energy systems by translating the components, structure and flows into tractable mathematical formulations (equations)
- The equations represent rule-based interactions between the key energy system components
- Once calibrated to reflect the current energy system and base year energy flows, future technology and fuel options (portfolio) as well as demand projections need to be added
- Forward looking is accomplished by the use of scenarios
- Different agents require different answers and thus different models or model detail (no one size fits all)
- Energy modelling is an art not a science
  - Systems boundary
  - Degree of detail
  - Number of technologies & fuels
- The information models provide is often complex and needs to be ‘interpreted/conditioned’ for use by decision makers or market agents

Energy modelling generates insights – NOT answers

Why energy modelling is important

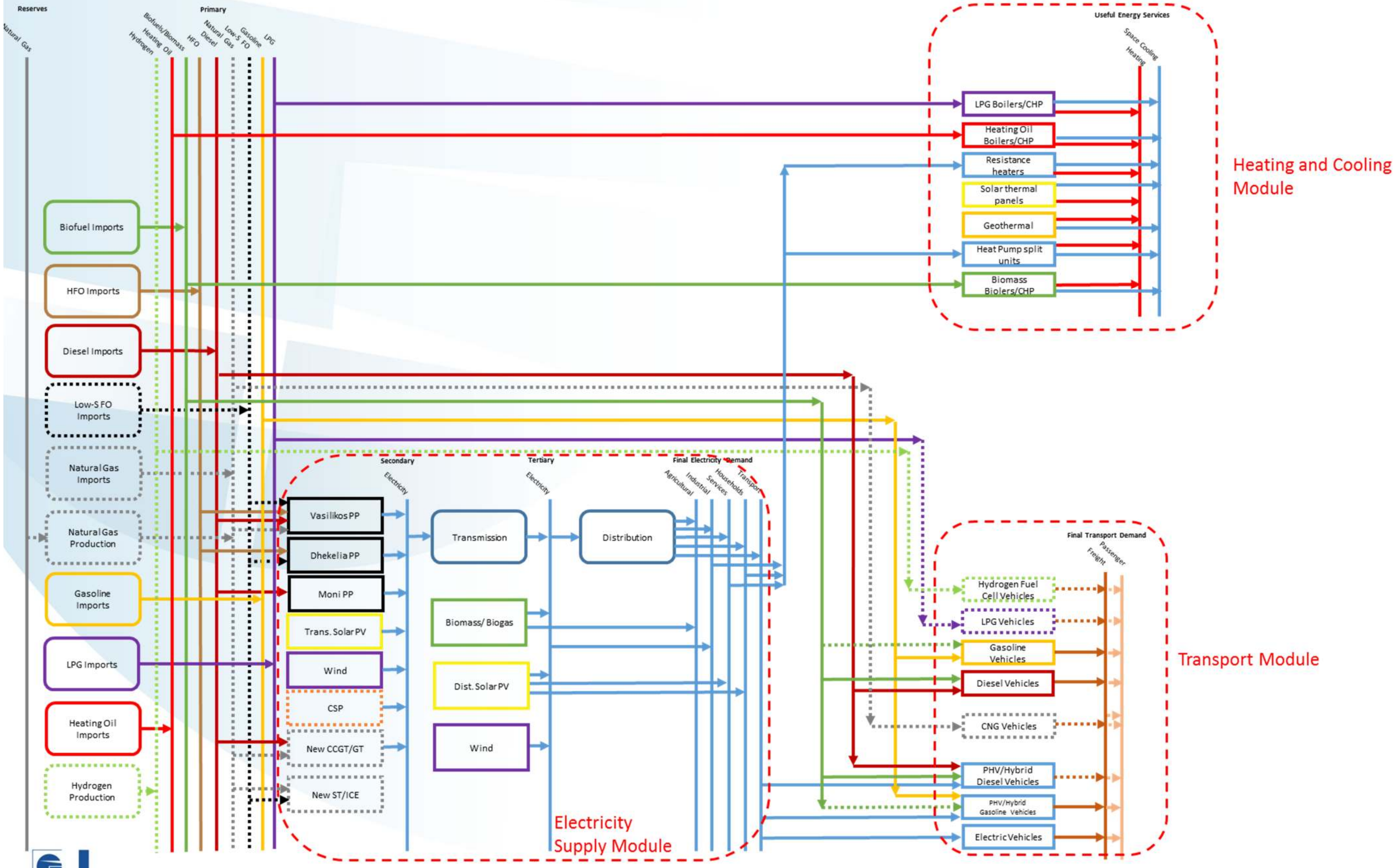
- Energy is not an end in itself
- Energy is a ’complex system’
- One needs to:
    - account for at least, technologies, infrastructures, costs, variability of demand, technology limitations, policy constraints, among others
    - ensure that demand is always meet in an efficient way (and now also sustainably)
    - select the most important drivers of the system with a quantification of their inter-relations.



Architecture of the Energy System

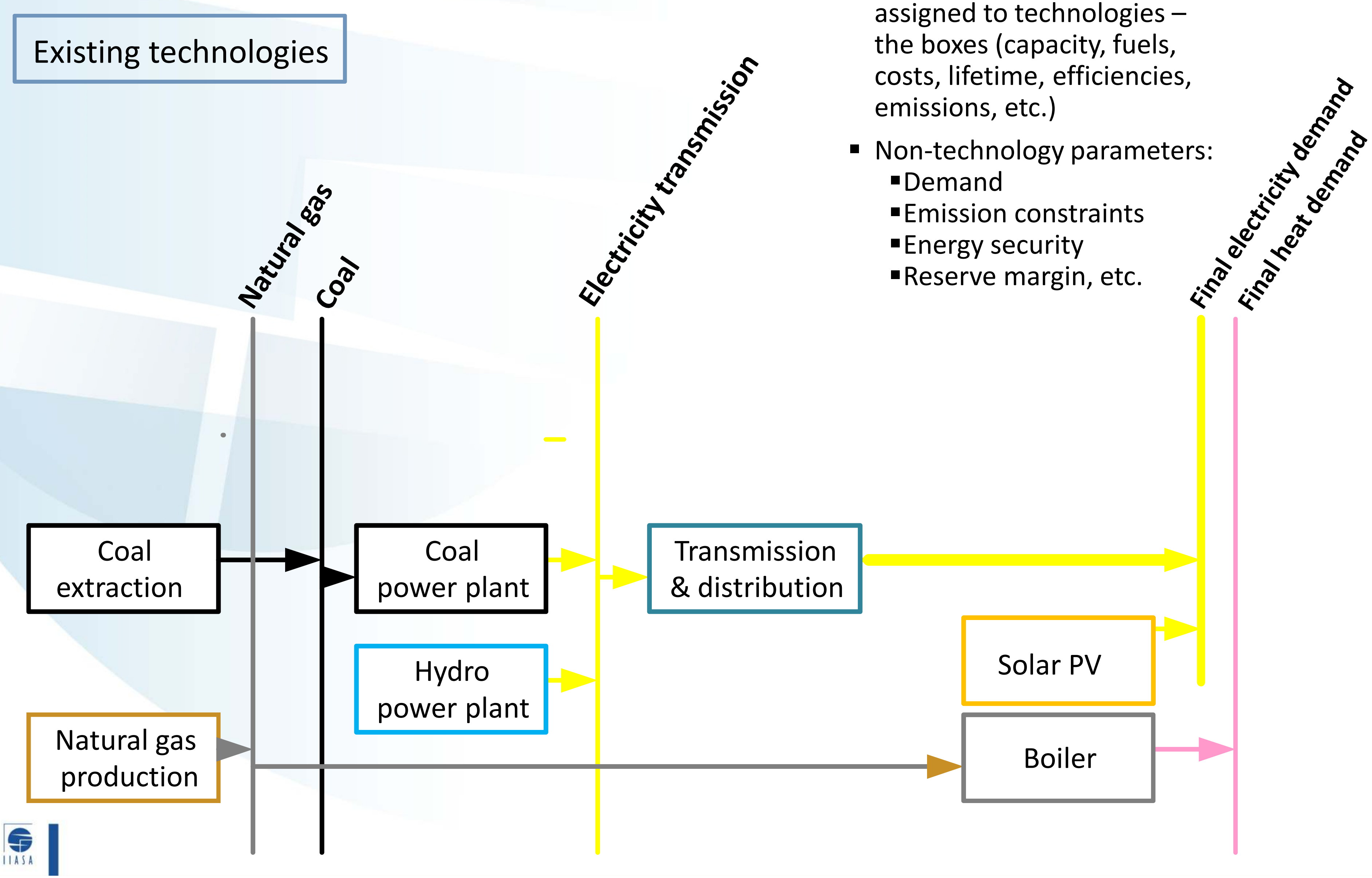
Sources	coal oil natural gas sunlight uranium wind biomass	*What nature provides*
Extraction Treatment	coal mine hydro dam oil rig cleaning separation benefication liquefaction gasification	
Conversion Technologies	hydro station thermal power plant oil refinery nuclear generating station photovoltaic cell wind converter	*Energy sector*
Energy flows 'Fuels'	electricity gasoline methanol methane hydrogen heat	
Distribution	electricity grid gas grid truck dewar railway district heat grid	
Service Technologies	automobile light bulb telephone furnace microwave oven aircraft PC	*Infrastructure*
Services	transportation communication keeping warm/cold food potable water health care security consumer goods	*What people want*

How a techno-economic optimization model sees the energy system



A more discernable view

- Most parameters are assigned to technologies – the boxes (capacity, fuels, costs, lifetime, efficiencies, emissions, etc.)
- Non-technology parameters:
  - Demand
  - Emission constraints
  - Energy security
  - Reserve margin, etc.



Designing & calibrating an energy supply model

- Purpose and scope of the model
  - Short-term vs long-term (next investment cycle vs system transformation)
  - Boundaries – geographical scope
  - Degree of detail – resolution
- Calibration
  - Existing plants, equipment and infrastructure
    - Vintage & life time
    - Fuel input(s) – output(s)
    - Performance (thermal efficiency, emissions, load factor, operating costs, etc.)
    - Base year energy and electricity mix, trade flows
    - Model ‘repeats’ the base year in a satisfactory fashion

Now we want to look forward and explore the future

- Energy models use assumptions to look into the future
    - What will be the energy/electricity demand by sector?
        - Demographics
        - Economic structure and growth
        - Infrastructure, capital stock and technology
        - Consumer preferences
        - …..
    - How are int’l oil and gas prices going to develop?
    - Which technology is winning a particular innovation race?
    - Which kind of markets will prevail – regulated or liberalized?
    - Will nations live up to their NDC commitments under the Paris Agreement?
    - How will domestic energy and environmental policy evolve?

Exploring the future

- Models require analysts to quantify assumptions about the key driving forces of demand and supply
  - Models make assumptions visible
  - Models allow repeatability under different assumptions
  - Model encourage and analyze ‘what if’ questions
  - Models can support “Transparency”
  - Modeling sharpens the focus of the analysis and defines scope and boundaries
- Modelling is a communication tool and if correctly used, can be a powerful informing debates
- But who provides the crystal ball that reveals the quantified assumption about the future course of key energy system drivers?

Scenarios and storylines

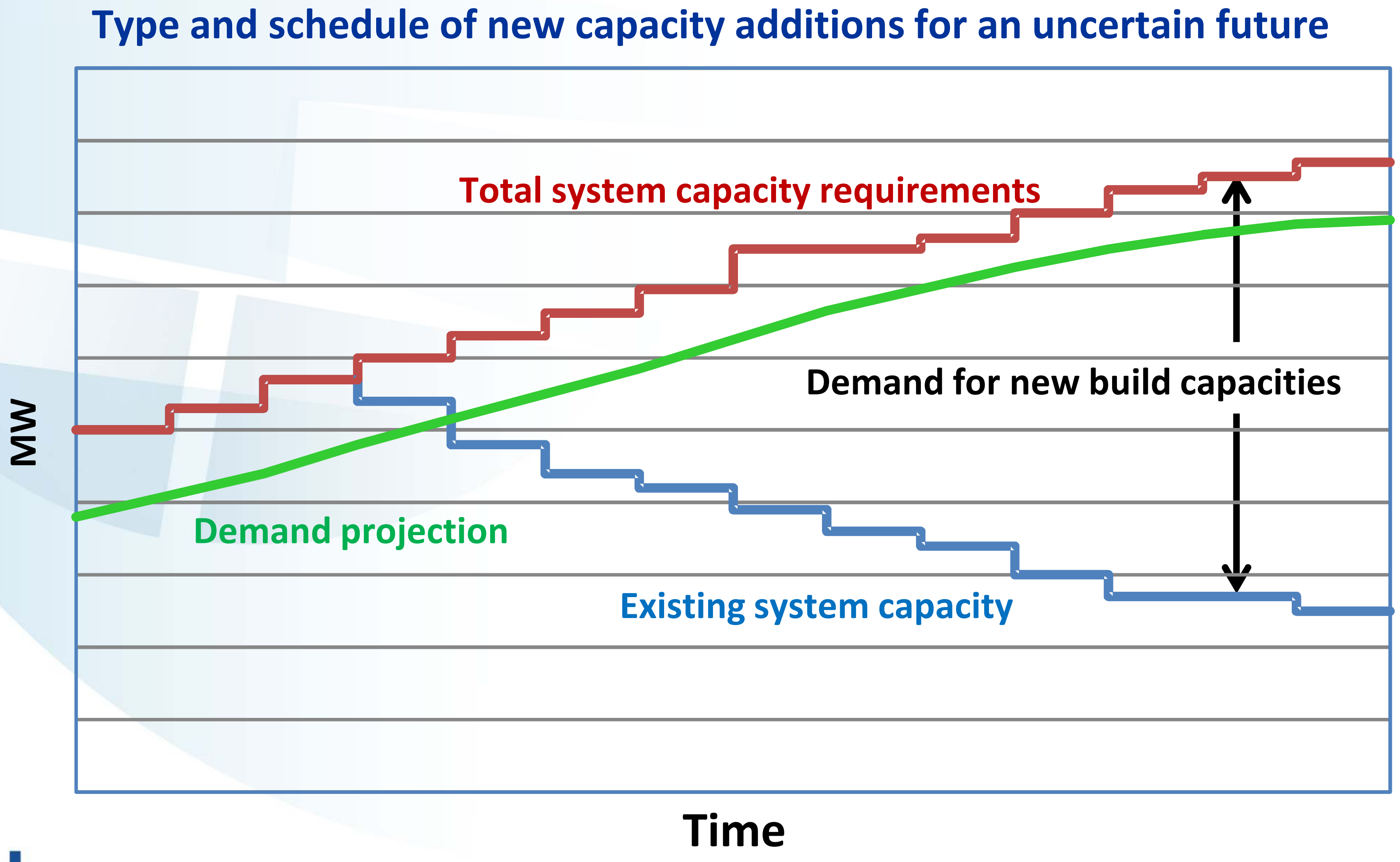
Predictions are difficult, especially about the future (Niels Bohr)

- Because the future is unknowable, analysts and modelers resort to scenarios
- Scenario analysis is not the attempt to predict or forecast the one future to come but to explore a range of possible futures
- Scenario is an internally consistent image of a possible future based on sets of transparent assumptions about future developments affecting demand and supply
- Scenarios, therefore, help organize assumptions, analyze and compare the implications of different potential futures
- Scenarios are decision focused clarifying the decisions and actions required to successfully deal (hedge against) against an uncertain future
- Storyline is a narration of a scenario – identification of its key drivers, their relationships and interlinkages, dynamics, discontinuities and signposts

Storyline and scenario consistency

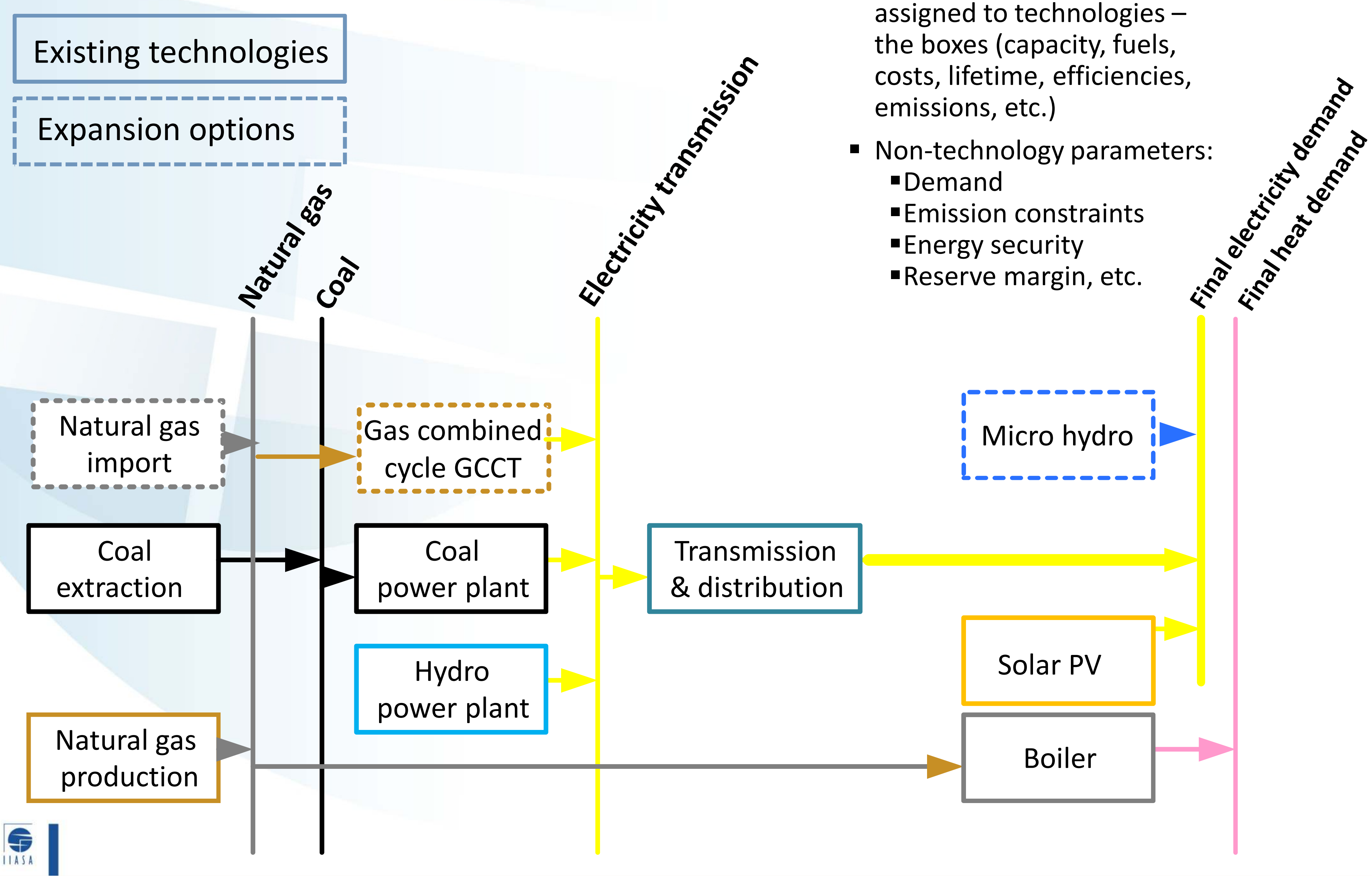
- …drivers are not independent → beware of path dependencies
    - Examples
        - Fossil fuel reserves are a function of demand, prices, technology and policy
        - Demand - Demographic profiles, economic structure, economic growth, climate change
        - All of the above - Education, migration, wage differentials, innovation, R&D investment, governance, trade
- Any change in any of the above factors changes the volume of reserves (but not the resource base)

Electricity expansion planning……



Adding supply technology options

- Most parameters are assigned to technologies – the boxes (capacity, fuels, costs, lifetime, efficiencies, emissions, etc.)
- Non-technology parameters:
  - Demand
  - Emission constraints
  - Energy security
  - Reserve margin, etc.



Sample technology characterization

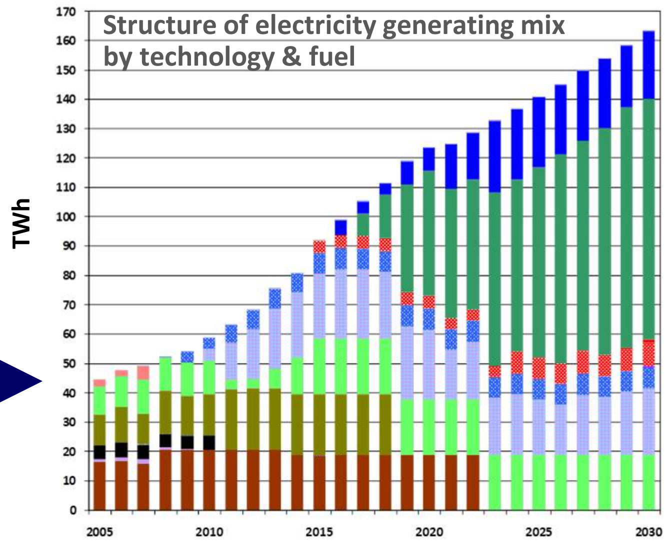
		Nuclear	Coal	Gas	Oil	CSP	Wind-S	Wind-W
Real interest rate	%/yr	6	6	6	6	6	6	6
Life time	years	50	40	30	30	25	25	25
Annuity factor	%	0.0634	0.0665	0.0726	0.0726	0.0782	0.0782	0.0782
Load factor	%	85	85	85	77	55	36	22
Overnight capital costs	**$/kW**	**5,000**	**2,200**	**1,000**	**1,300**	**5,000**	**1,800**	**1,800**
Investment schedule	-6	0.10						
	-5	0.20						
	-4	0.25	0.15					
	-3	0.25	0.30	0.10	0.2	0.20		
	-2	0.15	0.35	0.55	0.5	0.40	0.05	0.05
	-1	0.05	0.20	0.35	0.3	0.40	0.95	0.95
IDC	$/kW	1,222	334	108	153	558	114	114
Total investment	**$/kW**	**6,222**	**2,534**	**1,108**	**1,453**	**5,558**	**1,914**	**1,914**
Investment costs	Mills/kWh	53.02	22.62	10.81	15.65	90.25	47.47	77.68
Fix O&M	$/kW	80.00	60.00	25.00	30.00	50.00	25.00	20.00
Var O&M	$/MWh	10.00	9.80	4.60	7.99	4.60	1.00	1.00
Fuel price	$/GJ	0.68	2.75	4.00	10.00			
Ffficiency	%	32.0	42.0	48.0	36.0			
Fuel costs	$/kWh	0.0077	0.0236	0.03	0.1			
Total generation LCOE	**$/MWh**	**81.41**	**64.05**	**48.77**	**128.09**	**105.22**	**56.40**	**89.06**

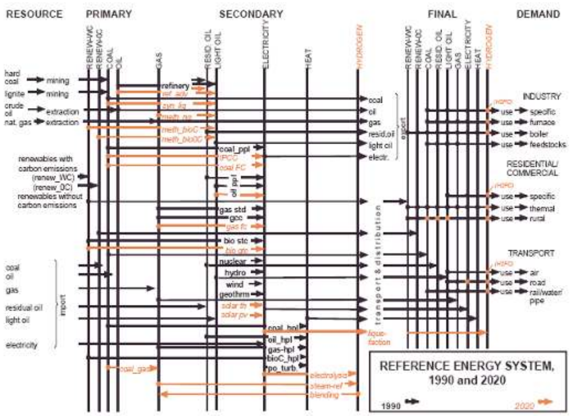
MESSAGE: Model for Energy Supply System Alternatives and their General Environmental Impacts

INPUT

- Energy system structure (including vintage of plant and equipment)
- Base year energy flows and prices
- Energy demand via link to MACRO
- Technology and resource options & their techno-economic performance profiles
- Technical and policy constraints

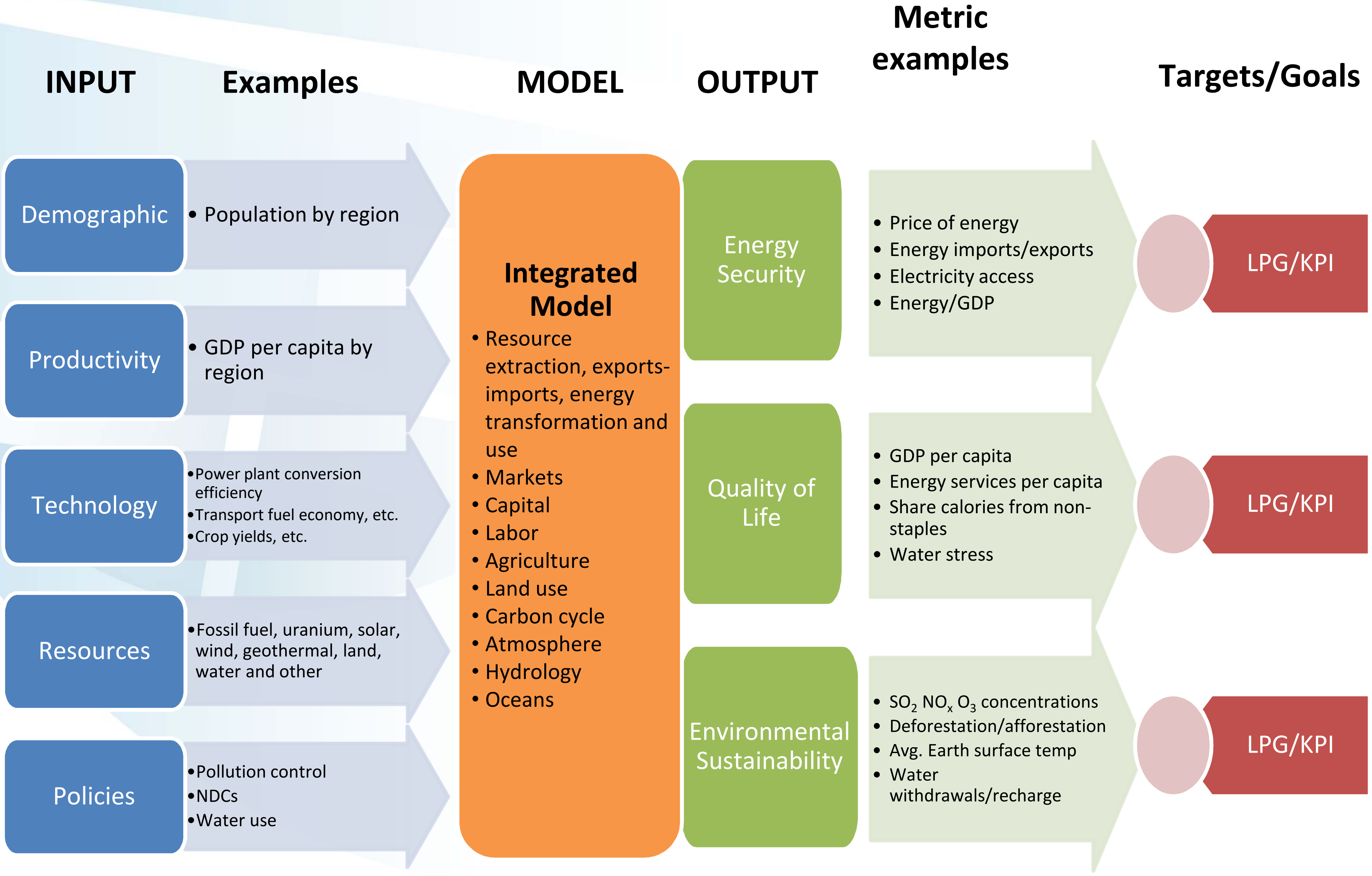
OUTPUT





- Primary and final energy mix
- Electricity generating mix, capacity expansion/retirement, investments
- GHG missions, air pollution, wastes
- Health and environmental impacts - via link to GAINS and LCA module
- Resource use - energy, water, land (via link to GLOBIOM), materials
- Trade & import dependence
- Prices

Illustration of scenario design



INPUT | **Examples**

Demographic
- Population by region

Productivity
- GDP per capita by region

Technology
- Power plant conversion efficiency
- Transport fuel economy, etc.
- Crop yields, etc.

Resources
- Fossil fuel, uranium, solar, wind, geothermal, land, water and other

Policies
- Pollution control
- NDCs
- Water use

MODEL

Integrated Model
- Resource extraction, exports-imports, energy transformation and use
- Markets
- Capital
- Labor
- Agriculture
- Land use
- Carbon cycle
- Atmosphere
- Hydrology
- Oceans

OUTPUT | **Metric examples** | **Targets/Goals**

Energy Security
- Price of energy
- Energy imports/exports
- Electricity access
- Energy/GDP

LPG/KPI

Quality of Life
- GDP per capita
- Energy services per capita
- Share calories from non-staples
- Water stress

LPG/KPI

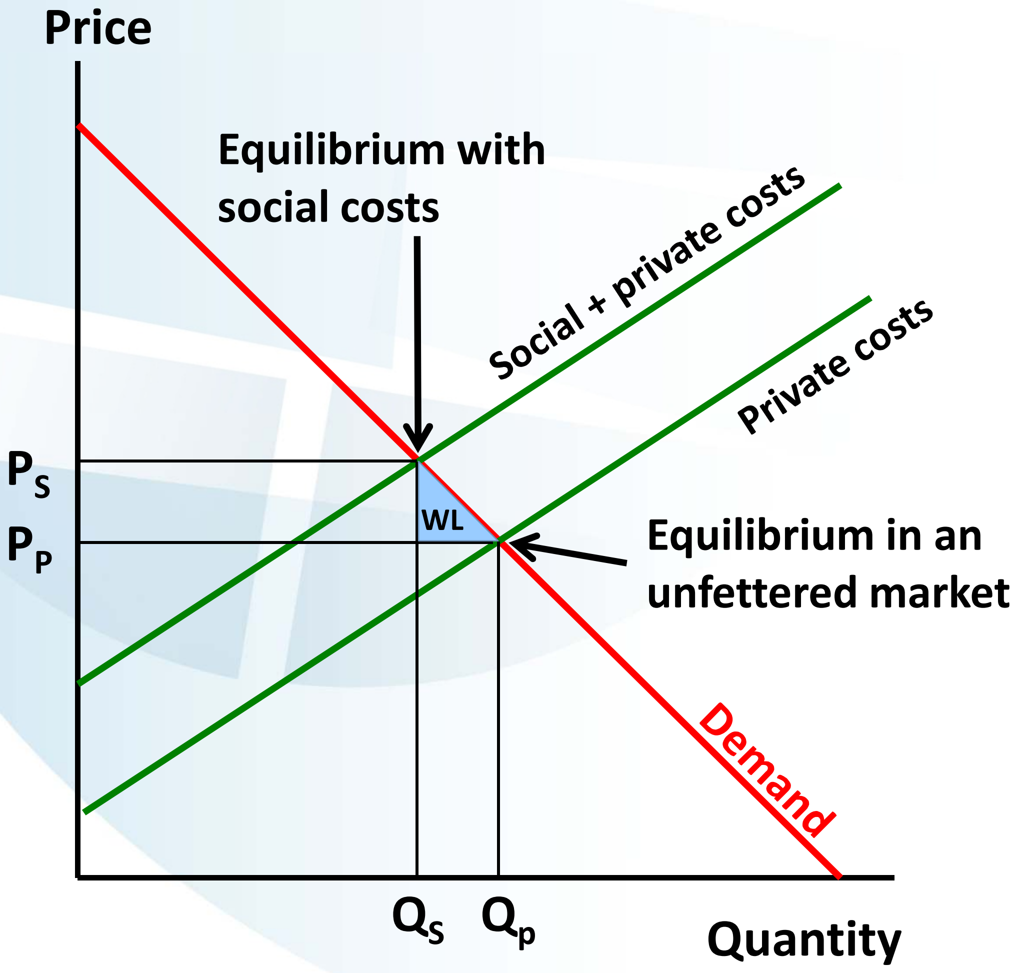
Environmental Sustainability
- SO_2 NO_x O_3 concentrations
- Deforestation/afforestation
- Avg. Earth surface temp
- Water withdrawals/recharge

LPG/KPI

Final remarks

- Storylines provide a common language for stakeholders to communicate, compare and debate complex input assumptions
- Storylines require imagination, suspension of belief, thinking “out of the box” and innovative ways of implementation
- Modelling helps inform the scenario process by linking the storylines with the existing (energy) system and the future to identify and quantify
  - cataclysmic technological or socio-economic change
  - feasibility of climate stabilization targets and postulated emissions paths
  - metrics, signposts, performance indicators, and
  - policy requirements
- At the end of the day, in an internally scenario input and results are the two sides of the same coin

Contemporary challenges: Externalities



What is an externality?

A cost or benefit that is 'external' to the transaction...

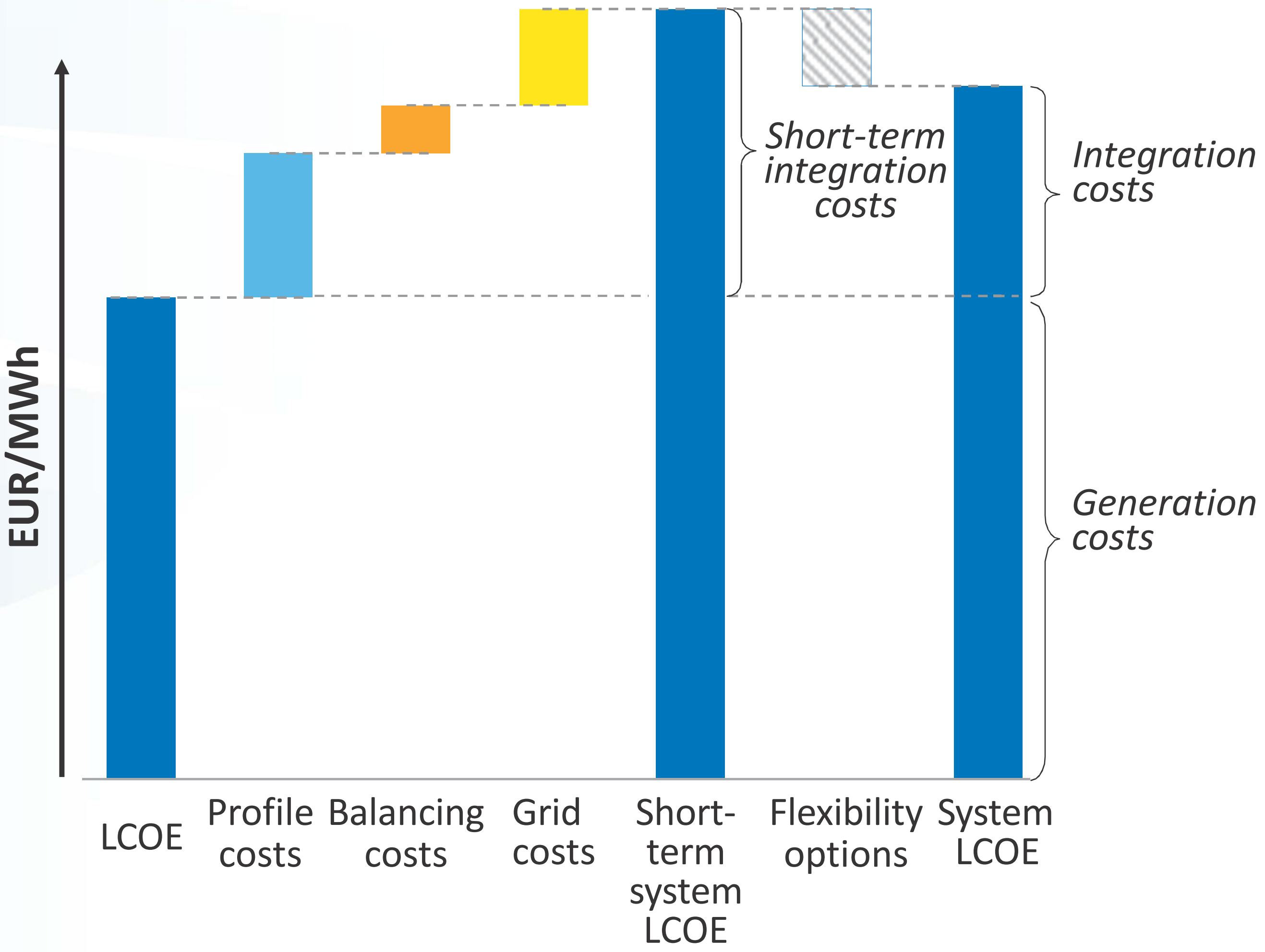
Any examples?

OK, so we damage the environment... how much are you willing to pay to:

- avoid the damage?
- fix the damage?
- live with the damage?

Illustration of electricity system costs

- *Profile (variability) cost:* Costs caused by the variability in the output of intermittency of wind, solar, etc. (back-up cost)
- *Balancing (uncertainty) cost:* Costs of uncertainty in the output of intermittent generation (frequent and close to real time changes in plant schedules, higher reserves)
- *Grid-related (location) costs:* Costs associated with the transmission and distribution of intermittent electricity from remote locations



LCOE = Levelized costs of electricity