From long-term global energy system research to national energy analyses and planning

Dr. H-Holger Rogner

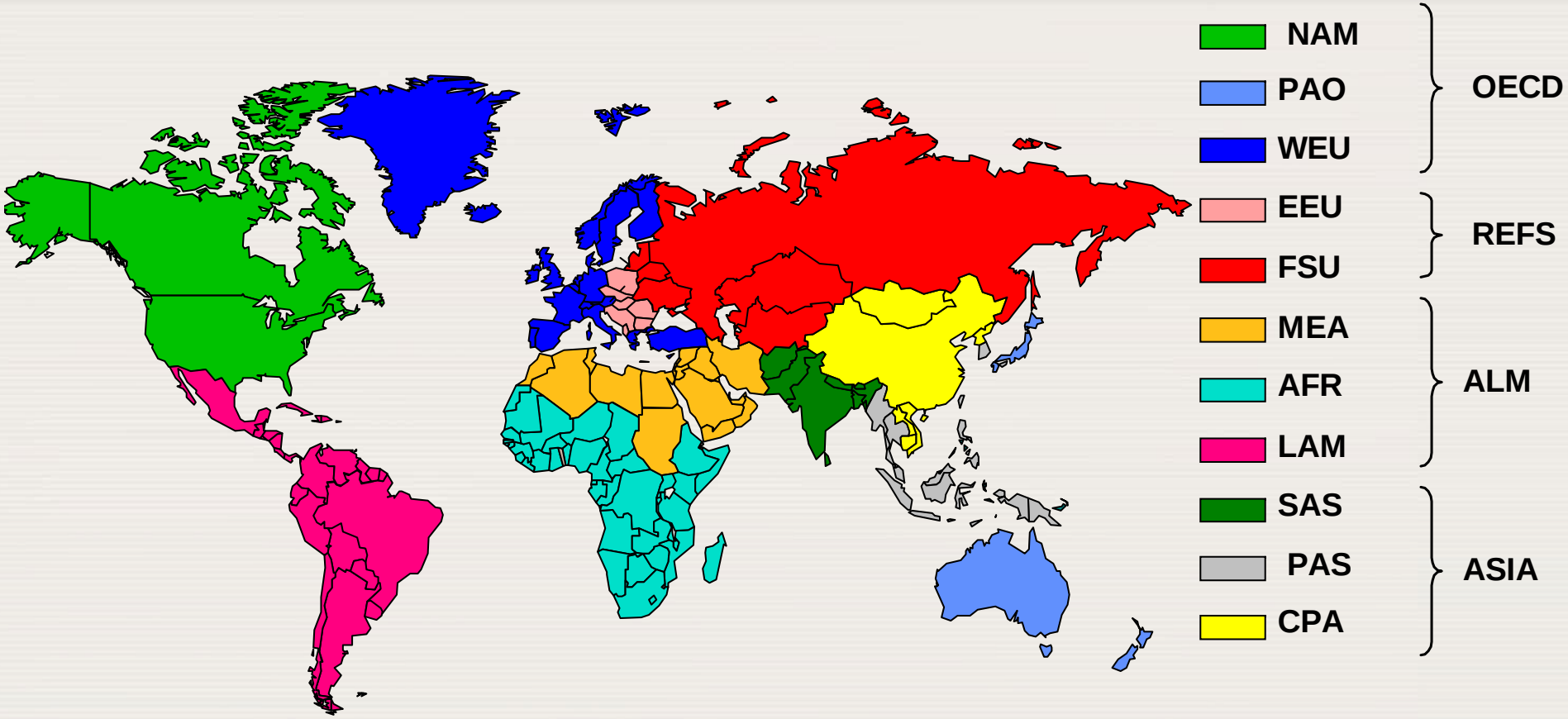
International Institute for Applied Systems Analysis (IIASA), Austria

Royal Institute of Technology (KTH), Stockholm, Sweden

Modelling energy system transformation at IIASA

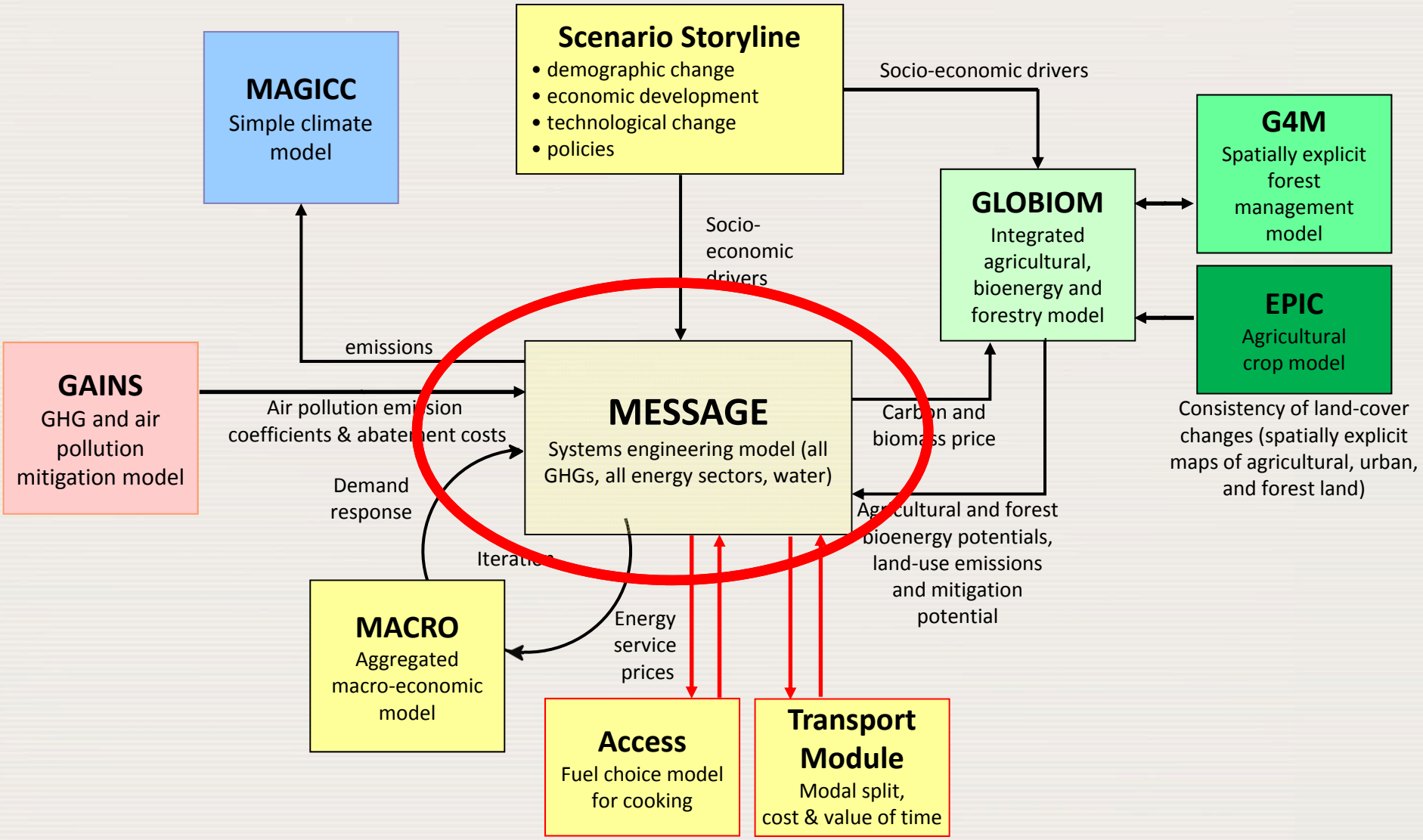
- Origin dates back to 1974
- Spatial focus: Global – world segregated into 11 regions
- Temporal focus: Long-term: 50 to 100 years plus
- Objectives:
  - Analysis of long-term demand & supply strategies under different technology & resource futures
  - Development of robust technology strategies and related investment portfolios to meet a range of policy objectives, and
  - Appreciation of uncertainty
- Several models – demand & economic development, supply, resources, impacts
- Primus inter pares: MESSAGE (*M*odel of *E*nergy *S*upply *Sy*stems *A*nd their *G*eneral *E*nvironmental Impact)

Geographical resolution – the “Regions”



1 NAM North America
2 LAM Latin America & The Caribbean
3 WEU Western Europe
4 EEU Central & Eastern Europe
5 FSU Former Soviet Union
6 MEA Middle East & North Africa
7 AFR Sub-Saharan Africa
8 CPA Centrally Planned Asia & China
9 SAS South Asia
10 PAS Other Pacific Asia
11 PAO Pacific OECD

IIASA Integrated Assessment Framework



Characterization of MESSAGE

- Linear and mixed integer programming (LP & MIP) model
  - Continuous variables for linear processes
  - Integer or binary variables for unit commitment and decisions
- Equations to reflect operational constraints
  - Technical
  - Legal
  - Environmental
- Optimization target (objective)
  - minimize system cost
  - maximize profit
  - minimize import dependence
  - etc.

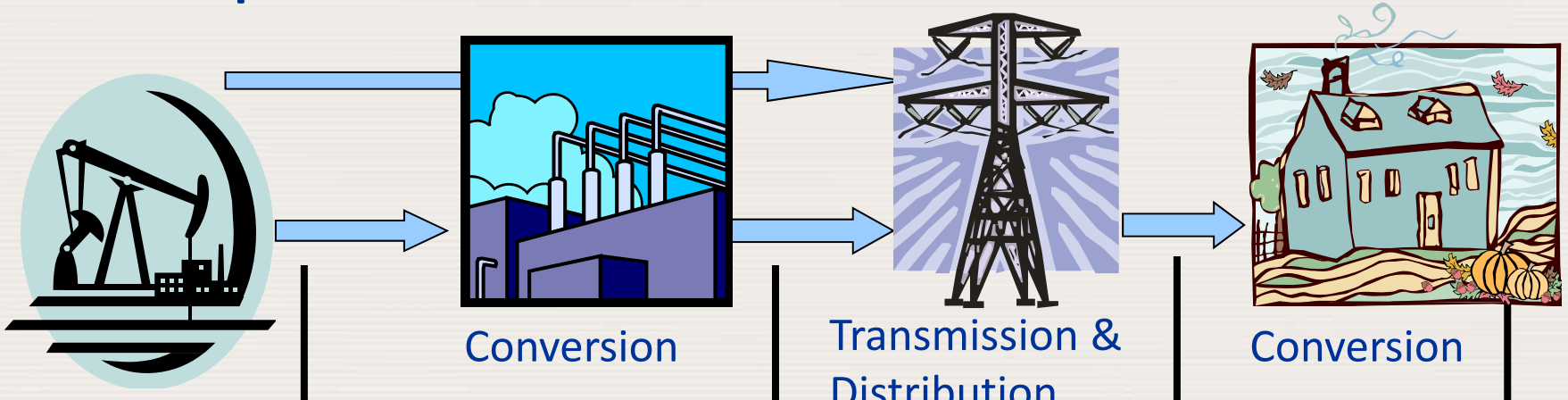
An Energy "Chain"

Oil extraction
Coal import

Power plant
Refinery

T&D Network

End user



Conversion

Transmission & Distribution

Conversion

PRIMARY

Oil
Natural gas
Coal
Hydro
Solar
Uranium

SECONDARY

Diesel
Kerosene
Gas
Electricity
Heat
Coal

FINAL

Diesel
Kerosene
Gas
Electricity
Heat
Coal

USEFUL

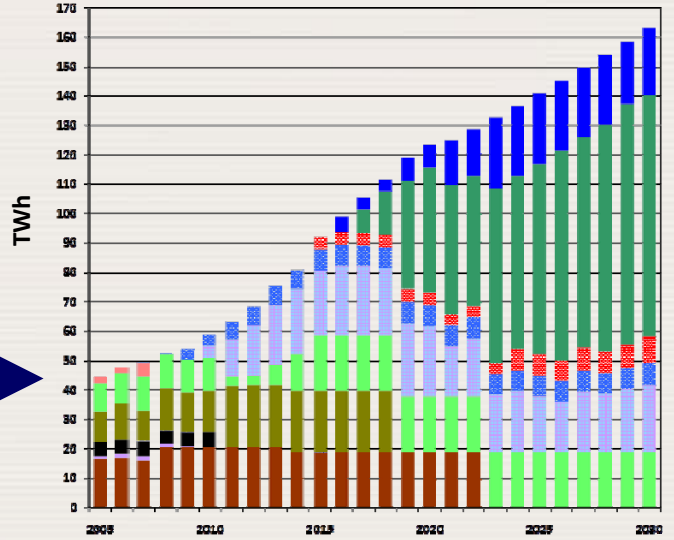
Low temp heat
High temp heat
Cold
Light
Mechanical energy

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

INPUT

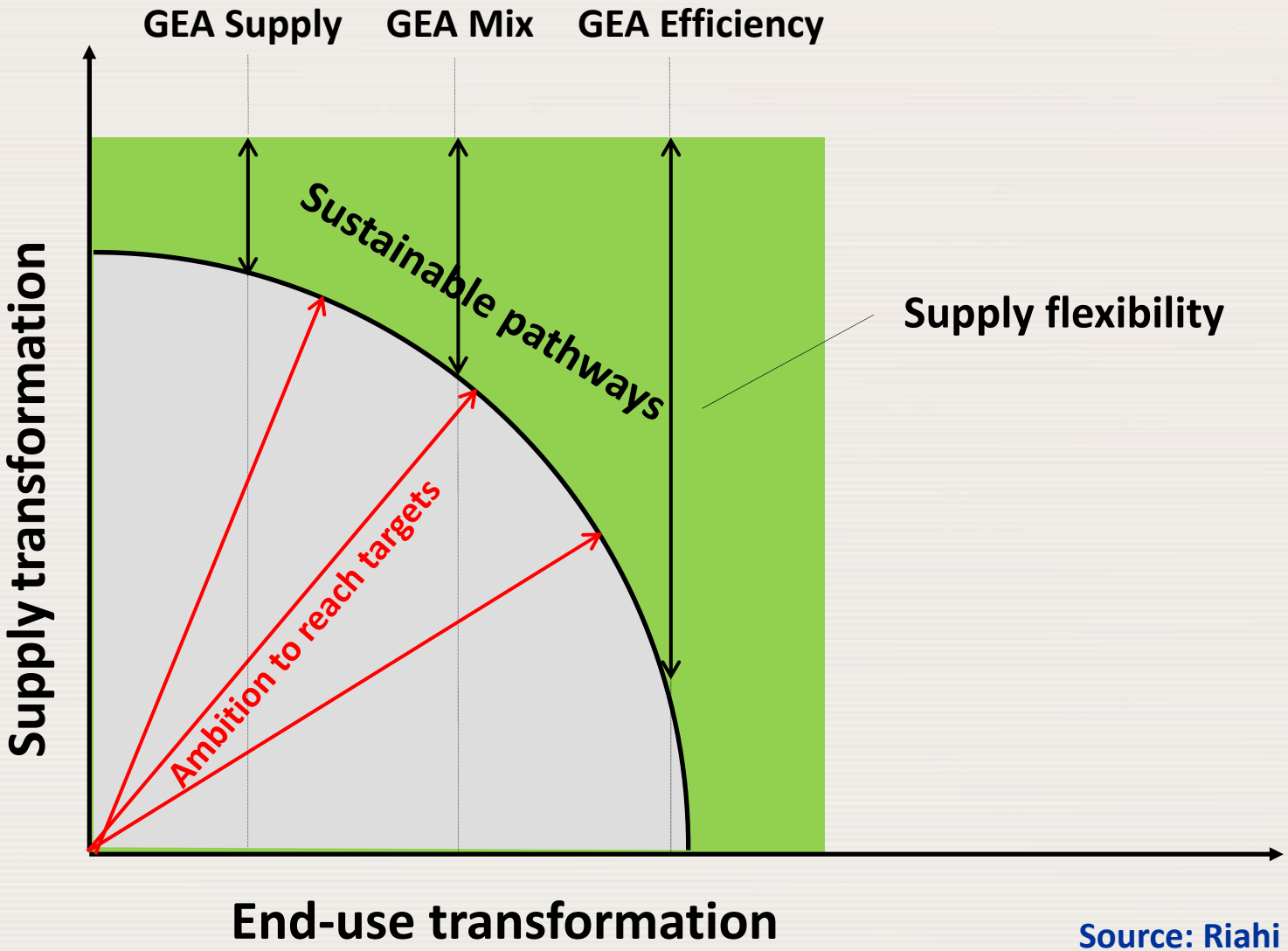
- Energy system structure (including vintage of plant and equipment)
- Base year energy flows and prices
- Energy demand projections (e.g. MAED)
- Technology and resource options & their techno-economic performance profiles
- Technical and policy constraints

OUTPUT



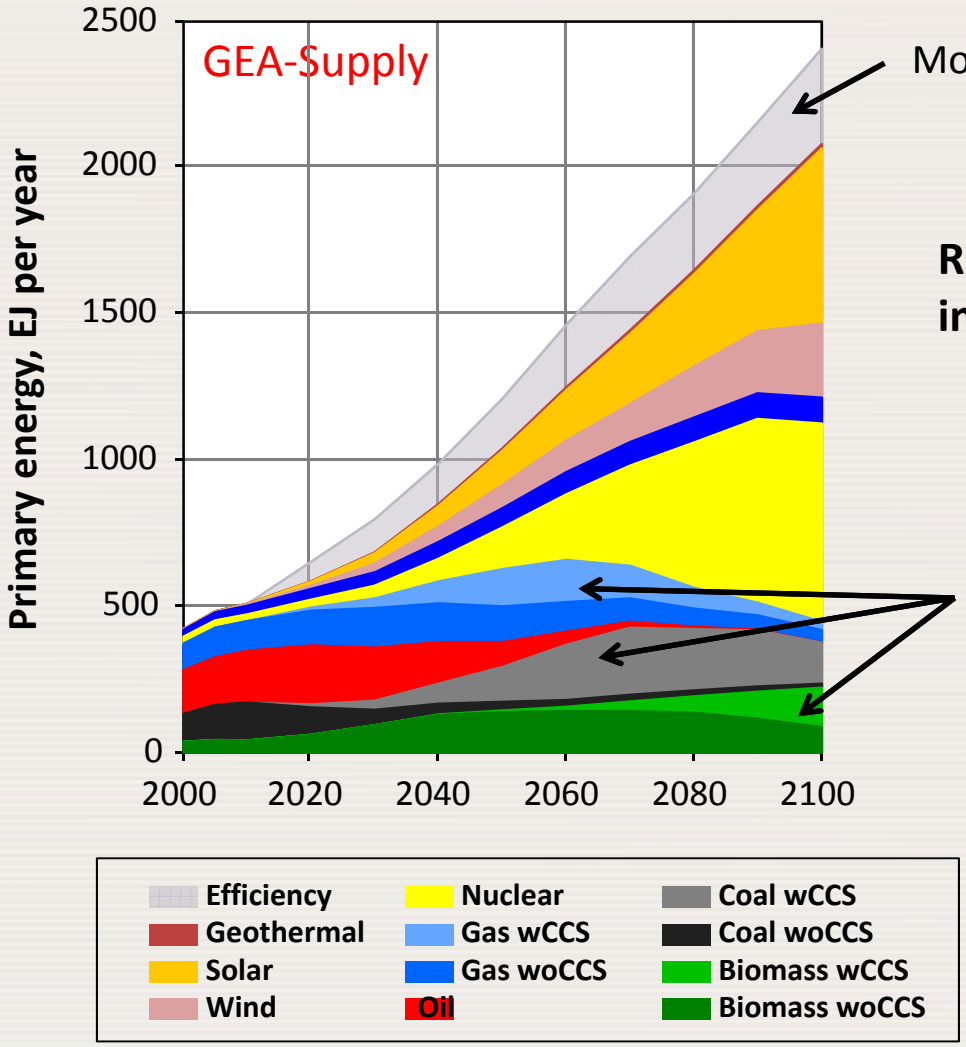
- Primary and final energy mix
- Electricity generating mix
- Capacity expansion/retirement
- Emissions & waste streams
- Resource use (energy, water, land, etc.)
- Trade & import dependence
- Investment requirements
- Prices

Schematic illustration of GEA pathways



Source: Riahi et al, 2011

Supply-side Focus
(= high demand-side flexibility)



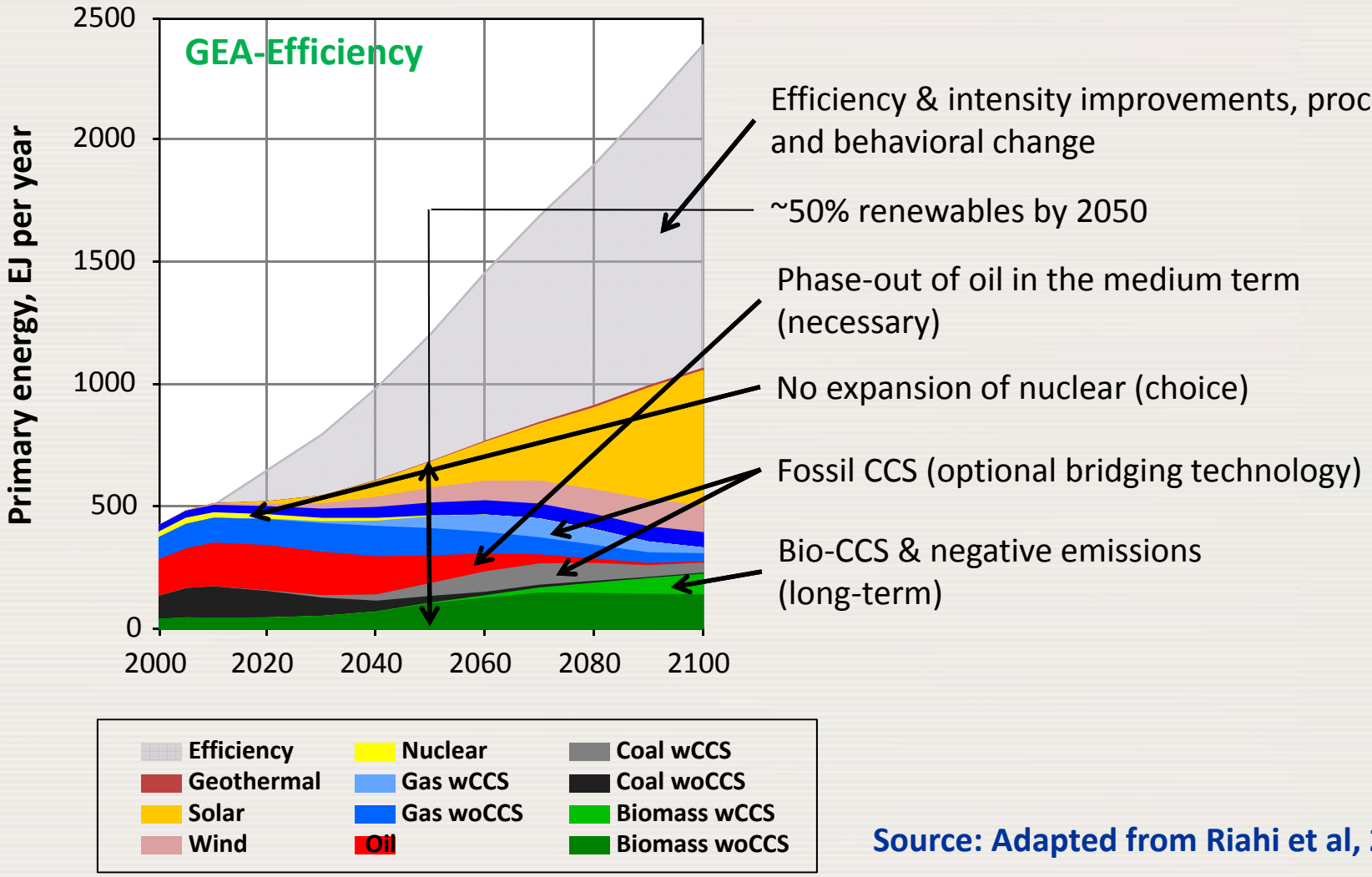
Modest efficiency focus

Rapid up-scaling of all options, including renewables and nuclear

CCS needed as transitional technology & BioCCS for negative emissions

Source: Adapted from Riahi et al, 2011

Efficiency & Demand-side Focus (= high flexibility for supply)



Source: Adapted from Riahi et al, 2011

Zooming from global to national

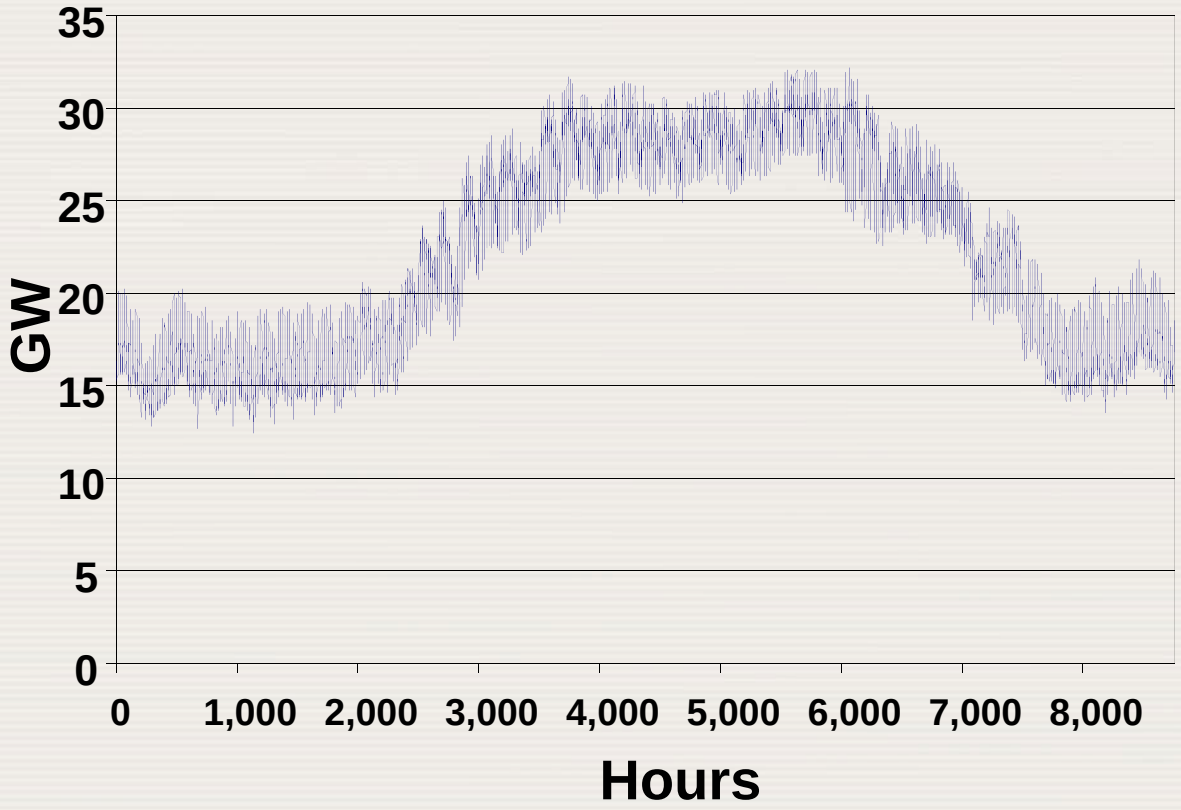
- **National (sustainable) energy development objectives**
  - **Long-term regional/global averages provide indications at best**
  - **National specificity**
    - **National energy security**
    - **Indigenous resources**
    - **Detailed representation of the existing infrastructure (vintage, performance, reliability)**
    - **Variability of demand**
    - **Menu of technology options**
    - **Investment, finance, market structure and subsidies**
    - **Affordability & access**
    - **Demand side vs supply side considerations**
    - **Local generating costs**
- **MESSAGE adapted to meet national and subnational requirements**

International Atomic Energy Agency (IAEA)

- MESSAGE adopted in 1998 (replacement of WASP used since the early 1970s)
- IAEA provides energy planning services to its MS
  - Training of MS experts in the use of MESSAGE
  - Model distribution (to governmental institutions)
  - E-Learning, E-Assistance & help desk
  - Note: Data & assumptions are the responsibility of MS
- Objective: Capacity building in energy analysis & comprehensive energy planning
- Decision support system at the national level
- Essential for a national decision to introduce nuclear power

Load curves

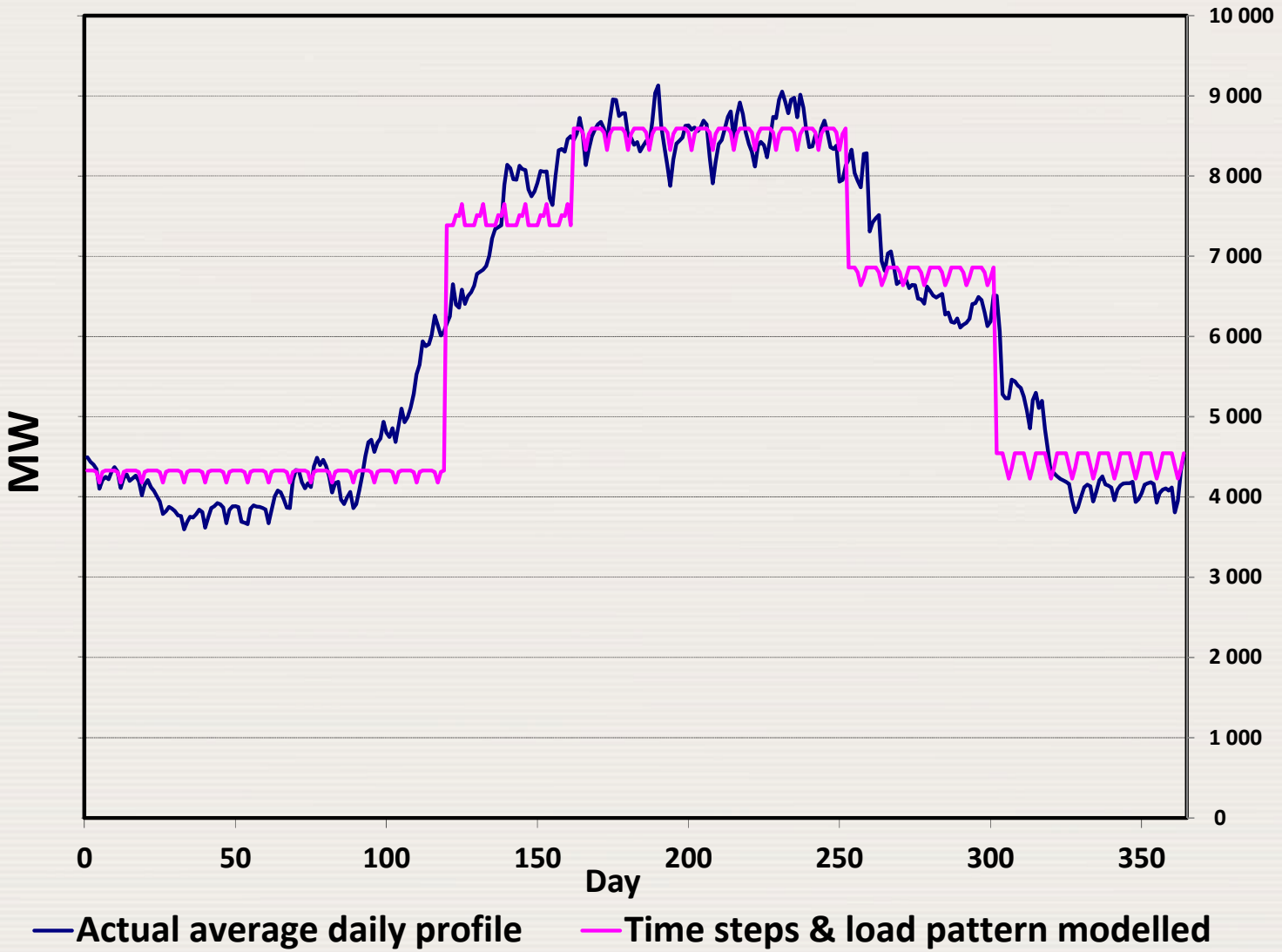
- Variability of demand: electricity, heat, natural gas
- Intermittency of renewables
- Transmission



Example: Oil exporting country in the region

- Transformation of the national energy system
  - Associated gas on the decline
  - Subsidized energy & water not sustainable
  - Galloping electricity & water demands
- No compromise on energy security
- Use current & future oil revenues to finance transition
- Explore different futures and technology options
- Understanding future uncertainties
- Communication tool (transparency)

Model representation of load curves



Comparative assessment of options

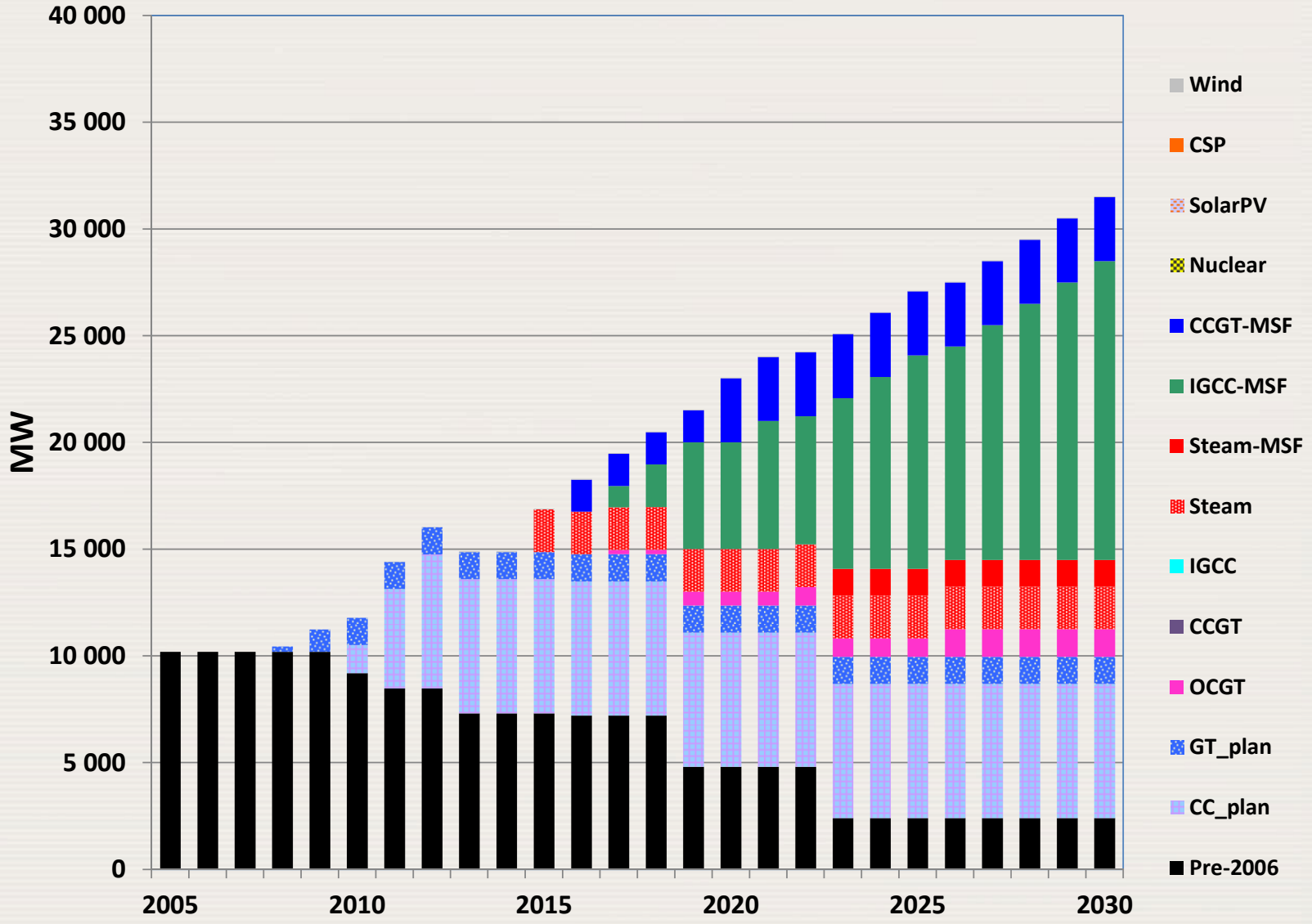
How to combine these criteria?

How to compare these alternatives?

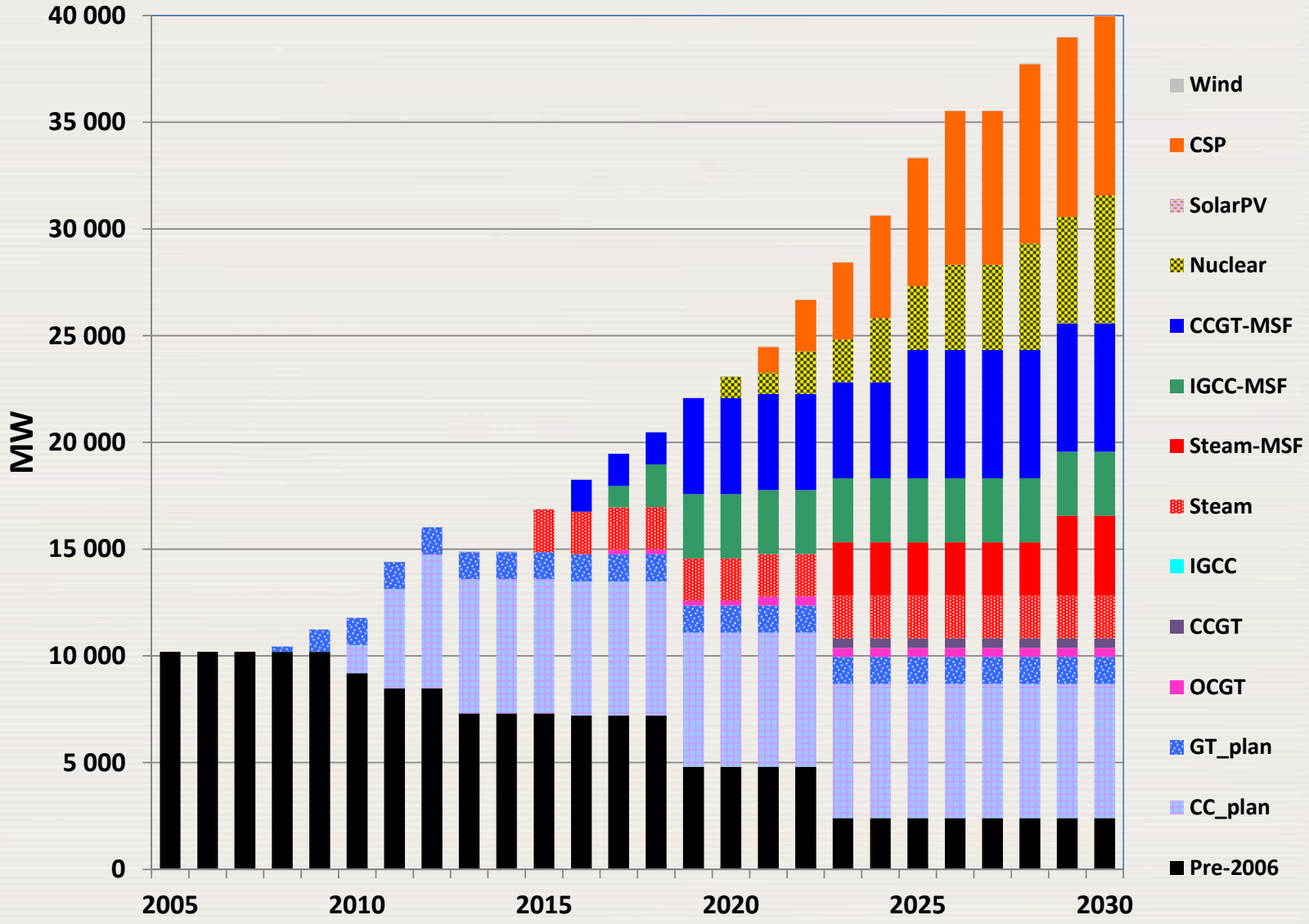
How to interpret the results?

Criteria / Alternatives	I…	…ments	Fuel costs	Waste/ decom	Reliability	Secutiy	Environment	Material	Acceptance
Wind		…0	0	15	low intermittend	high	very good	very high	high
Coal (imported fuel)		…0	4	80	base load / intermediate	very high	low	high	low - high
IGCC (oil)		…0	0					…lium	high
Nuclear		…0	0.7	1,800	base load	high	very good	high	low
Gas combined cycle turbine		…0	1 - 5	40	base load / intermediate	medium	medium	low	high
Gas turbine		…0	1 - 6	12	peak	low	medium	low	high
Concentrated solar		…0	0	50	low intermittend	high	good	high	medium
End-use efficiency		…5	0	1	-	very high	excellent	low	mixed

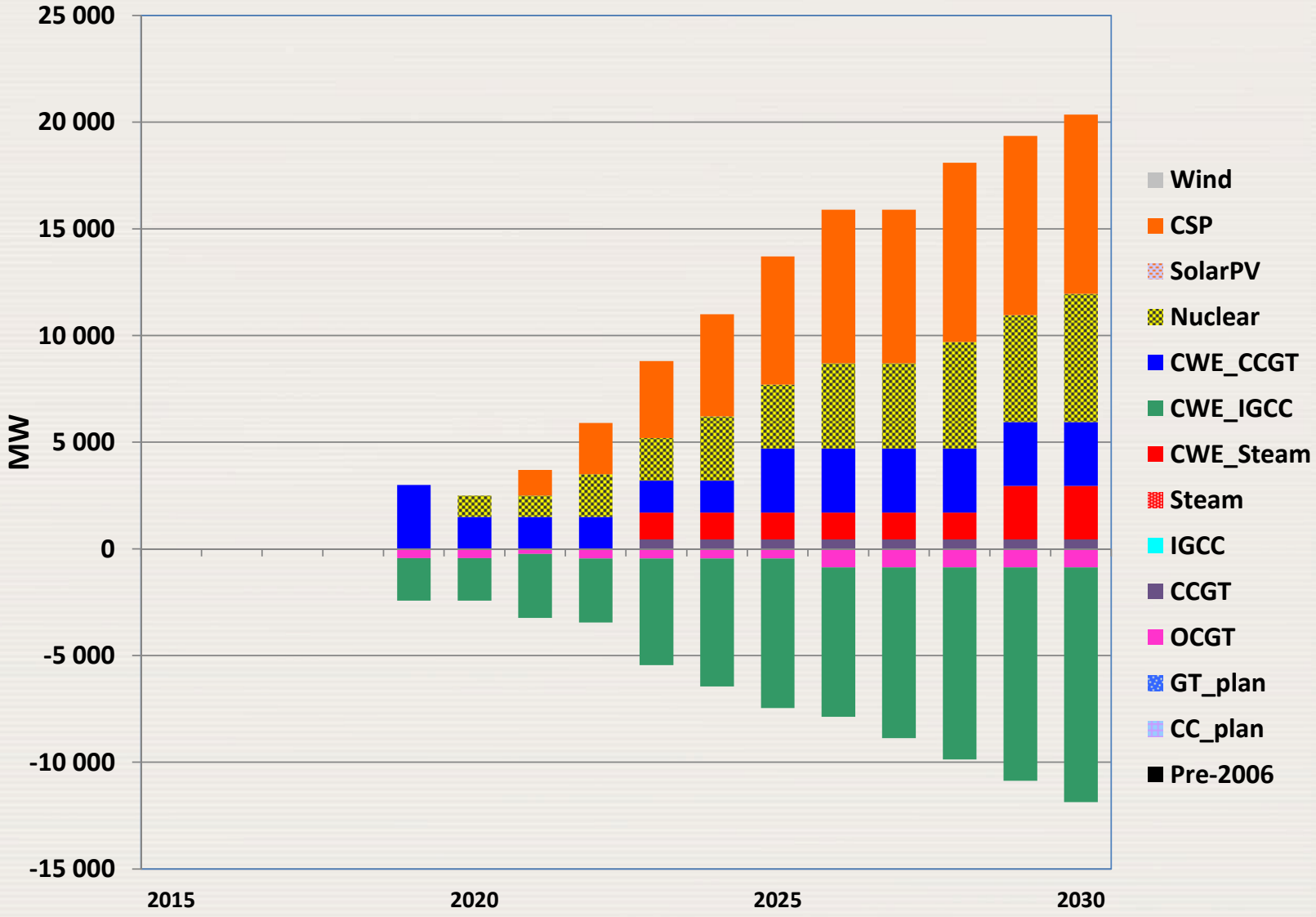
Generating capacity – Business-as-usual



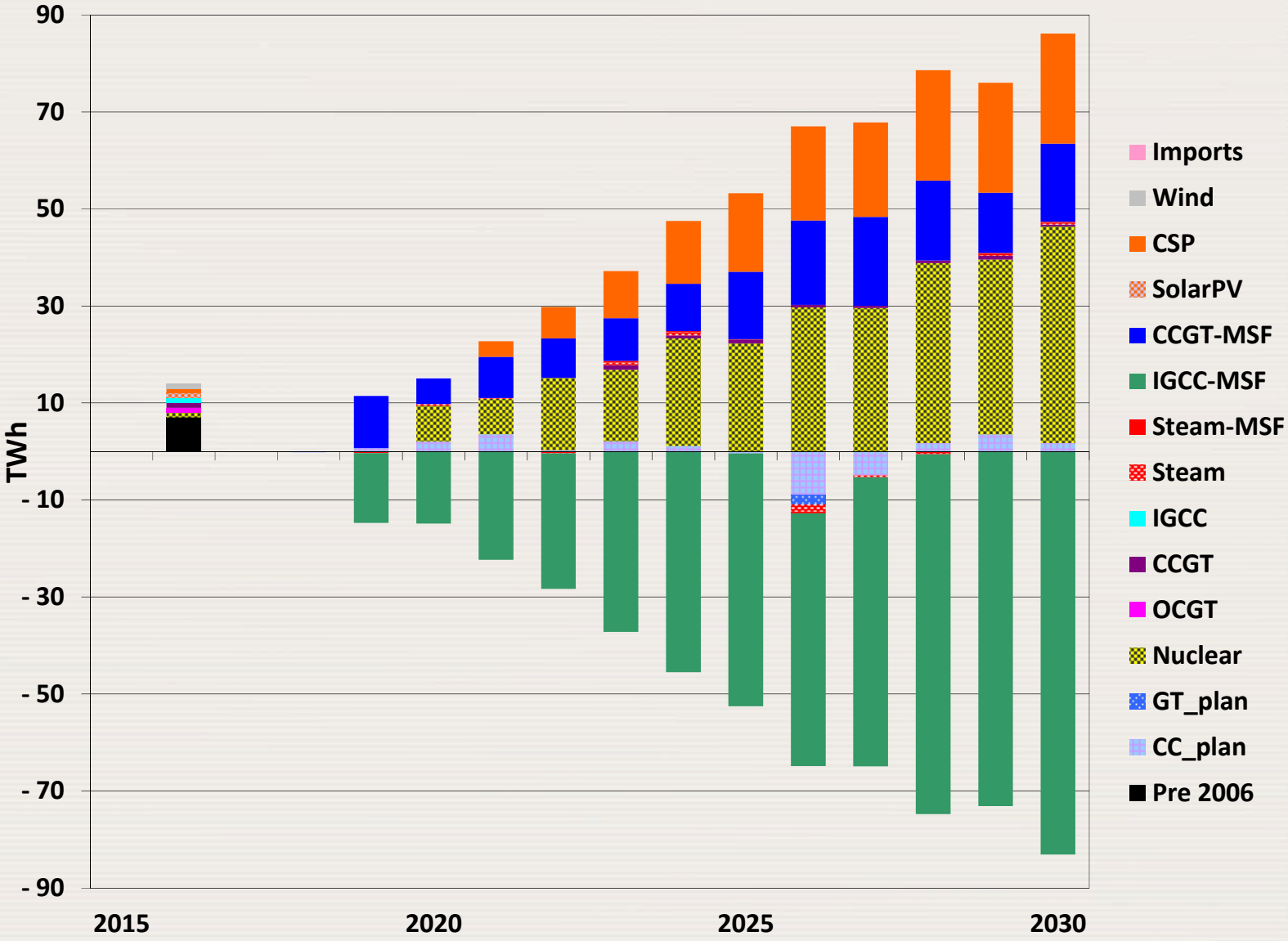
Generating capacity – Transformation (TR)



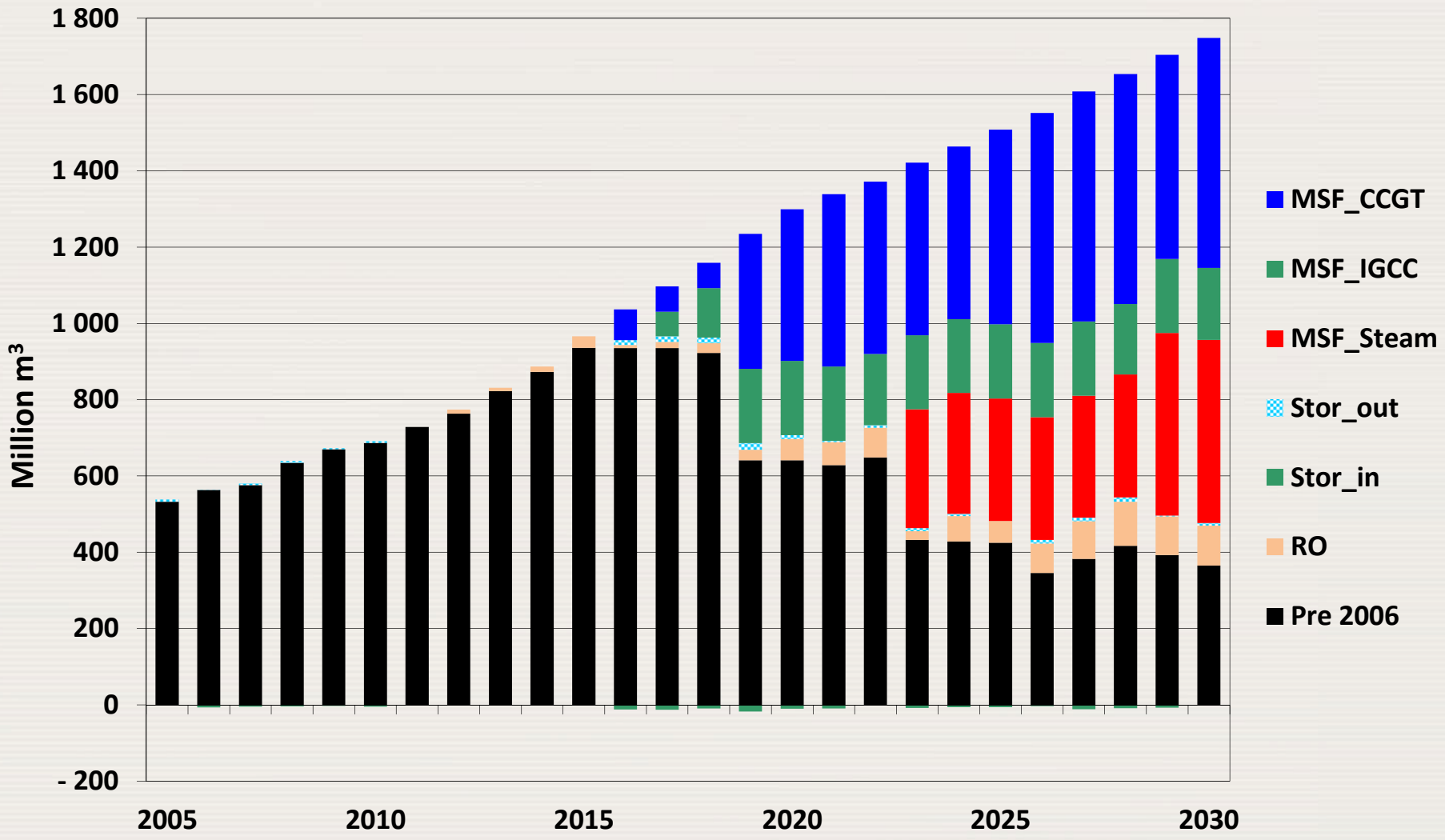
Difference in capacities between BAU and TR



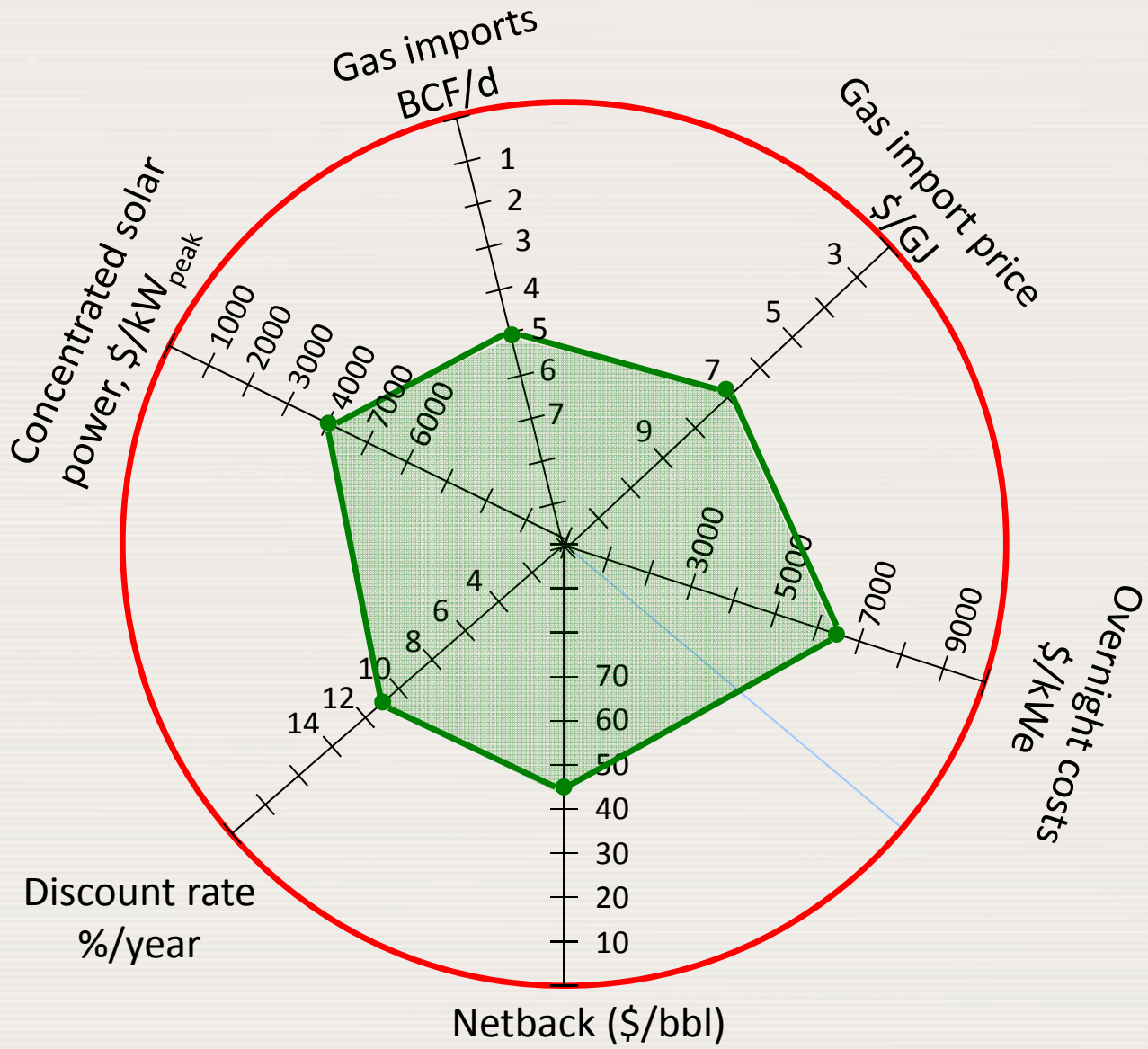
Difference in generation between BAU and TR



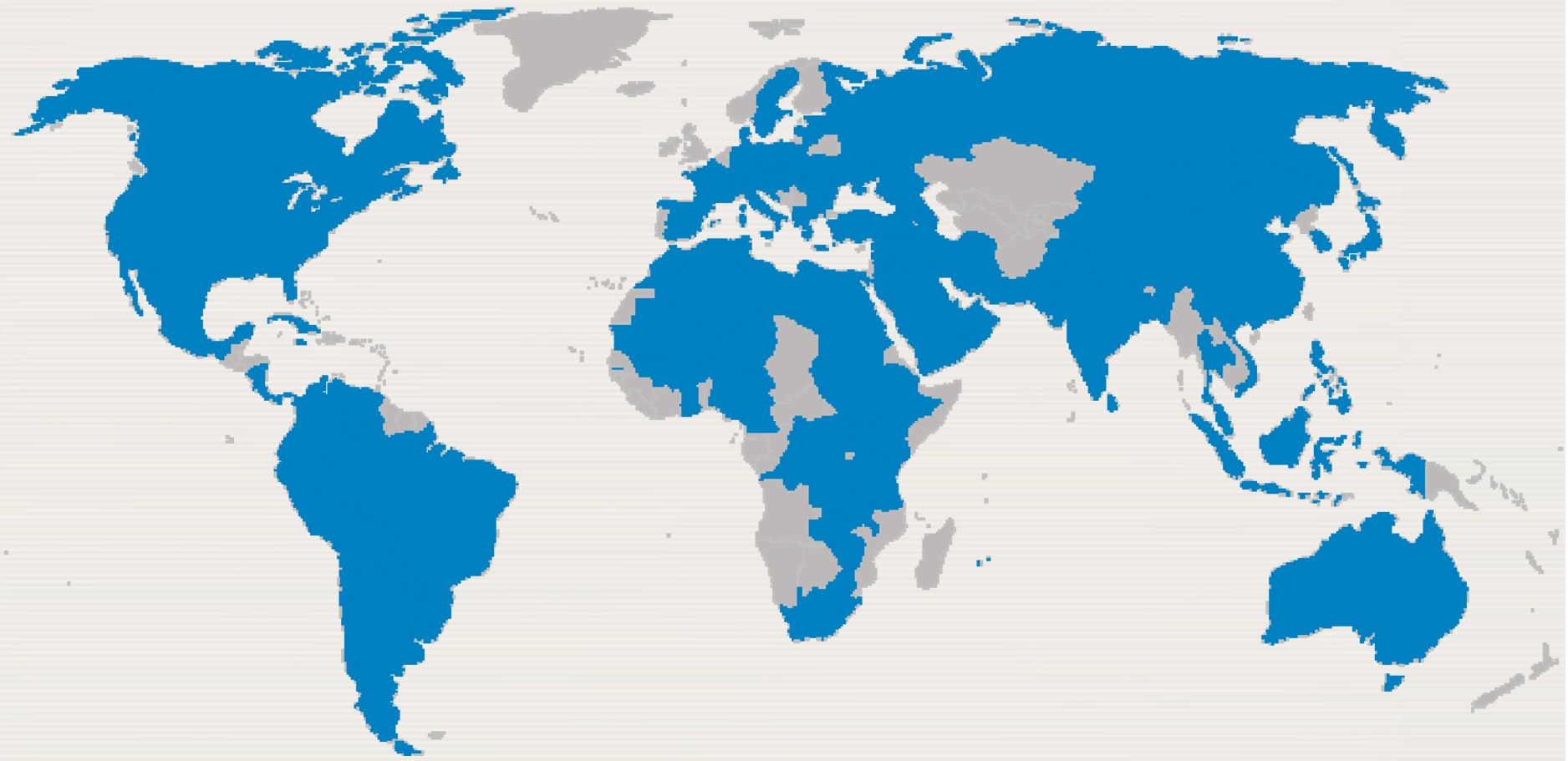
Fresh water supply in TR



Sensitivities & solution space for nuclear power



Distribution of MESSAGE to IAEA member States



Model transferred to 102 countries by the end of 2015

MESSAGE has been the tool for

- Numerous national electrification and energy plans
- Energy policy formulation at various jurisdictional levels
- Utility capacity expansions and investment decisions
- Accounting of material (energy and non-energy) flows
- Communication of energy related GHG emissions to UNFCCC

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