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Joint ICTP-IAEA Advancing Modelling of Climate, Land-use,
Energy and Water (CLEW) Interactions

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Introduction to Energy Systems Analysis

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Introduction to Energy Systems Analysis

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Introduction to energy assessments: Complexity and models

- **Energy is strategic:** An important component of sustainable development in key dimensions: Economic, Social and Environmental
- **Energy is integrated:** One part of the system affects another
- **Energy is "intra-grated":** Energy policies affect and are affected by a myriad of other resources
- The energy system and its technologies are **dynamic**
- Energy modelling is an art, however there are various "accepted methods"
- Energy modelling provides **insights** NOT answers
- Different actors require different answers and thus different approaches (no one size fits all)
- Answers for and thus information to actors and markets are not trivial – Models (with their faults) are simply **needed**

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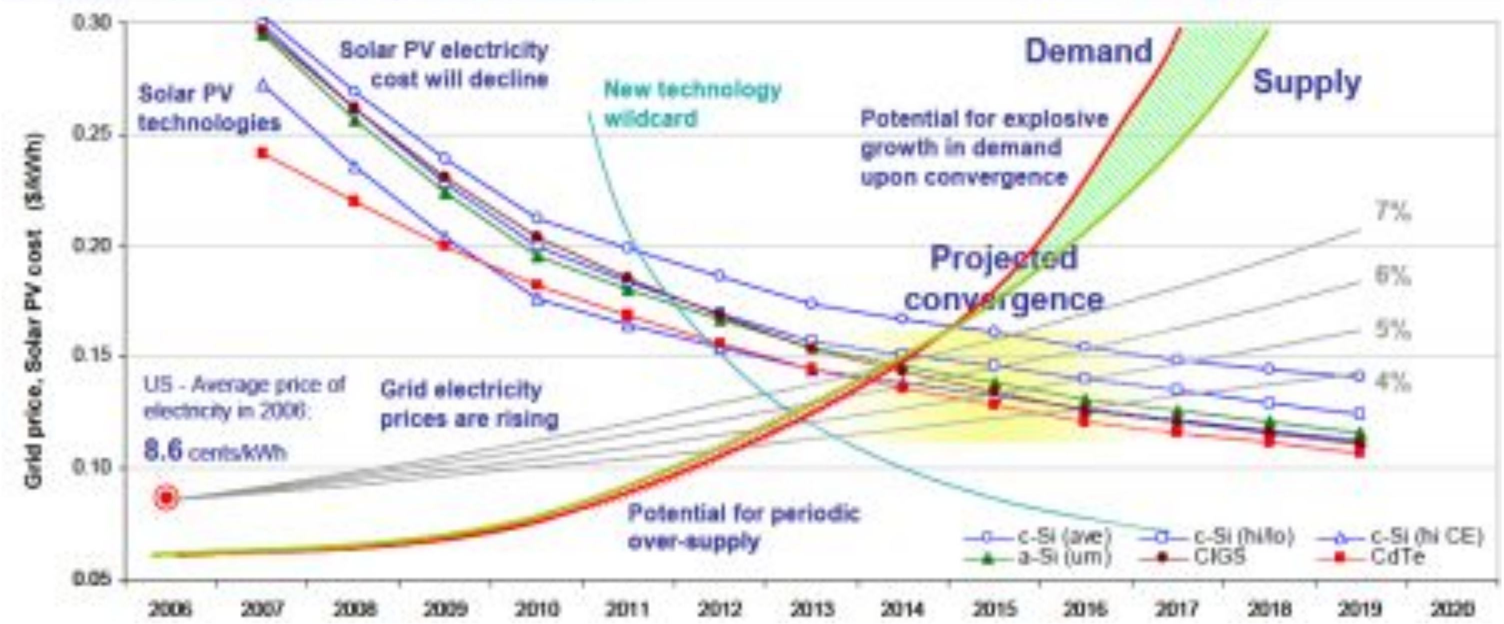
The energy system and its technologies are **dynamic**

Figure 2: Long term view of the solar PV industry



Introduction to energy assessments: Complexity and models

- With a **model** we make an abstraction of the real world and simulate / plan … something
- A typical "energy systems model" will relate techno-physical aspects of **the energy system** *such as:*

  type of energy technology(e.g. Gas GGCT vs Wind) required, the extent of that installation (MWs) required, when the installation operates, its level of activity etc.

  to **attributes** *such as:*

  cost, environmental or economic impact, flexibility,robustness
- It may include some level of feedback between the two.
- And this may (and may not) be to meet some **objective** subject to various constraints
- For different **scenarios** of the future
- Often related to **policy** formulation, implementation and monitoring

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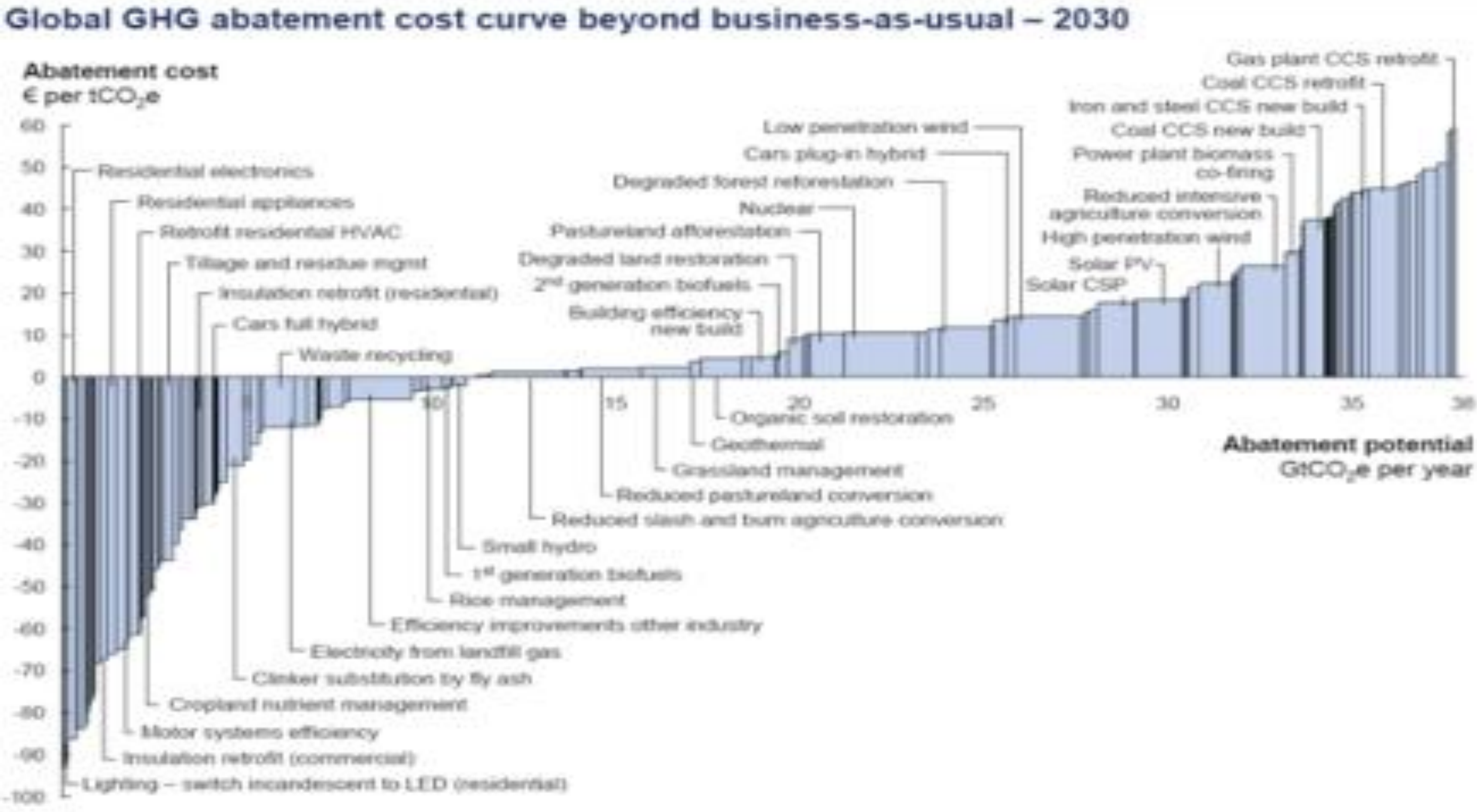
Introduction to energy assessments: Complexity and models

(Good) Models enable:

- Comparative assessment of options
- Transparency & boundaries
- Quantification
- Repeatability / reproducibility
- Sensitivity analyses
- Documentation
- Communication & acceptance
- What – if questions
- Indicators for monitoring progress
- Re-occurring or rolling activity

Assesments:
Mitigation cost curves



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: Global GHG Abatement Cost Curve v2.0

Assesments: Affordable, Appropriate, Adequate energy services

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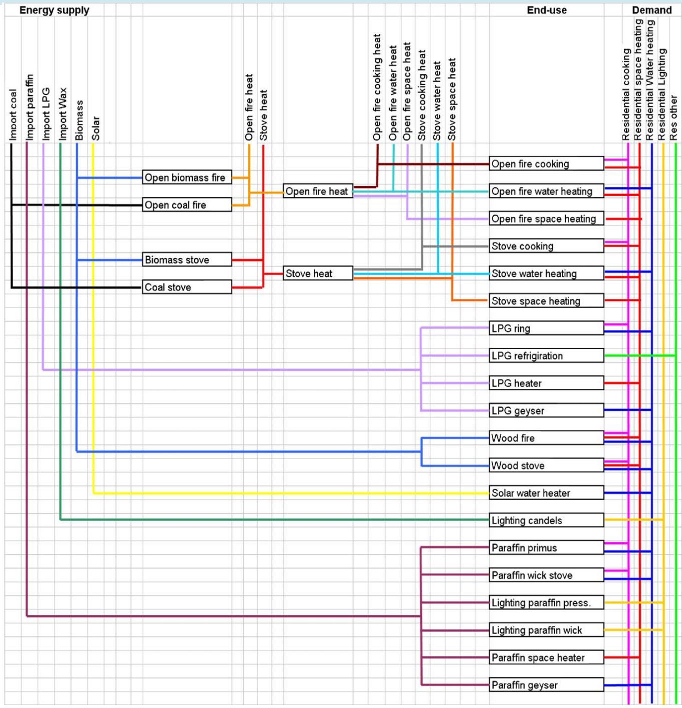

The current cost of energy in rural remote areas is high!

ELSEVIER

Energy Policy 33 (2005) 1833–1851

ENERGY POLICY

www.elsevier.com/locate/enpol

A model of household energy services in a low-income rural African village

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Assesments: Energizing Africa

Access, Integration, Power planning, RE

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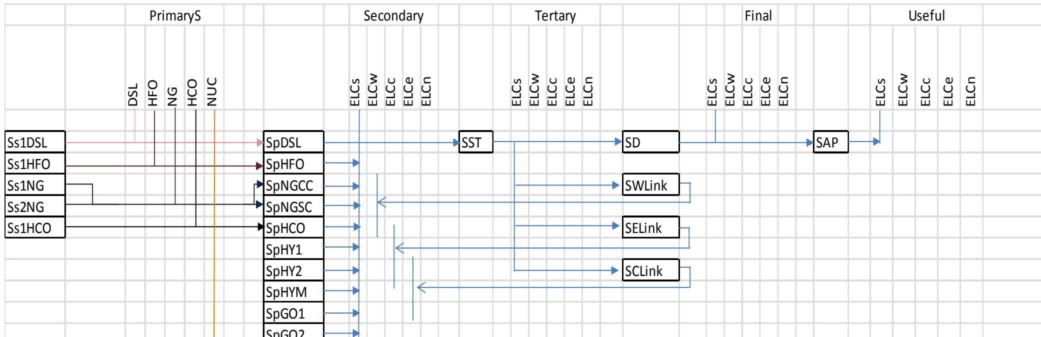
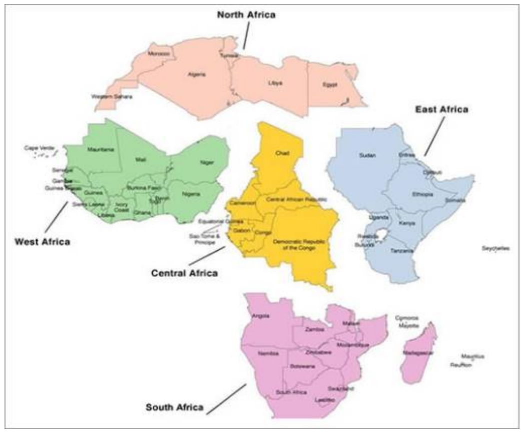
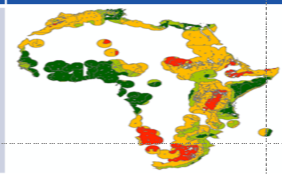
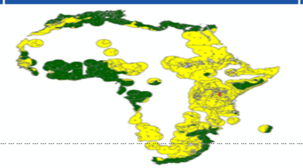
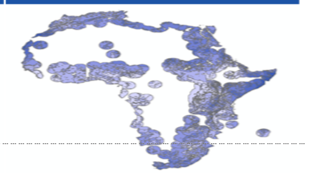
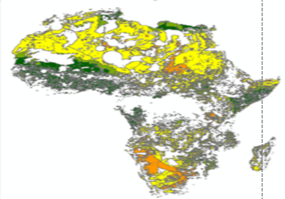
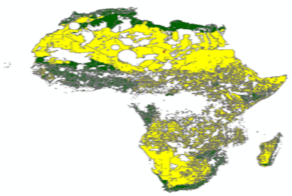
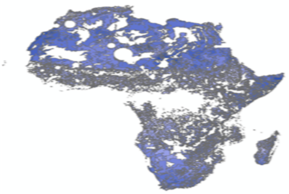
International Renewable Energy Agency





	CSP	Solar PV	Wind
Resource Assessment: 10 – 200km form cities			
Resource Assessment: Total Africa minus exclusion areas			

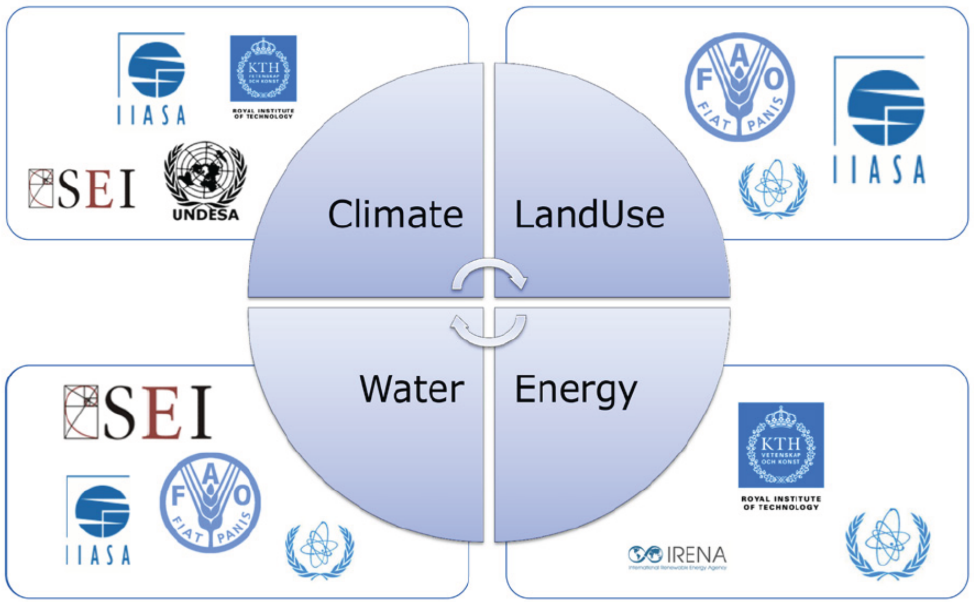
Assesments:

Integrated Climate, Land, Energy and Water strategies

- *How we can meet these common development needs in a sustainable manner*
- *What technologies and configurations of technologies are best going to help*
- *What policies are going to make this feasible and economically viable – and thereby help reduce future conflicts*
- *And what happens if we do nothing…*

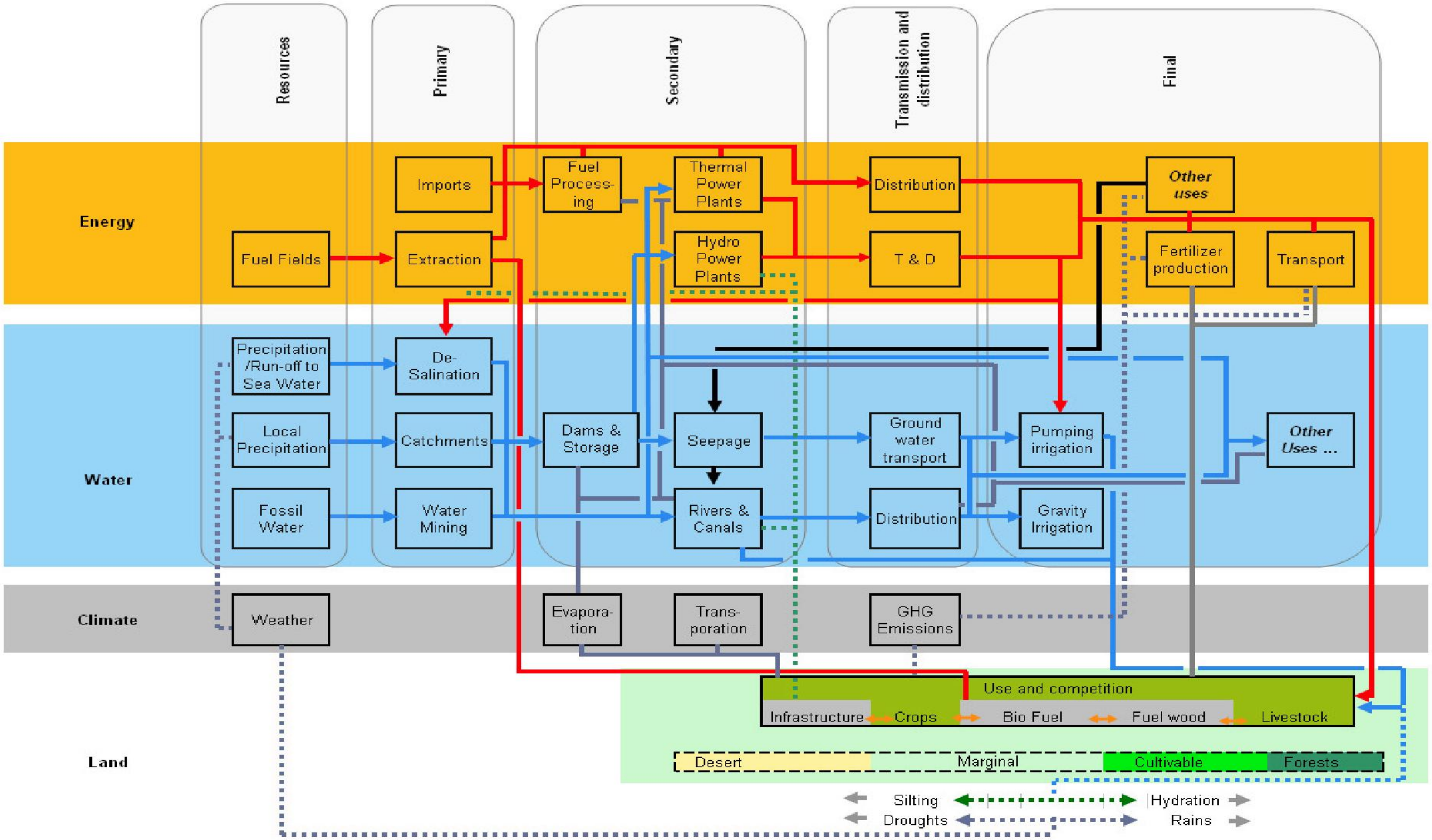
What is happening?

- *Post graduate course alongside Stockholm water week*
- *Case studies*
- *Paper commissioned in Nature*
- *Features in RIO+20*



Assesments:

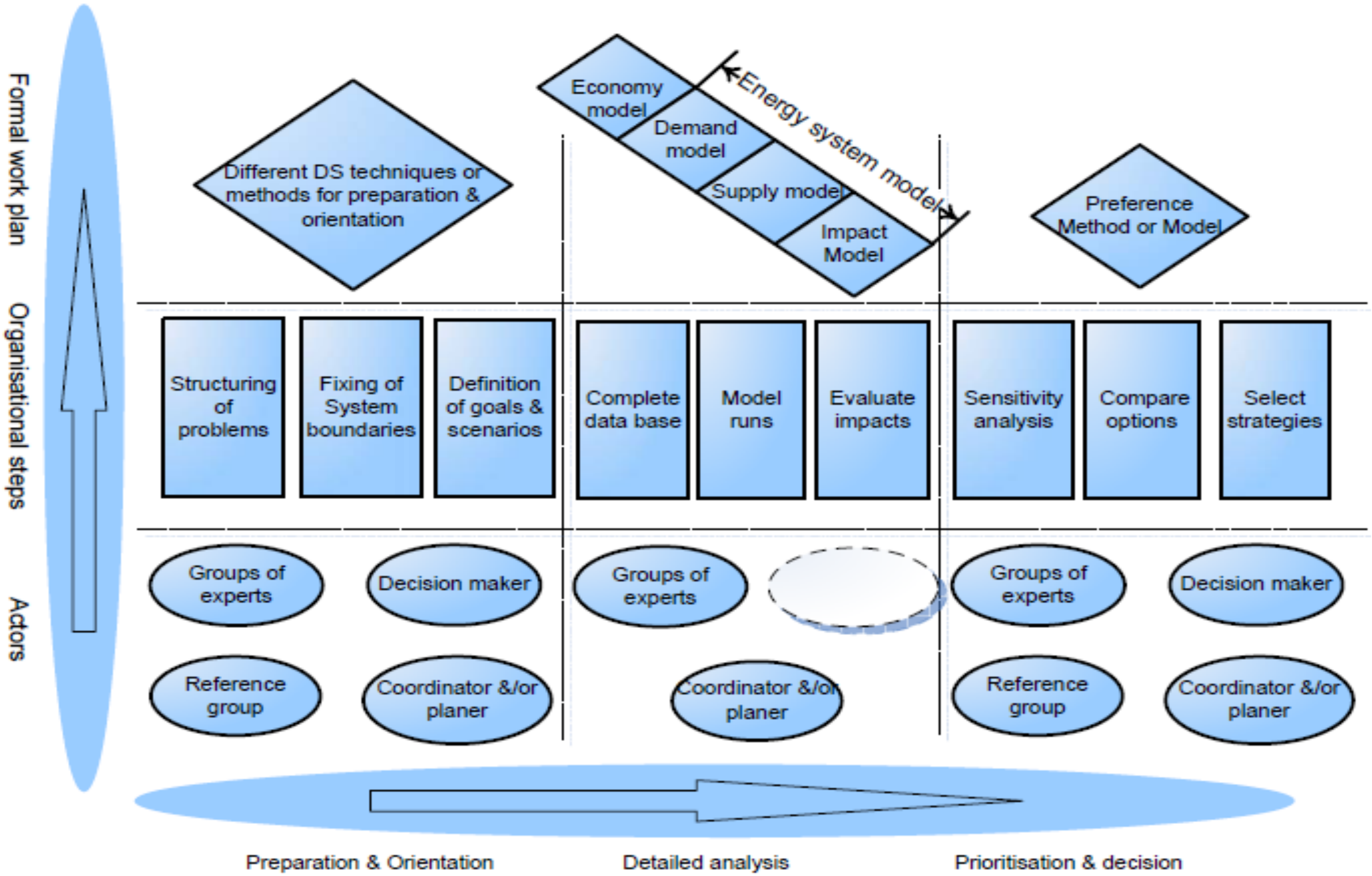
Integrated Climate, Land, Energy and Water strategies



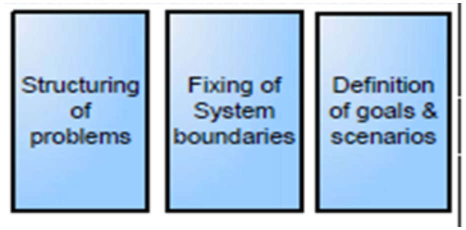
A ‘typical’ medium-to-long-term Energy Technology/Systems/ Policy Assessment

- A typical approach to energy planning / systems analysis is to minimize the economic cost while accounting for important technical physical constraints for energy system development over a 20-30-(+) year period
- Beginning with as simple a representation as possible to account for constraints that may effect general conclusions
- Of interest is:
  - Broadly: what technologies or policies help meet the development objective in a techno-economic manner?
  - What *(1)* kind of investments need to take place, *(2)* when, *(3)* at what level of investment and *(4)* operation?
- This is then iterated in more detail (together with other studies) as more information/detail is required for the target investments/technologies/polices…

A ‘typical’ medium-to-long-term Energy Technology/Systems/ Policy Assessment

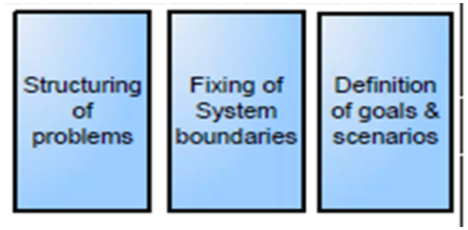


Introduction to energy planning Process selected notes



- **Structuring the problem** - questions can include (amongst many others):
  - Producer: how to increase profits
  - Consumer: improve my quality of life
  - Policy maker: how to improve energy import/export security? Consider the environment? Implement RE targets ? etc.
- **The goals could include** (amongst many others):
  - Finding the most profitable / least risk / most flexible robust etc investment
  - Determining costs of access to affordable, appropriate fuels, technologies and services
  - Costs of reducing import levels or diversifying supply
  - Derive a GHG/other emission mitigation cost curve
  - Improving economic growth or job creation etc.

Introduction to energy planning Process selected notes



Determining the system boundary is important and a function of the question at hand (as well as limitations such as the data available ...)

Energy carriers: Single or multi-fuel? (LPG distribution (competing with wood-fuel), an expanding electricity system with multiple fuel sources, full energy system representation from energy service requirements to trade and resource extraction etc)

Technology representation: Detail and diversity? (Production and use of fuel in 15min intervals or 10 year periods? Tech's which can produce and use multiple fuels (CHP, refineries)? Representing individual technologies (large power plants) or groups of millions (e.g. Lightbulbs), technology learning etc..

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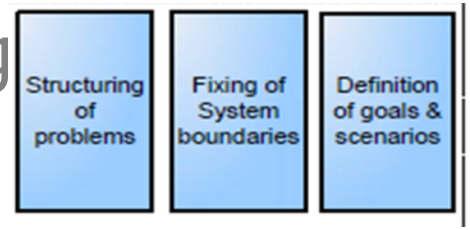
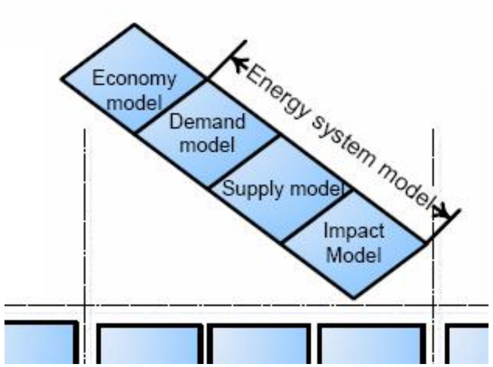
Introduction to energy planning Process selected notes



- **Determining the system boundary** *con't…*
- Level of interaction with other systems: Economy, Water usage, Land, Material, Environment etc
- Level of regional integration and trade: Explicit imports and exports, indications of trading partners, number of regions etc
- Level of energy demand "endogenisation" and feedback: Demands in terms of final energy or energy service? Do demands change as a function of price or income? Etc
- Dealing with uncertainty: Parametric sensitivities, scenario sensitivities, hedging strategies etc.
- Objectives: profitable, sufficient, robust, cost-optimal, creates the most jobs, provides flexibility and options, sustainable, single or several?

Energy systems models



- Demand analysis
  - What energy services are needed to meet different scenarios of socio-economic development?
- “Supply” analysis
  - What options are available to provide the required services?
- “Integration” analysis
  - How can supply and demand be matched?
- “Impact” analysis
  - What are the implications of different investments / policy

- Can be in separate or connected models

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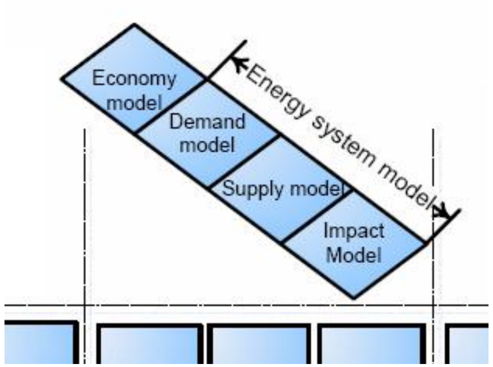
Energy systems models

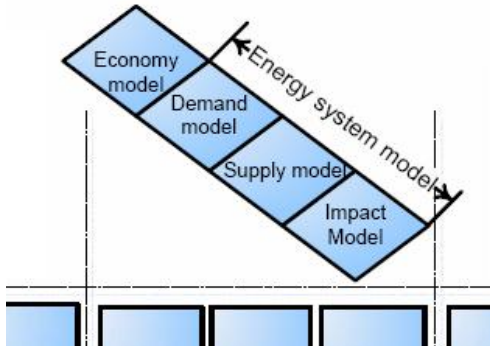


- Bottom up "energy systems models"
  - Accounting (e.g. LEAP, MAED etc.)
  - Simulation (e.g. Balance etc.)
  - Optimisation (e.g. MARKAL, MESSAGE etc.)
- Top down "energy-economy models"
  - Econometric (Barker et al 2005)
  - Input-Output (e.g. Hawdon & Pearson (1995) and Muller (1979))
  - CGE (e.g. SGM, AMIGA (Shelby et al. 2006)
- And different levels of integration of each...
  - (MARKAL-MACRO, IOSYM etc.)

	General equilibrium models	*Input-output models*	*Optimisation models*	*Simulation mode*
Timeframe	Medium to Long Term	Short to Medium Term	Short to Long Term	Short to Long Term
Focus	Macroeconomic (with micro-substructures)	Macroeconomic	Technological energy systems with cost structures	Technological systems with speci general conditions barriers
Calibration	Usually one reference year	Usually many years	One reference year	One reference year
Critical Factors	Nesting structure, elasticities	Quality of the historical time series, dynamics	Additional conditions (Bounds)	Quality of technica and economic analyses
Level of Detail of the Energy Systems	Low	Low	High	Partially high
System Boundaries	Entire economy	Entire economy	Energy system	Energy system
Flexibility in terms of a sectoral question formulation	High	High	Limited	Low
Interaction and Feedback with the entire	Considered	Considered	Not implicit, only with coupling	Not considered

Classical Question Formulation	Macroeconomic effects of environmentally economic instruments	Sectoral effects on environmentally economic instruments	Cost-effectiveness analyses	Identification of priorities for a mix of technological measures
Price-Quantity-Relations	Implicit	Implicit	Considered	Only in part, not implicitly considered
Rationality and Market Balances	In principle assumed	Not relevant	Implicit for future decision-making	Independent
Development of Reference Scenarios	Endogenous	Dependent on level of endogenisation, usually considered endogenous	Plausible expert assumptions	With considerable exogenous guidelines
Technology and Technological Development	For the most part, combined together to single or few technologies	Aggregated at the level of interacting structures	As separate technologies and explicit estimations of each future development	As separate technologies and explicit estimations of each future development
Model Generator			Mostly yes	Mostly no
Strengths	Closed theoretical structure	Broad empirical foundation, sectoral disaggregation of industrial sectors	Applicable to technical total systems technological detailed questions, flexible application possibilities	Also usable without targeted entities for optimisation, applicable to technical total systems technological detailed questions
Weaknesses	Small empirical	Statistical	Implicitly rational	Economic influences

Some basic equations



When a technology is actively operating it can use and/or produce: Energy, Emissions, Material and other "flows":

Σ_t *Activity[y,l,t]*FlowFactor [y,t,f] = Production/use of that flow [y,l,f]*

There must be enough capacity to "contain" the activity / operation of the technology:

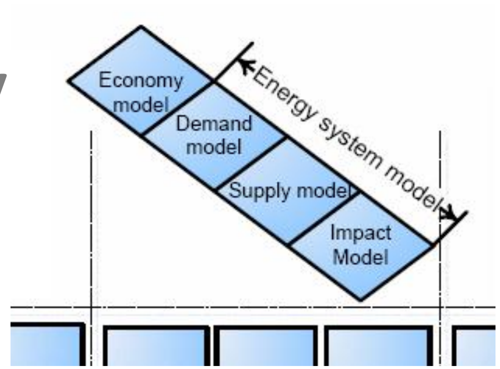
Activity[y,l,t] <= TotalCapacity[y,t] * CapacityFactor[y,t]

There is an "energy balance":

Production[y,l,f]>= Demand[y,l,f] + Use[y,l,f]

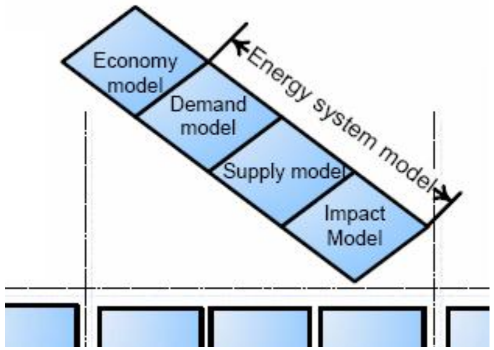
Where: y – year, l – time slice, f – fuel, t - technology (see suggested reading at the end of lecture)

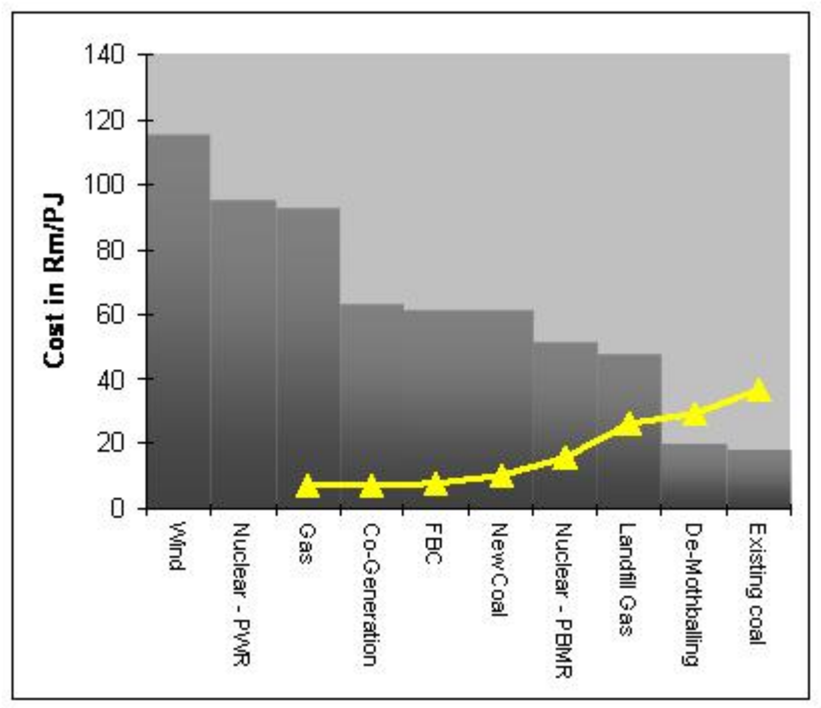
The optimizing energy systems model

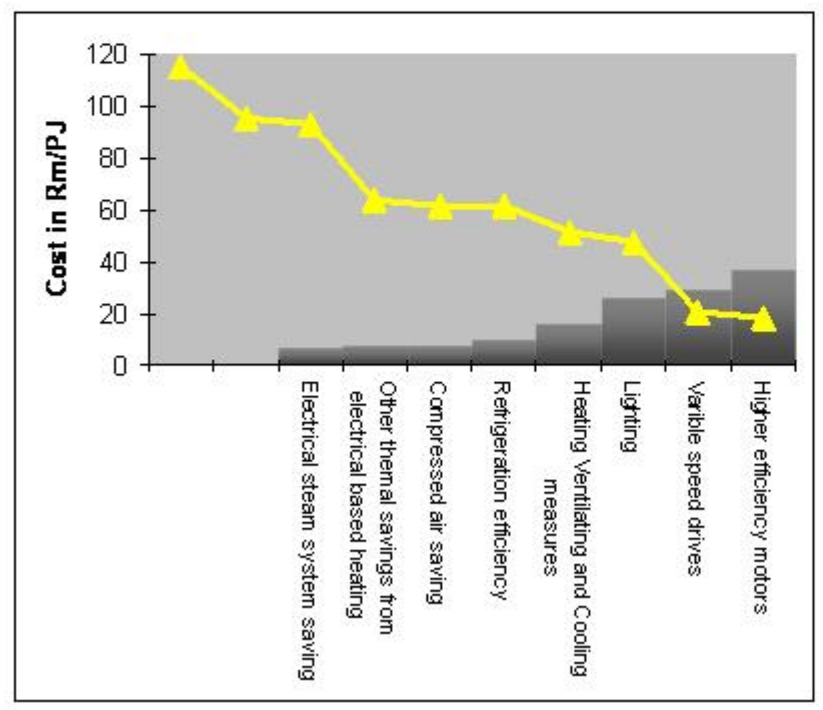


- Gives indication of the role of technologies
- An indication of the prices of energy that result
- Shows the optimal set of investments, emissions levels, prices and cost to the economy
- Allows the analyst to develop consistent pictures of the economy which can be quantified (including a range of indicators)
- Micro-economic representation of supply and demand…

The optimizing energy systems model

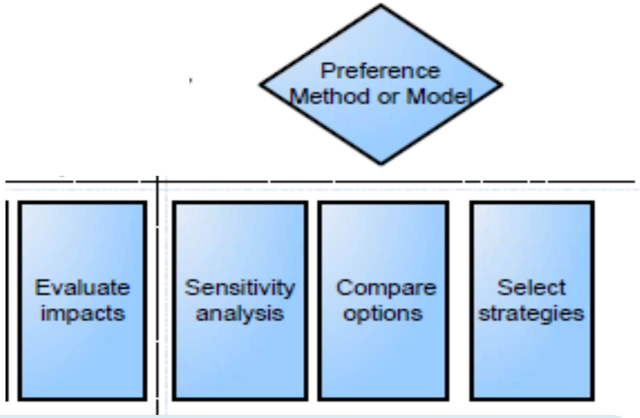


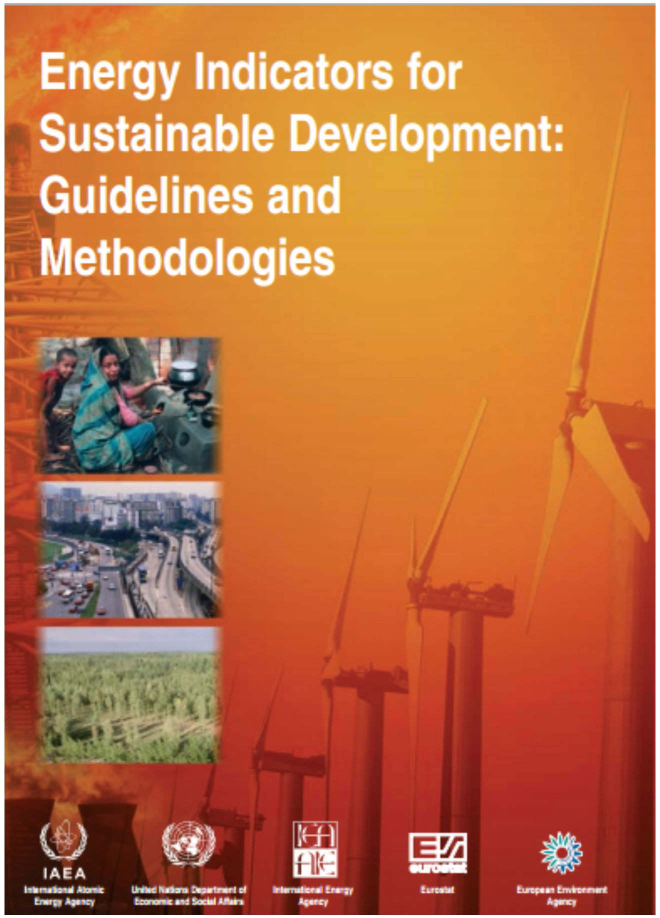




Illustrative micro-economic representation of supply and demand.

Evaluation





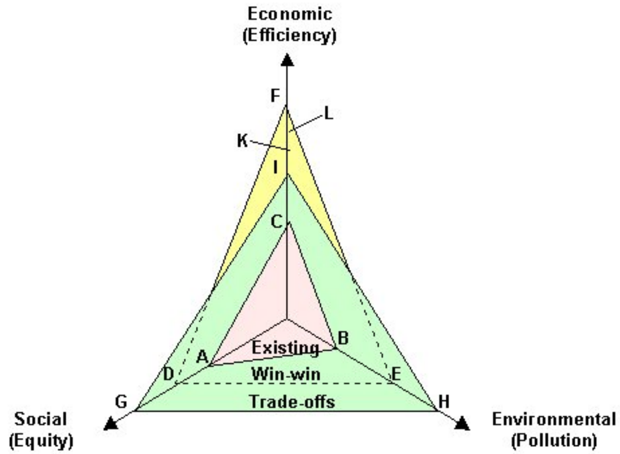
Choice of indicators:

-- Economic, Social, Environmental etc.

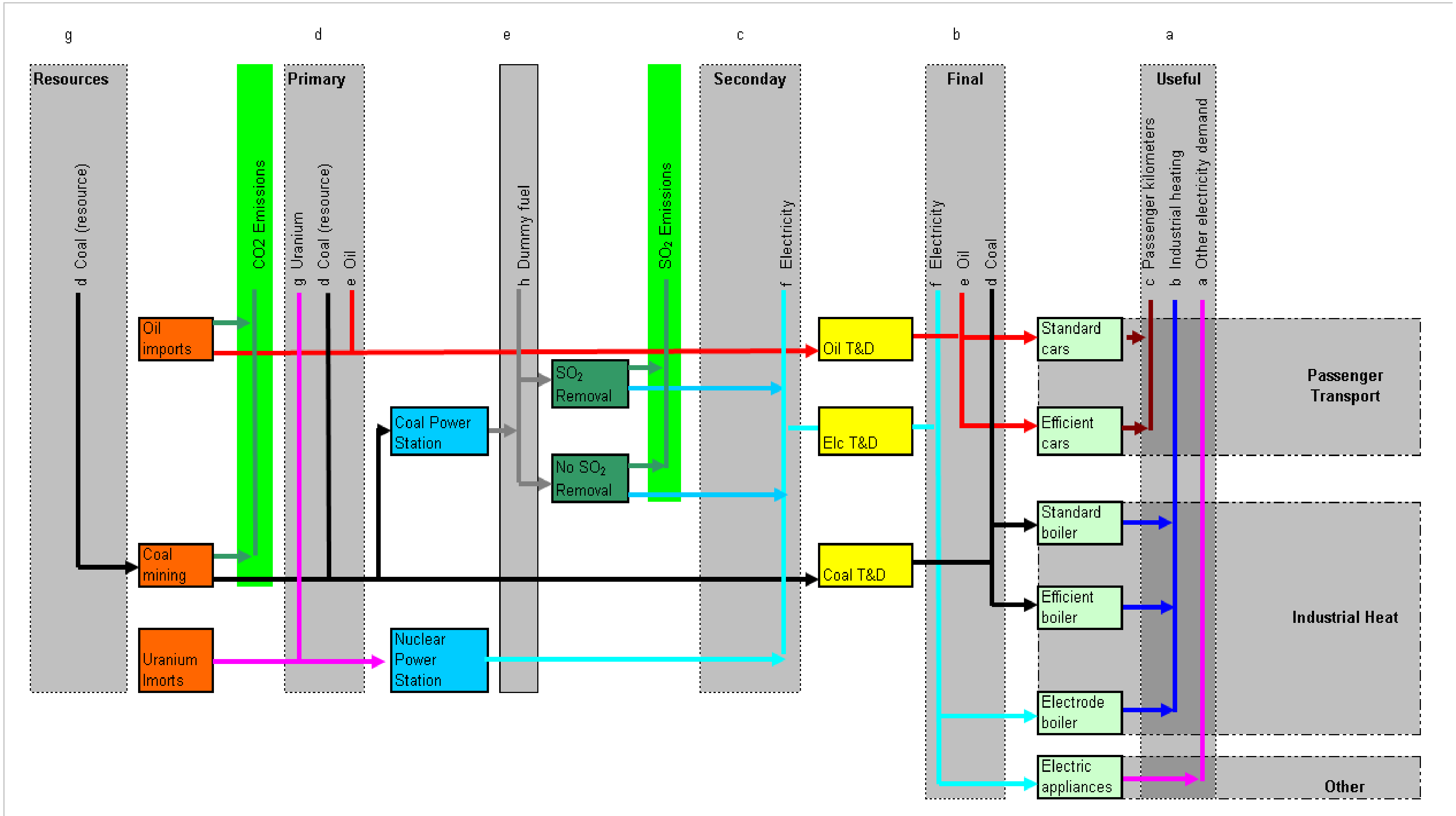
Evaluation of outputs / options

Sensitivity / Robustness / Hedging assesments

Itteration



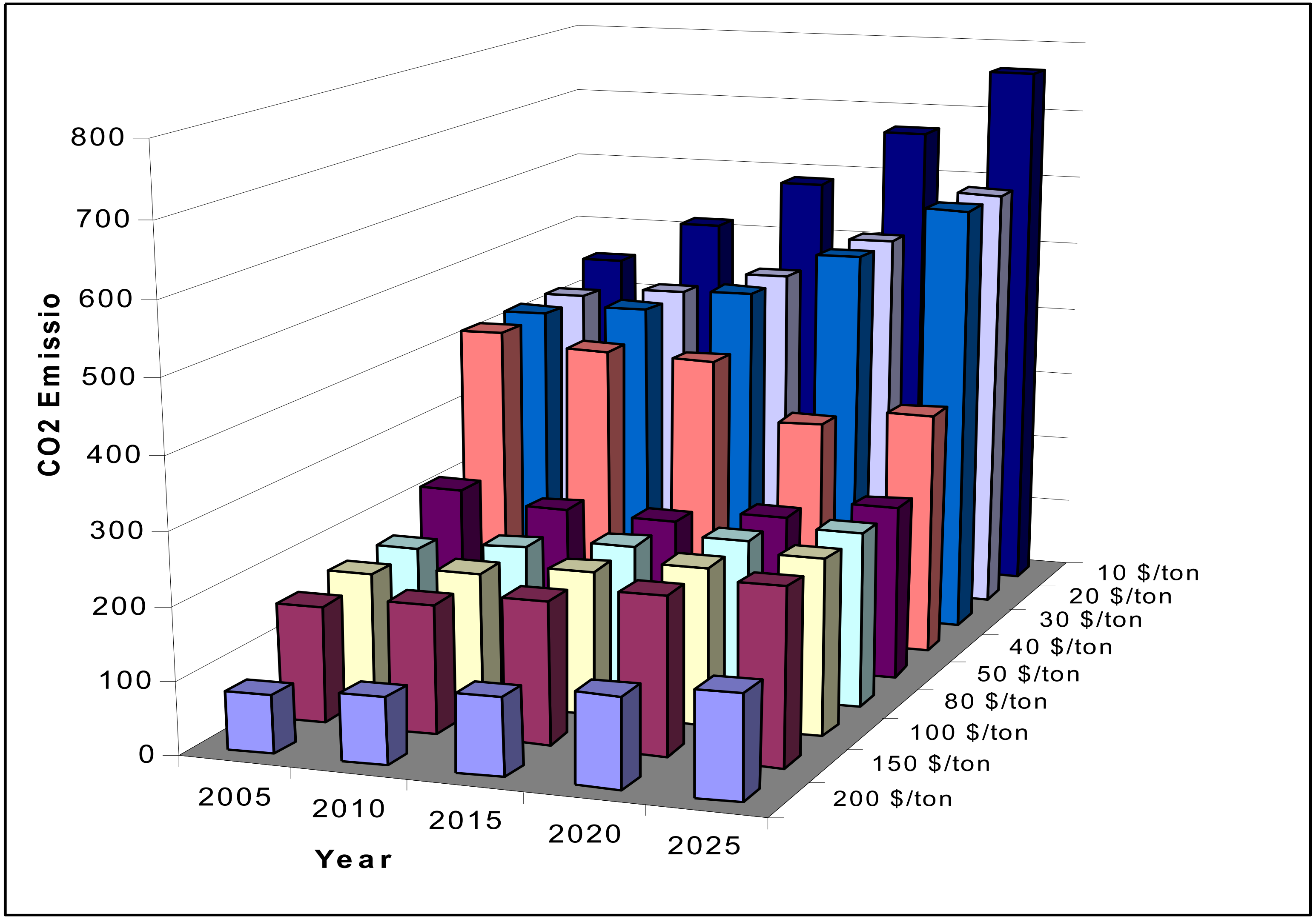
Assessment dynamics: A hypothetical energy system and its RES



Assessment dynamics: some constraints

- Employing an optimising energy systems analysis model
- A series of scenarios with increasing emissions taxes
- 10$/ton-200$/ton
- Identify reduction in emissions
- What were the mitigation options invested in at what cost
- GHG mitigation cost curve
- (Purely fictitious)

Assessment dynamics: effects



Suggested reading:

Howells. M., Victor, D. G., Gaunt T., Elias, R., Alfstad T., (2006). Beyond free electricity: The costs of electric cooking in poor households and a market-friendly alternative, Energy Policy 34 (2006) 3351-3358 and http://iis-db.stanford.edu/pubs/20928/WP-42.pdf

For a fully functional free optimisation model please see: www.osemosys.org

Winkler H., Alfstad T., & Howells M., (2005), South African Energy Policies for Sustainable Development, http://www.erc.uct.ac.za/publications/IAEA%20ESD%20Nov%202005,%20final.pdf Energy Research Centre, November

Mirakyan et al 2008. http://www.iea.org/work/2008/iew/Wednesday/Mirakyan.pdf

Howells et al 2010. Incorporating macroeconomic feedback into an energy systems model using an IO approach: Evaluating the rebound effect in the Korean electricity system, Energy Policy, Volume 38, Issue 6, June, Pages 2700-2728

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Hawdon, D., & Pearson P., (1995), Input-output simulations of energy, environment, economy interactions in the UK Fuel and Energy Abstracts, Volume 36, Number 4, July, pp. 295-295(1)

Muller, F., (1979), Energy and environment in interregional input-output models 137 pp, Martinus Nijhoff, Boston and London

Shelby, M., Fawcett, A., Smith, E., Hanson D., and Sands, R., (2006), Representing Technology in CGE Models: A Comparison of SGM and AMIGA for Electricity SectorCO2 Mitigation. International Energy Workshop ERC, EMF, IEA, IIASA. Capetown, 27-29 June.

MARKAL – see www.etsap.org

MESSAGE/ MAED – see http://www.iaea.org/OurWork/ST/NE/Pess/PESSenergymodels.shtml

LEAP – see www.energycommunity.org