

Energy Systems Modelling for a Changing Climate

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OVERVIEW

Part A

- Choosing a model
- ‘State of the Art’ – a brief review
- EnergyPLAN, LEAP

Part B

- A new paradigm
- Custom models
- Conclusions

CHOOSING A MODEL

- What do I want to know? E.g. will it work? What will the transition look like? What outputs are of interest?
- Over what timeframe? E.g. minutes, hours, years, decades
- Do I wish to compare with previous studies?
- Do I want to link with other models?
- Open source or licence? User friendly?

‘STATE OF THE ART’

Connolly et al. (2010)

- 68 models (tools) identified
- 37 models reviewed

Table 3
Type of each tool reviewed.

Tool	Type						
	Simulation	Scenario	Equilibrium	Top-down	Bottom-up	Operation optimisation	Investment optimisation
AEOLIUS	Yes	–	–	–	Yes	–	–
BALMOREL	Yes	Yes	Partial	–	Yes	Yes	Yes
BCHP Screening Tool	Yes	–	–	–	Yes	Yes	–
COMPOSE	–	–	–	–	Yes	Yes	Yes
E4cast	–	Yes	Yes	–	Yes	–	Yes
EMCAS	Yes	Yes	–	–	Yes	–	Yes
EMINENT	–	Yes	–	–	Yes	–	–
EMPS	–	–	–	–	–	Yes	–
EnergyPLAN	Yes	Yes	–	–	Yes	Yes	Yes
energyPRO	Yes	Yes	–	–	–	Yes	Yes
ENPEP-BALANCE	–	Yes	Yes	Yes	–	–	–
GTMax	Yes	–	–	–	–	Yes	–
H2RES	Yes	Yes	–	–	Yes	Yes	–
HOMER	Yes	–	–	–	Yes	Yes	Yes
HYDROGEMS	–	Yes	–	–	–	–	–
IKARUS	–	Yes	–	–	Yes	–	Yes
INFORSE	–	Yes	–	–	–	–	–
Invert	Yes	Yes	–	–	Yes	–	Yes
LEAP	Yes	Yes	–	Yes	Yes	–	–
MARKAL/TIMES	–	Yes	Yes	Partly	Yes	–	Yes
Mesap PlaNet	–	Yes	–	–	Yes	–	–
MESSAGE	–	Yes	Partial	–	Yes	Yes	Yes
MiniCAM	Yes	Yes	Partial	Yes	Yes	–	–
NEMS	–	Yes	Yes	–	–	–	–
ORCED	Yes	Yes	Yes	–	Yes	Yes	Yes
PERSEUS	–	Yes	Yes	–	Yes	–	Yes
PRIMES	–	–	Yes	–	–	–	–
ProdRisk	Yes	–	–	–	–	Yes	Yes
RAMSES	Yes	–	–	–	Yes	Yes	–
RETScreen	–	Yes	–	–	Yes	–	Yes
SimREN	–	–	–	–	–	–	–
SIVAEL	–	–	–	–	–	–	–
STREAM	Yes	–	–	–	–	–	–
TRNSYS16	Yes	Yes	–	–	Yes	Yes	Yes
UniSyD3.0	–	Yes	Yes	–	Yes	–	–
WASP	Yes	–	–	–	–	–	Yes
WILMAR Planning Tool	Yes	–	–	–	–	Yes	–

Model Categories

- Simulation: *hourly res, typically 1 y*
- Scenario: *annual res; 20-50 y*
- Equilibrium: *supply-demand-prices*
- Top-down: *macroeconomic; price growth; equilibrium assumed*
- Bottom-up: *specific technologies; investment focus*
- Operation optimisation (simulation)
- Investment optimisation (scenario)

‘STATE OF THE ART’

Chang et al. (2021)

- 42 review papers!
- 137 models identified; 54 examined
- Trends: cross sector synergies; open access (Open Energy Modelling Initiative); temporal detail
- Challenges: high resolution demand data; model coupling; engagement with policy makers
- One tool cannot do it all!

Fig. 1. Modelling time-step by time horizon of the 54 surveyed tools. Note that the sum exceeds 54 as some tools can operate with different user-defined time resolutions.

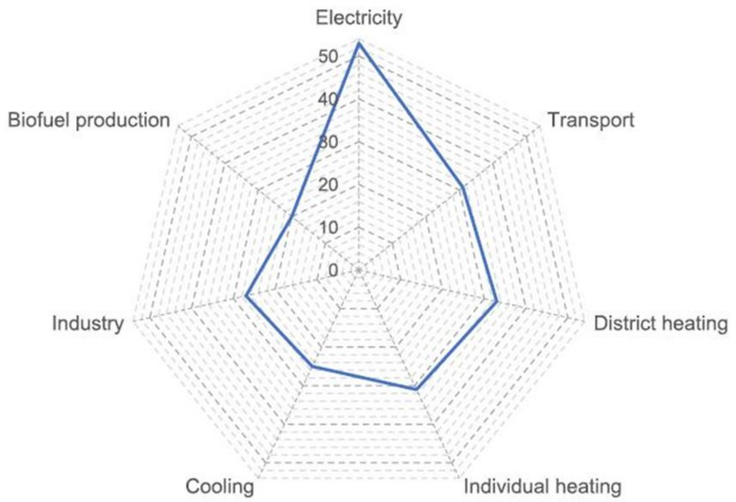


Fig. 2. Sector & end-use coverage in the 54 surveyed modelling tools.

'STATE OF THE ART'

Prina et al. (2020)

- Reviewed 22 'bottom-up models'; 13 short-term; 9 long-term
- Challenges; temporal and spatial resolution; detail; sector-coupling
- LUT model includes transmission constraints; nodal analysis

Table 6
Position of the reviewed long-term models towards the identified challenges of energy system modelling.

Bottom-up long-term models	*Foresight approach*	*Resolution*				*Transparency*
		In time	*In space*	*In techno-economic detail*	*In sector coupling*	
LEAP [120]	Perfect foresight	Low	Low	Low	High	Medium
MARKAL/TIMES [101,102]	Perfect foresight	Low	Medium	Low	High	Low
OSeMOSYS [104,105]	Perfect foresight	Low	Medium	Low	High	High
Temoa [107,108]	Perfect foresight	Low	Medium	Low	High	High
MESSAGE [110]	Perfect foresight	Low	Medium	Low	High	Low
Balmorel [112]	Perfect foresight	High	High	Medium	Low	High
eMix [121]	Perfect foresight	Medium	Medium	High	Low	Low
EPLANoptTP [119]	Perfect foresight	High	Low	Low	High	Medium
Mahbub et al. [118]	Myopic	High	Low	Low	High	Medium
LUT [114,117]	Myopic	High	High	Medium	High	Medium

TWO MODELS COMPARED

Will it work at the technical level?

EnergyPLAN ✓

- User-friendly
- Hourly time step, 1 y, 8784 h
- Electricity, heat, fuels
- Technical (efficiency) optimisation
- Financial optimisation
- Emissions
- High renewables futures
- Many peer-reviewed studies

What will the transition look like?

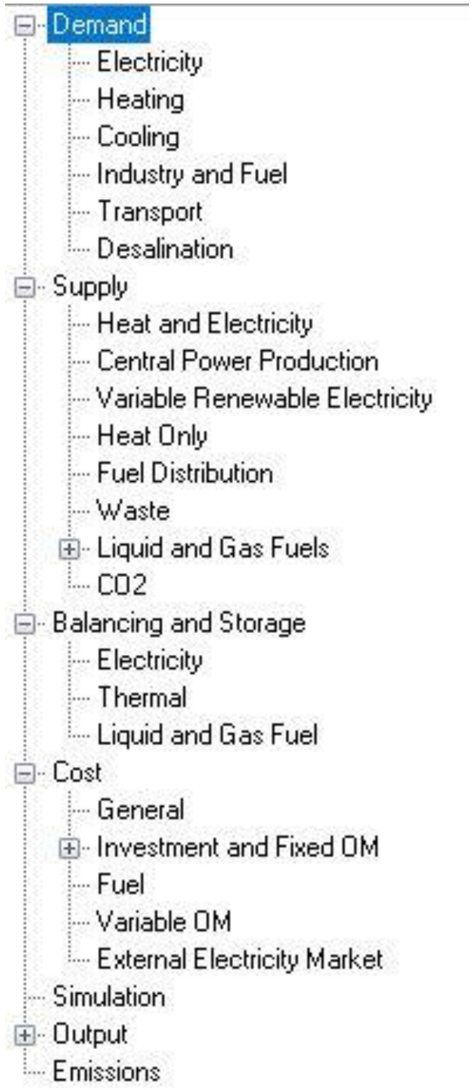
LEAP ✓

- User-friendly
- Yearly time step
- Electricity, heat, fuels
- Broad scope (charcoal, rural/urban)
- Financial optimisation
- Environmental impacts
- Transition planning (Paris INDC)
- Many peer-reviewed studies

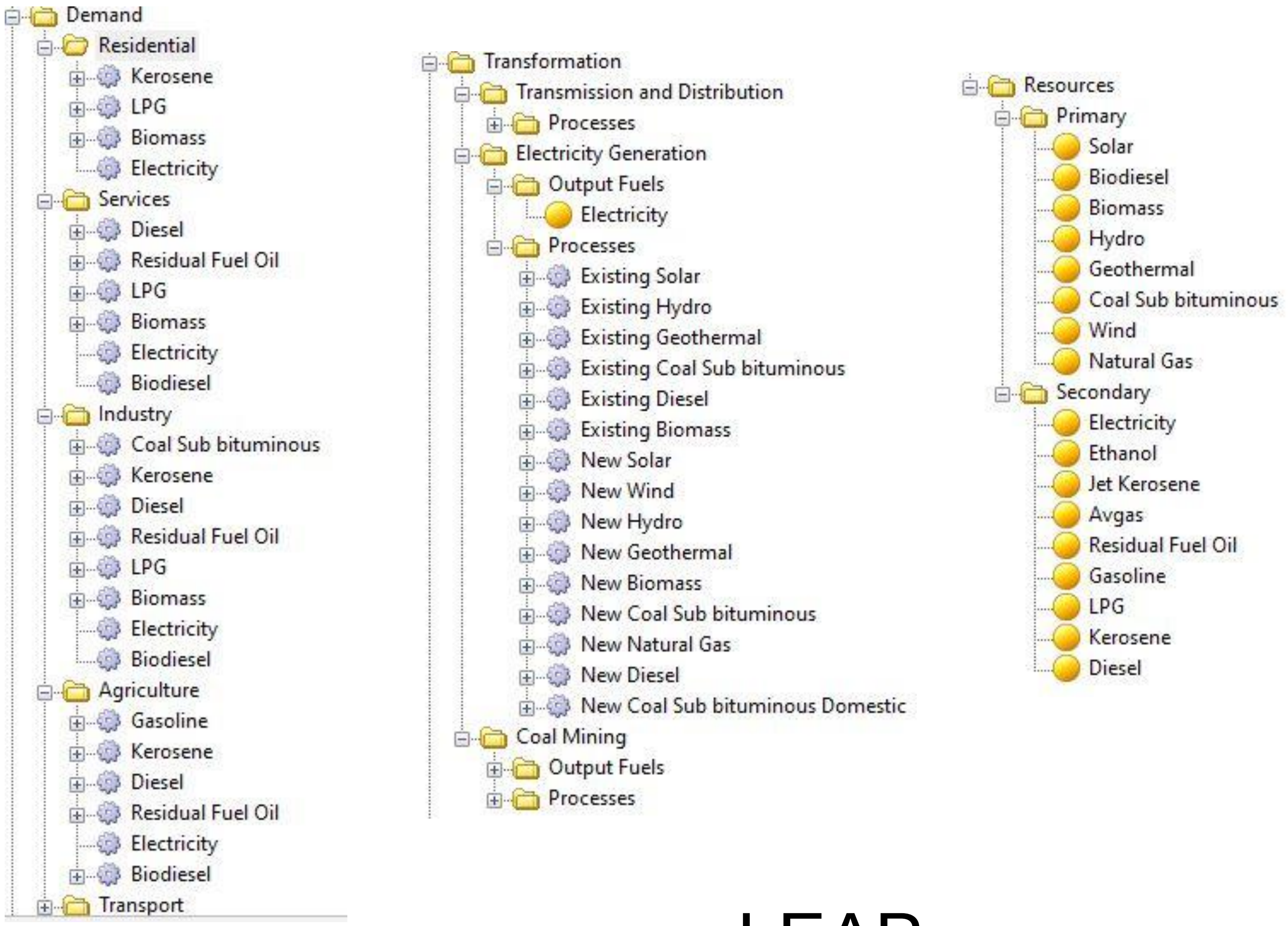
Energy PLAN
Advanced energy system analysis computer model

LEAP *Tools for Sustainable Energy Analysis*

TREE STRUCTURES/DETAIL



EnergyPLAN

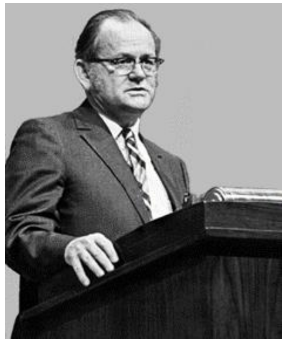


LEAP

MODELLING FOR A CHANGING CLIMATE
TWO CHALLENGES

‘Tragedy of the Commons’

(Hardin, 1968)



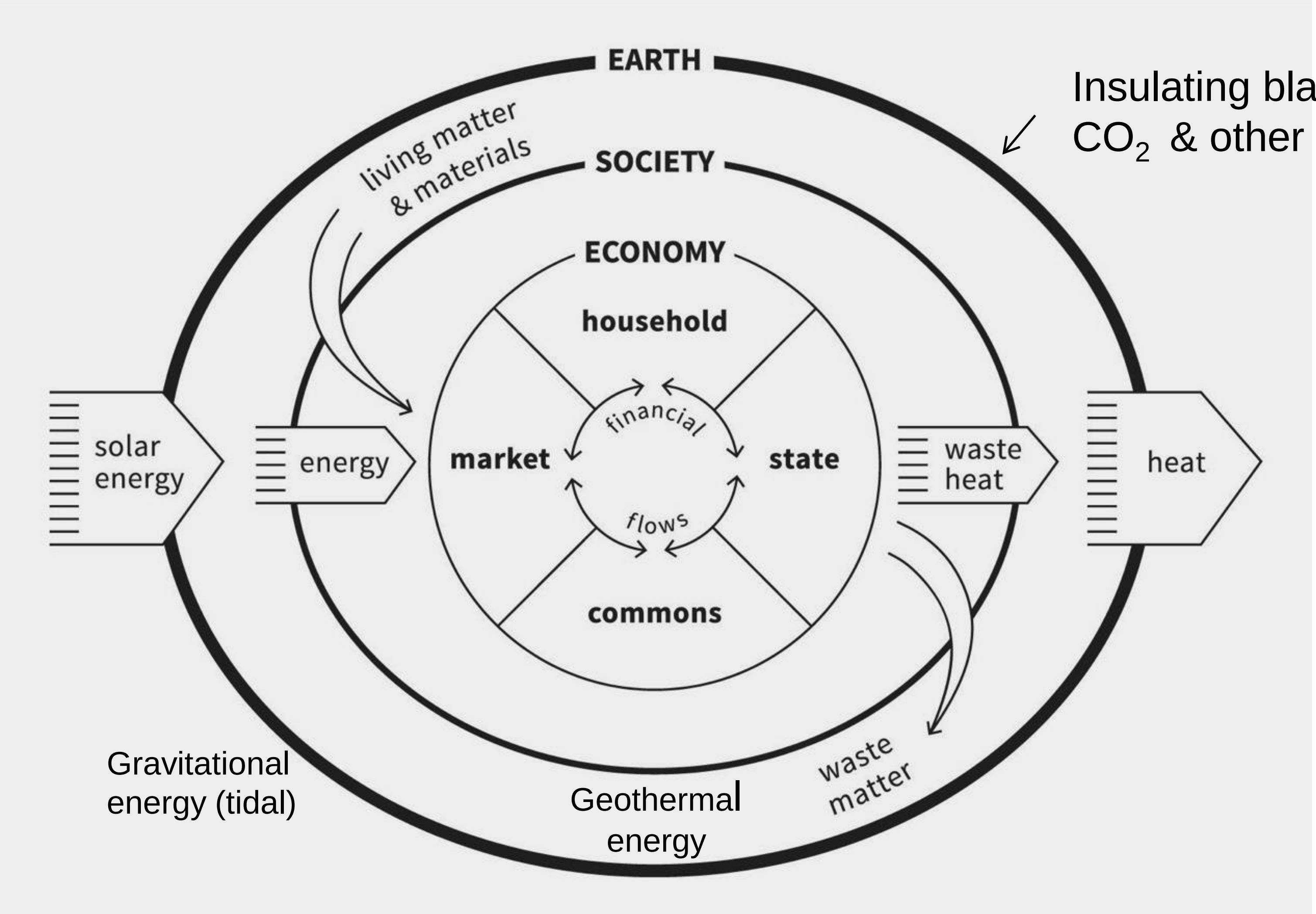
‘Tragedy of the Horizon’

(Carney, 2021)

‘Making a profit is no more the purpose of business than breathing is the purpose of life’ (John Kay)

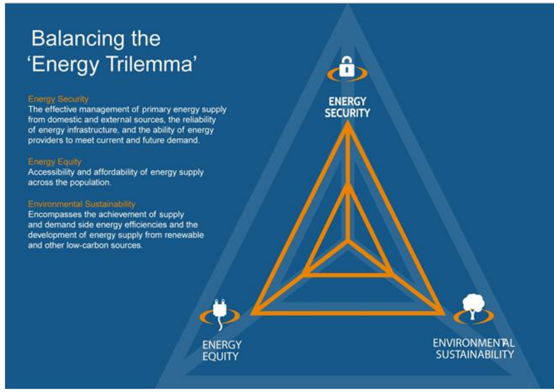
MODELLING FOR A CHANGING CLIMATE
A PARADIGM SHIFT

Finite Solar resource;
682 million PJ/y at surface



Laws of physics

Ecological Economics



MODELLING FOR A CHANGING CLIMATE

Observation

- Finite resources; physical laws, entropy
- Societal issues are critical
- ‘Economic’ only if above satisfied
- Rapid transition to renewables required
- Sector integration is key

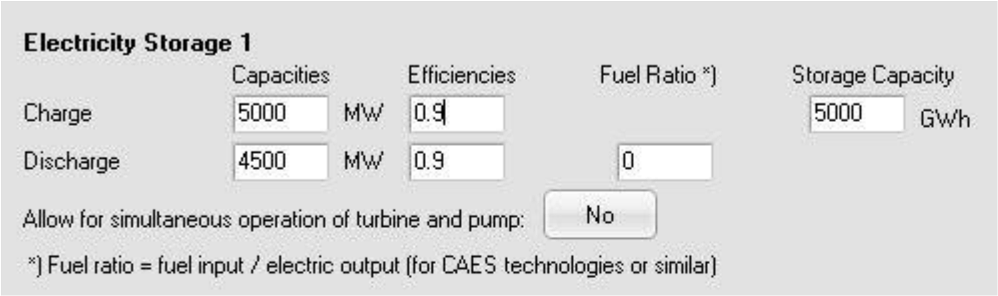
Conclusion

- First criteria: EROEI, ESOI, exergy
- Second: ‘Doughnut’, SCOE
- Third: NPV, LCOE…
- Model transition options & pathways
- Model integrated complete systems

CUSTOM MODELS

Problem

- Storage: EnergyPLAN does not solve for storage directly; must iterate charge/discharge capacities (MW) & storage capacity (GWh) until no excess energy production
- Optimisation: most models optimise based on mainstream neo-classical economics



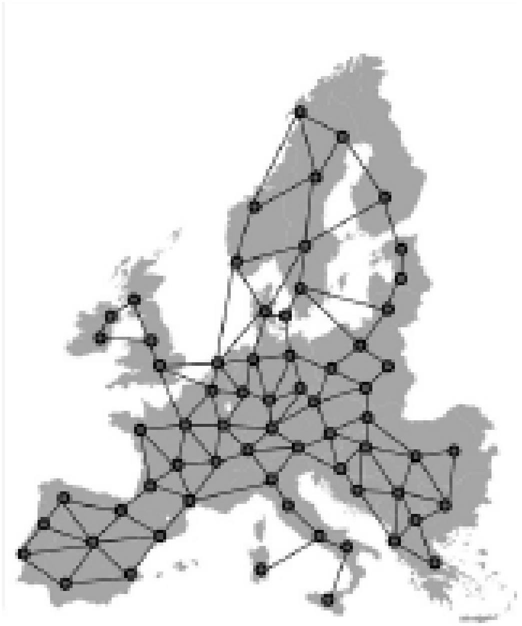
Solution

- Own code to compute storage needed & show charge/discharge capacities; spill
- AND/OR contribute to EnergyPLAN development
- Own code to optimise according to EROEI, ESOI, or societal well-being (e.g. Doughnut), or purpose-driven business (ESG) criteria

KEY ADDITIONS

Transmission

- Move from a ‘copper plate’ approach to constraints/nodal analysis (e.g. LUT model)



Grid Stability

- High levels of converter-based generation (PV and wind) reduce system inertia
- E.g. Jacobson et. al (2015) has ~ 91% converter-based generation!
- Solution: synthetic inertia; synchronous condensers… this must be factored into models

SUMMARY

- There are many energy systems models to choose from; over 135 reported here!
- Paradigm shift for a changing climate: energetics, social equity, finance, in that order!
- No one model will do it all! It’s ‘Horses for Courses’.

THANKS FOR LISTENING

Any questions

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