MEDEAS

MODELING THE RENEWABLE ENERGY TRANSITION IN EUROPE

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691287

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The MEDEAS suite of models: improvements as compared with literature

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The MEDEAS suite of models

AUSTRIAN ENERGY AGENCY

LEAP Tools for Sustainable Energy Analysis

MEDEAS MODELING THE RENEWABLE ENERGY TRANSITION IN EUROPE

TIMES-MARKAL
(Austria)

LEAP
(Bulgaria)

MEDEAS
World
Europe
Austria
Bulgaria

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TIMES-MARKAL (Austria) and LEAP (Bulgaria)

- TIMES-MARKAL
  - •Model type: bespoke energy model
  - •Geographical focus: Austria
  - •Aim: create medium to long-term scenarios for the Austrian energy system.
  - •Definition: TIMES is an energy system model generator that uses linear optimization to produce a least-cost energy system, optimized according to a number of constraints.

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- LEAP
  - •Model type: bespoke energy model
  - •Geographical focus: Bulgaria
  - •Aim: create energy and emissions scenarios for Bulgaria
  - •Description: LEAP is a tool for energy policy and climate change mitigation assessment. The assessment is based on the comparison of scenarios, typically in long-term (20-50 years).

LEAP *Tools for Sustainable Energy Analysis*

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The MEDEAS model

- Model type: aggregated energy-economy-environment model (or Integrated Assessment Model)
- Modelling approach: System Dynamics (dynamic modelling)
- Geographical areas :
    - World - MEDEAS-World
    - Europe - MEDEAS-Europe
    - National (Austria and Bulgaria) - MEDEAS-Austria, MEDEAS-Bulgaria
- Aim: develop medium to long-term scenarios for energy system at different geographical levels
- Description: the MEDEAS model(s) simulate the World/Europe/National energy systems and can be used to develop long-term socio-economic-environmental scenarios. This tool will support policy and decision-makers in the assessment of the requirements and consequences of the transition to a decarbonised European energy system.

- MEDEAS tries to overcome three limitations present in the current literature:
    1. Open feedback loops (fossil fuels magically appear)
    2. Linear optimisation approach
    3. Absence of feedback from climate change.

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MEDEAS improvements compared with literature

MEDEAS features several improvements compared with other Integrated Assessment Models available in the literature:

1. Net Energy Approach
2. Accounts for and highlights availability constraints of renewable and non-renewable resources (i.e. minerals)
3. "Hard"/consistent climate change impacts
4. "Technological realism" vs. “Technological optimism" in the literature (e.g. Carbon Capture and Storage, Hydrogen, etc)
5. Simulation vs. optimization approach
6. World-Europe-country level approach

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Net energy approach

'We need to 'spend' energy to 'make' energy'

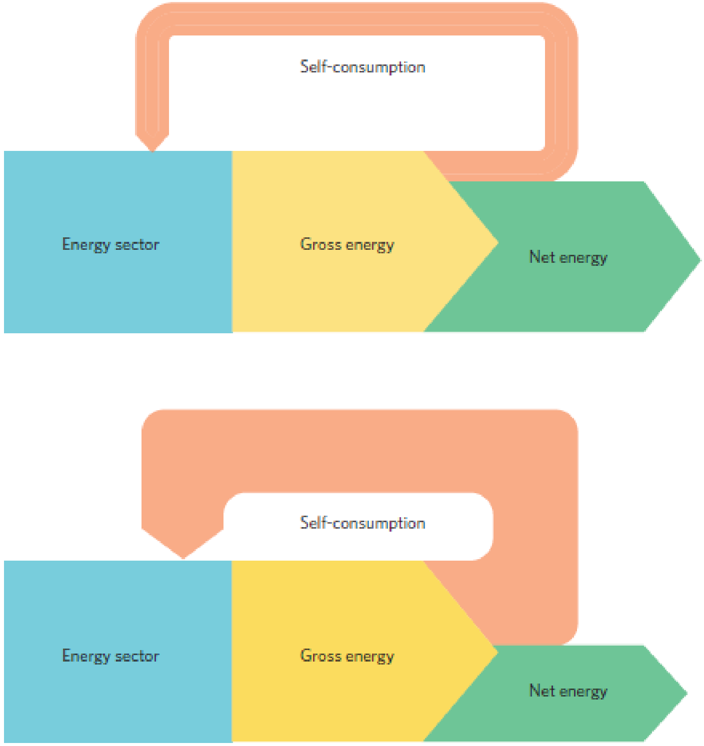

Figure 1 | Net energy analysis (NEA) studies the net output of energy-producing technologies, accounting for the energy consumed, directly and indirectly, by the energy sectors, in contrast to the gross energy production measured by the International Energy Agency and US Energy Information Administration in their analyses. Only net energy is available for end uses within society. As net energy output from a system declines (top to bottom), less energy is available to society per unit of total energy consumption, increasing investment requirements and environmental impacts of final energy use.

Source: Carbajales-Dale et al. 2014.

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Energy Returned On (Energy) Invested (EROEI)

- EROI identifies the efficiency of energy sources as a relation between energy invested and gained
- In MEDEAS this metric drives the final energy mix (priority to renewables)
- Formula:

- Energy required to deliver that energy = energy necessary to:
    - Explore
    - Extract
    - Refine

- Accounts for:
    - Thermodynamic limits
    - Technological aspects
    - Economic aspects

EROI for functional society > 3:1 (Hall et al. 2009)

EROI < 1:1 is uneconomical

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ERO(E)I of RES (in reality, not within the model)

Trend -> increasing

Table 30 ; EROI over lifetime for each of the RES technologies for electricity generation considered in MEDEAS. We take g(year=2015)=0.66) from MEDEAS. See section 0 for the recycling rates considered for estimating the EROI of dispatchable RES. Values of EROIpou can be estimated as EROIst-1. * EROIst including additional grids and storage is scenario dependent is not reported here.

Technology	**EROIst over lifetime (static definition)**	**Reference**
	Dispatchable RES	
Hydroelectricity	50	Annex 3 from (MEDEAS, 2016a)
Geothermal	7	Low range in Annex 3 from (MEDEAS, 2016a) and correction with real Cp from (IRENA db, 2017).
Solids bioenergy	1.5	(de Castro et al., 2014)
Oceanic	3.25	Own estimation (see text)
	*Variable RES**	
Wind onshore	10.2	This work
Wind offshore	6.5	This work
Solar PV	5.2	This work
CSP	3.5	(De Castro and Capellán-Pérez, 2017)
	Electricity storage (ESOI)	
EV batteries	6.1	This work

Source: MEDEAS Deliverable 4.1

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ERO(E)I of non-RES (in reality, not within the model)

Trend -> decreasing

Table 1
Published EROI values for various fuel sources and regions (adapted from Murphy et al. (2011)).

Resource	Year	Country	EROI (X:1)[1]	Reference
Fossil fuels (Oil and Gas)				
Oil and gas production	1999	Global	35	Gagnon, 2009
Oil and gas production	2006	Global	18	Gagnon, 2009
Oil and gas (Domestic)	1970	US	30	Cleveland et al. 1984, Hall et al. 1986
Discoveries	1970	US	8	Cleveland et al. 1984, Hall et al. 1986
Production	1970	US	20	Cleveland et al. 1984, Hall et al. 1986
Oil and gas (Domestic)	2007	US	11	Guilford et al. 2011
Oil and gas (Imported)	2007	US	12	Guilford et al. 2011
Oil and gas production	1970	Canada	65	Freise, 2011
Oil and gas production	2010	Canada	15	Freise, 2011
Oil, gas & tar sand production	2010	Canada	11	Poisson and Hall, in press
Oil and gas production	2008	Norway	40	Grandell, 2011
Oil production	2008	Norway	21	Grandell, 2011
Oil and gas production	2009	Mexico	45	Ramirez, in preparation
Oil and gas production	2010	China	10	Hu et al. 2013
Fossil fuels (Other)				
Natural Gas	2005	US	67	Sell et al. 2011
Natural Gas	1993	Canada	38	Freise, 2011
Natural Gas	2000	Canada	26	Freise, 2011
Natural Gas	2009	Canada	20	Freise, 2011
Coal (mine-mouth)	1950	US	80	Cleveland et al. 1984
Coal (mine-mouth)	2000	US	80	Hall and Day, 2009
Coal (mine-mouth)	2007	US	60	Balogh et al. unpublished
Coal (mine-mouth)	1995	China	35	Hu et al. 2013
Coal (mine-mouth)	2010	China	27	Hu et al. 2013
Other non-renewables				
Nuclear	n/a	US	5 to 15	Hall and Day, 2009, Lenzen, 2008

Source: Adapted from Hall et al. 2014

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Renewable Energy Sources RES

RES technologies prioritised in the energy mix to promote decarbonisation

Challenges	Opportunities
Intermittency	
Seasonality	
Uneven spatial distribution (requires storage)	
Lower energy density	
Lower EROI than fossil resources	
Finiteness of minerals and materials needed	
Environmental impacts (e.g. landscape, ecosystem services)	

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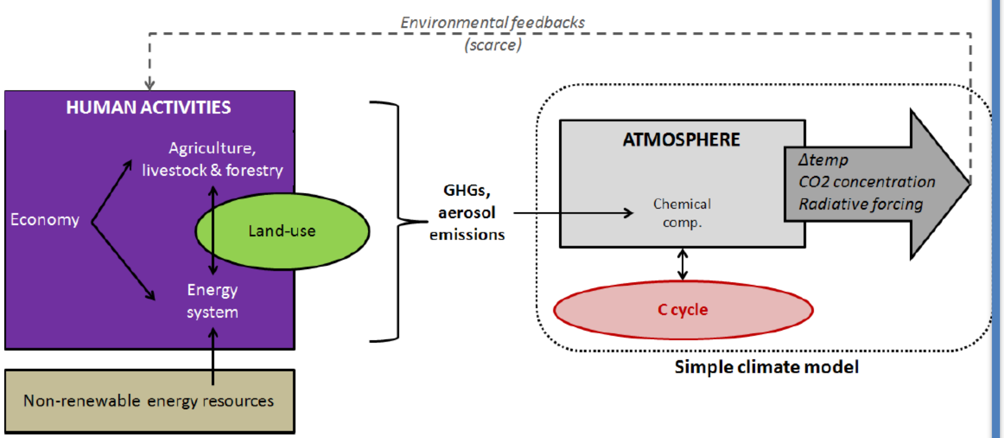
MEDEAS improvements compared with literature

IAMs vs MEDEAS



Notes: In practice, IAMs usually focus on the interactions between processes and systems within the "Human Activities" box of Figure 1.1, including the energy system, the agriculture, livestock and forestry system and the other human systems. Some also include Land-use, while environmental feedbacks are scarce in the literature.

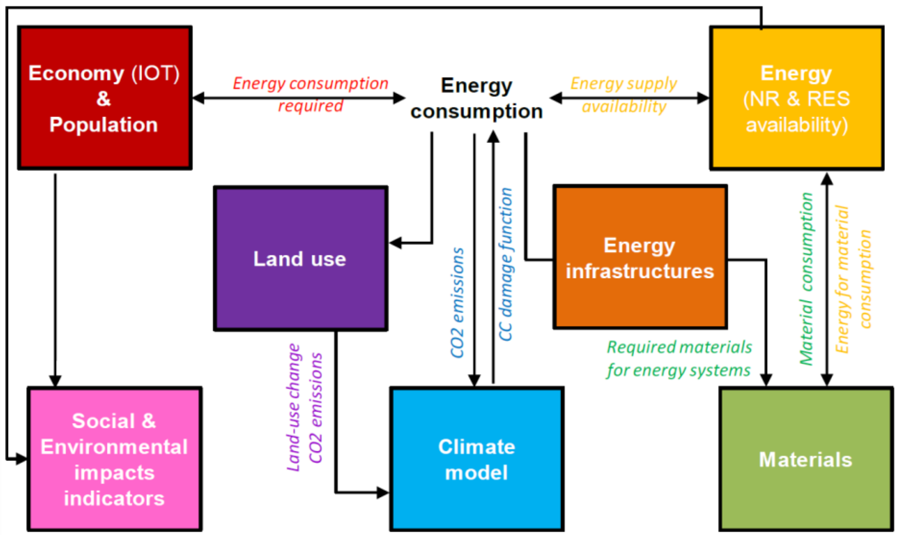


Figure 2: Overview of MEDEAS-World by modules and the modelled linkages between them

IAMs vs MEDEAS

Source: Deliverable 4.1

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- MEDEAS Deliverable 2.1
- MEDEAS Deliverable 4.1

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Depletion of non-renewable resources

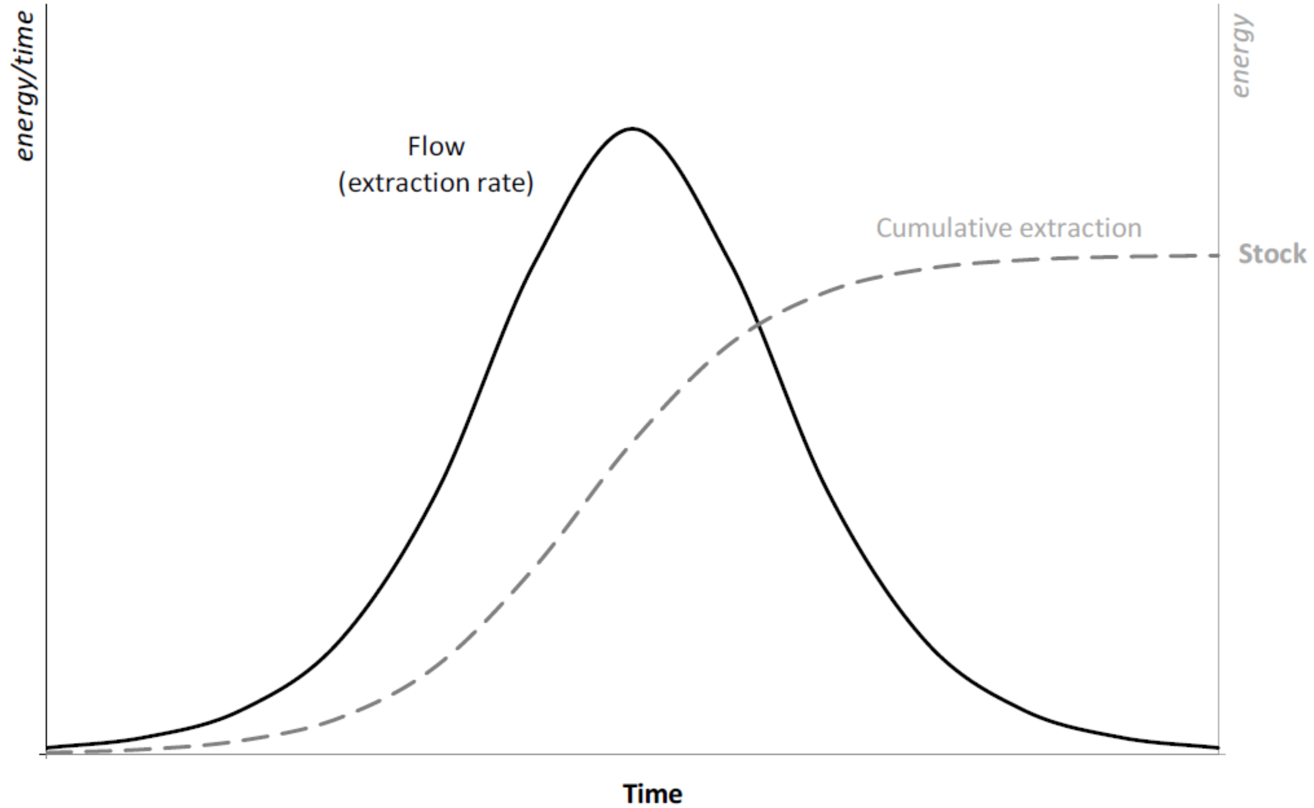

Figure 16 : (Kerschner and Capellán-Pérez, 2017): Simplified representation of the depletion of a non-renewable resource in the absence of non-geologic constraints. Stocks and flows of energy relative to time.

Source: Deliverable 4.1.

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