Open Source energy MOdelling SYStem for GReece – OSeMOSYS-GR

Version 1.0

OSeMOSYS-GR
Open-Source energy Modeling SYStem for GReece

Model factsheet

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Note about contributors

This model factsheet has been prepared by researchers of the Technoeconomics of Energy Systems laboratory (TEESlab) of the University of Piraeus Research Centre (UPRC).

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Abbreviations & Acronyms

Acronym	Description
CEM	Capacity Expansion Model
CCS	Carbon Capture and Storage
EC	European Commission
NECP	National Energy and Climate Plan
OSeMOSYS	Open Source energy MOdelling SYStem
OSeMOSYS-GR	Open Source energy MOdelling SYStem for GReece
PCM	Production Cost Model
RES	Renewable Energy Sources
TEEM	TEESlab Modelling
TEESlab	Techno-Economics of Energy Systems laboratory
UPRC	University of Piraeus Research Centre
VRE	Variable Renewable Energy

1. Introduction to OSeMOSYS

The **O**pen **S**ource **e**nergy **MO**delling **SYS**tem (OSeMOSYS) is an open source modelling system for long-run integrated assessment and energy planning. It was developed by a range of international institutions, and its first version was made available in 2008, while the first peer-reviewed publication describing its ethos and structure was available in 2011 (Howells et al., 2011). It has been used to create energy system models from the scale of continents down to the scale of countries, regions and villages. Designed to require no upfront financial investment, a fast learning curve and little time commitment to operate, it is fit for use by communities of developers, modellers, academics up to policy makers. Thanks to its transparency, it is broadly employed as a training and dissemination tool (Gardumi et al., 2018).

OSeMOSYS computes the energy supply mix (in terms of capacity and energy generation) which meets the energy service demands every year and in every time step of the case under study, minimising the total discounted costs. It can cover all or individual energy sectors, including heat, electricity and transport and has a user-defined spatial and temporal domain and scale. The energy demands can be met through a range of technologies which have certain techno-economic characteristics and draw on a set of resources, defined by certain potentials and costs. On top of this, policy scenarios may impose certain technical constraints, economic realities or environmental targets. As in most long-term optimisation modelling tools, OSeMOSYS in its standard configuration assumes a unique decision-maker, perfect foresight and competitive markets.

In mathematical terms, it is a deterministic, linear optimisation, long-term modelling framework. Mixed-integer linear programming may be applied for certain functions, like the optimisation of discrete power plant capacity expansions. One of its main characteristics is the wide and flexible definition of technology and energy vector. A technology represents any asset operating energy conversion processes, from resource extraction and processing to electricity supply, transmission and distribution and end-use appliances. It could therefore refer to, for example, an oil refinery, a hydropower plant or a heating system. Each technology is characterised by a transfer function defined by numerous economic, technical and environmental parameters (e.g. investment and operating costs, efficiency, availability, emission factors, capacity factor, minimum load, etc.).

The original OSeMOSYS code[1] is written in GNU MathProg, a high-level mathematical programming language, yet straightforward enough to be understandable by all kinds of users, expert or not in linear programming. In its full version, the code consists of 700 text lines, highly resembling algebraic expressions. Further parallel versions of the code have been written in GAMS and Python, for better connection to the respective families of users and coders. The open-source solver GLPK may be used for translating the models in matrices, finding the optimal solution and printing the numerical outputs.

[1] https://github.com/OSeMOSYS/OSeMOSYS

2. Context and need

Greece has limited capacity for interconnections and heavy reliance on imported fuels for electricity production; however, it possesses a significant potential for renewable energy sources (RES) and presents a case of a significant paradigm shift in planning for its future energy system's development (Kleanthis et al., 2022). In parallel with the launch of the European Green Deal by the European Commission (EC) in 2019, which presented the vision of climate neutrality in the European Union by 2050 (European Commission, 2019), the Greek government decided to terminate the domestic lignite mining and lignite-fired electricity generation by 2028, and set ambitious climate and policy goals, including the achievement of decarbonisation in the power sector by expanding RES capacity. Consequently, the National Energy and Climate Plan (NECP) was published in 2019 to specify energy and climate goals, policy priorities, and targets, as well as the potential impacts of phasing out lignite and using natural gas as a transition fuel in the future transition of the Greek energy system (Hellenic Ministry of Environment and Energy, 2019).

After the energy crisis in 2022, the Greek government has been reconsidering the role of natural gas in the national energy planning. On one hand, the country takes steps to lower its dependence on Russian gas so as to increase energy security, while, on the other hand, schedules significant expenditures to expand gas infrastructures concurrently, which could, again, increase the domestic demand for gas and create a lock-in effect. In this regard, there is ambiguity in terms of how carbon neutrality can be achieved, and this issue needs to be further examined in view of the climate commitments instructed by the EC. Therefore, there is a need for addressing critical issues and challenges related to decarbonisation pathways in the Greek power sector, as for example, the future role of natural gas and hydrogen, the integration of variable renewable energy (VRE) with energy storage, the potential use of carbon capture and storage (CCS), etc.

3. Aim of the model and target audience

The Greek capacity expansion model (CEM), **O**pen **S**ource **e**nergy **MO**delling **SYS**tem for **GR**eece (OSeMOSYS-GR), assesses the capacity requirements of a wide range of electricity generation and storage technologies to identify the most cost-effective and sustainable electricity mix in the Greek power sector. Additionally, it evaluates the environmental impact of different electricity production methods, helping to determine optimal strategies for reducing emissions. The target audience for the OSeMOSYS-GR model embeds government organisations and agencies involved in energy planning and policymaking. This includes the Ministry of the Environment and Energy of Greece, which can use the model for strategic planning and policy development in the power sector and assess the environmental impacts of different energy policies and develop appropriate regulations. Additionally, the model can be useful for researchers, international organisations, and non-governmental organisations focused on energy sustainability, climate mitigation, and adaptation strategies in Greece. By providing a detailed analysis of electricity production and environmental impacts, the OSeMOSYS model supports evidence-based decision-making to ensure a sustainable energy future for Greece.

4. Model scope and structure

Table 1 presents details about the scope and structure of the OSeMOSYS-GR model.

Table 1. OSeMOSYS-GR scope and structure.

OSeMOSYS-GR	Scope	Detail
Rationale	Optimisation	
Mathematical formulation	Linear programming	
Sectoral coverage	Power sector. Electricity generation and storage.	Assessment of the installed capacities of the electricity system and the structure of electricity production in Greece.
Type of analysis	Deterministic; Dynamic; Cost-optimisation; Long-term planning	Optimisation of installed capacities and volumes of production of generating capacities depending on changes in the volume of electricity demand. All the scenarios represent cost-optimal solutions since the objective function consist of the minimisation of the system's Net Present Value. Additionally, all of them are subjected to specific constrains (such as GHG emissions, resource availability etc.) with the final aim of reaching specific targets set by the government while respecting environmental goals. The long-term planning is set on a time period of 30-years. The model outputs year-by-year capacity expansion, with intra-annual operation, and annual change in the amount of electricity produced at various generating facilities.
Modelling tool used	OSeMOSYS	Link to OSeMOSYS documentation: https://osemosys.readthedocs.io/en/latest/manual/Introduction.html
Open-source code	Yes	https://github.com/OSeMOSYS/OSeMOSYS
Open-access data	Yes	License and link to repository
Documentation	Yes	License and link to this factsheet
Previous use	Yes	Kleanthis, N., Stavrakas, V., Flamos, A. Bidirectional soft-linking of a Capacity Expansion Model with a Production Cost Model to evaluate the feasibility of transition pathways towards carbon neutrality in the power sector, Applied Energy, Volume 378, Part B, 2025, 124843, https://doi.org/10.1016/j.apenergy.2024.124843.
Institution that created the model	TEESlab UPRC	The model is developed as part of the TEESlab Modelling (TEEM) suite. More details can be found in the TEESlab UPRC website: https://teeslab.unipi.gr/
Institution that maintains the model	TEESlab UPRC	The model is maintained as part of the TEEM suite. More details can be found in the TEESlab UPRC website: https://teeslab.unipi.gr/
Geographical coverage	Greece	
Geographical resolution	National	
Time domain	2021 - 2050	

Time resolution	Intra-annual time steps	Each modelled year is split in 48 time slices, i.e., four different day-types (night, morning, noon, afternoon) for 12 different days, one for each month of the year. The four (4) day-types are considered to have an equal length, i.e., six (6) hours per day.
Technology richness	Bottom-up	In the OSeMOSYS-GR reference energy system (**Fig. 1**), the electricity supply system is represented by importing and extraction technologies, fossil-fired power plants using lignite, natural gas, and oil (planned investments in fossil-fired power plants are modelled exogenously), renewable energy technologies (i.e., hydro, wind onshore and offshore, solar photovoltaics, biomass, geothermal), battery energy storage systems and pumped hydro storage, hydrogen production and consumption (namely electrolysers and fuel cells), transmission, and distribution systems, as well as interconnections with neighbouring countries. The total number of technologies is 68. Each technology receives as an input and has as an output a commodity (such as natural gas, electricity, hydrogen, etc.). The total number of commodities is 15.
Solver used	CBC	Free and open source: https://github.com/coin-or/Cbc
Solution	~20 minutes	• RAM: 8 GB • Processor: Intel(R) Core(TM) i7-1065G7 CPU @ 1.30GHz 1.50 GHz • System type: 64-bit operating system, x64-based processor

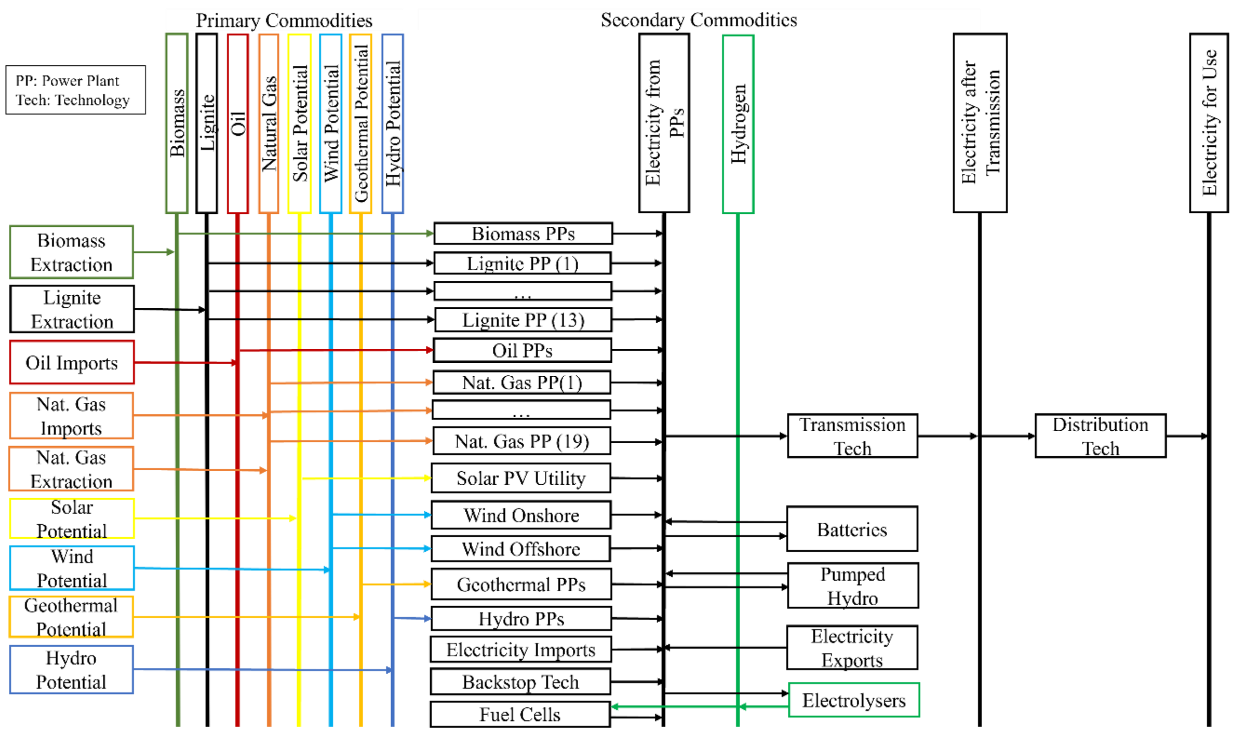

Fig. 1. Reference energy system in OSEMOSYS-GR as it currently stands.

5. Key data sources

Table 2 presents the references of the key data sources used to develop OSeMOSYS-GR.

Table 2. OSeMOSYS-GR key data sources.

Dataset	Source	Open access
AccumulatedAnnual Demand	Hellenic Ministry of Environment and Energy. National Energy and Climate Plan- Preliminary Draft Revised Version. 2023.[2]	Yes
AnnualEmissionLimit	Hellenic Ministry of Environment and Energy. National Energy and Climate Plan- Preliminary Draft Revised Version. 2023.[2]	Yes
AvailabilityFactor	Consultation with stakeholders from Public Power Corporation. More details in the following publication: Kontochristopoulos, Y., Michas, S., Kleanthis, N., Flamos A. Investigating the market effects of increased RES penetration with BSAM: A wholesale electricity market simulator. Energy Reports.7:4905–29. 2021. https://doi.org/10.1016/j.egyr.2021.07.052.	No
CapacityFactor	Renewables.ninja: https://www.renewables.ninja/ Pfenninger, S. and Staffell, I. Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data. Energy 114, pp. 1251-1265. 2016. doi: 10.1016/j.energy.2016.08.060	Yes
CapitalCost	Hellenic Ministry of Environment and Energy. (2019). Long Term Strategy for 2050 (In Greek).[3] IEA. World Energy Outlook 2022. 2022. https://www.iea.org/reports/world-energy-outlook-2022.	Yes
DiscountRate	Hellenic Ministry of Environment and Energy. (2019). Long Term Strategy for 2050 (In Greek).[3]	Yes

[2]https://commission.europa.eu/system/files/2023-11/GREECE%20-%20DRAFT%20UPDATED%20NECP%202021-2030%20EN.pdf

[3] https://ec.europa.eu/clima/sites/lts/lts_gr_el.pdf

EmissionActivityRatio	Emission Factor Database (EFDB). Intergovernmental Panel on Climate Change (IPCC). https://www.ipcc-nggip.iges.or.jp/EFDB/main.php	Yes
EmissionsPenalty	Hellenic Ministry of Environment and Energy. National Energy and Climate Plan-Preliminary Draft Revised Version. 2023.[2]	Yes
FixedCost	Hellenic Ministry of Environment and Energy. (2019). Long Term Strategy for 2050 (In Greek).[3] IEA. World Energy Outlook 2022. 2022. https://www.iea.org/reports/world-energy-outlook-2022.	Yes
InputActivityRatio	Hellenic Ministry of Environment and Energy. (2019). Long Term Strategy for 2050 (In Greek).[3] IEA. World Energy Outlook 2022. 2022. https://www.iea.org/reports/world-energy-outlook-2022.	Yes
OperationalLife	Hellenic Ministry of Environment and Energy. (2019). Long Term Strategy for 2050 (In Greek).[3] IEA. World Energy Outlook 2022. 2022. https://www.iea.org/reports/world-energy-outlook-2022.	Yes
REMinProduction Target	Hellenic Ministry of Environment and Energy. National Energy and Climate Plan-Preliminary Draft Revised Version. 2023.[2]	Yes
ResidualCapacity	ENTSO-e Transparency Platform[4] Hellenic IPTO. Ten-year development plan of the transmission system 2024-2033. 2023.[5]	Yes
SpecifiedAnnual Demand	Hellenic Ministry of Environment and Energy. National Energy and Climate Plan-Preliminary Draft Revised Version. 2023.[2]	Yes
VariableCost	Regulatory Authority of Energy. Average import prices of natural gas in Greece. 2023.[6]	Yes

[4] https://transparency.entsoe.eu/generation/r2/installedGenerationCapacityAggregation/show
[5] https://www.admie.gr/en/anakoinoseis/announcement/preliminary-draft-ten-year-development-plan-hets-period-2024-2033
[6] https://www.rae.gr/psysiko-aerio/agora/mesostathmiki-timi-eisagogis/

IEA. World Energy Outlook 2022. 2022. https://www.iea.org/reports/world-energy-outlook-2022.

European Commission D-G for CAD-G for ED-G for M and T, De Vita, A., Capros, P., Paroussos, L., Fragkiadakis, K., Karkatsoulis, P., et al. EU reference scenario 2020: energy, transport and GHG emissions : trends to 2050. 2021. https://data.europa.eu/doi/10.2833/35750

6. How to run the model

More details about running the model can be found in the online documentation of OSeMOSYS[7].

7. Indicative results

A study has been conducted to assess the capacity requirements in the Greek power sector to achieve carbon neutrality by 2040 (Kleanthis et al., 2025).

It examined three scenarios:

- "*Neutrality 1*": Focuses on the capacity expansion of VRE and energy storage. It aims at phasing out natural gas phaseout happens before 2040.
- "*Neutrality 2*": Assumes that natural gas plants are retrofitted with CCS in 2035. It expands VRE and energy storage capacity, but at a lower rate compared to "Neutrality 1".
- "*Neutrality 3*": Assumes that natural gas plants switch from gas to hydrogen in 2035. It also emphasises VRE and storage capacity additions; however, fuel cell investments happen at a lower rate compared to the previous scenarios, due to the use of hydrogen in power plants.

The indicative results show that the high adoption rate of VRE and storage technologies in the "*Neutrality 1*" scenario leads to the phaseout of natural gas by 2037 (**Fig. 2**). By 2030, ~27 GW of VRE technologies are installed in the three scenarios under study, and VRE capacity increases to 49-54 GW by 2040. By 2050, VRE capacity exceeds the NECP target of 69.5 GW in the "Neutrality 1" and the "Neutrality 3" scenarios, reaching 70.8 and 71.1 GW, while the target is not achieved in the "Neutrality 2" scenario (60.4 GW). In parallel, the battery and pumped hydro storage as well as electrolyser capacities grow significantly to match the high VRE capacity expansion, reaching 22.4-25.1 GW and 18-18.9 GW by 2050, respectively, among the scenarios. The lower installed VRE and energy storage capacity in the "Neutrality 2" scenario is offset by the higher baseload capacity.

[7] https://osemosys.readthedocs.io/en/latest/index.html

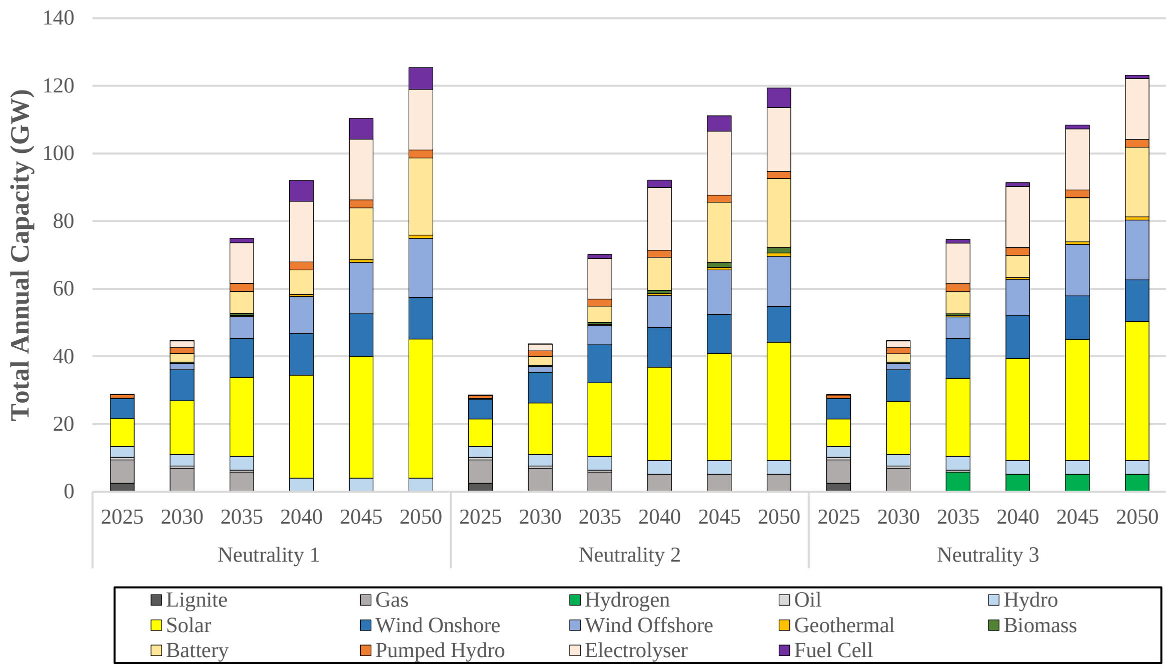

Fig. 2. Total annual capacity mix by 2050 in the Greek power sector for the three scenarios.

8. Limitations

Energy models are considered crucial tools for understanding and planning complex systems. However, it is acknowledged that they have limitations due to simplified assumptions, data quality and availability, uncertainty, and geographical and temporal resolution. For instance, OSeMOSYS-GR does not account for possible variations in resource availability and specific energy demand across multiple regions of Greece. Regarding time resolution, OSeMOSYS-GR, which considers 48 time slices) may not capture the variability in electricity supply and demand over shorter timescales, such as hourly variations in renewable energy supply, which can be crucial for understanding grid stability or integrating VRE. On the contrary, Production Cost Models (PCMs), such as the IRENA FlexTool (Taibi et al., 2018), are capable of precisely depicting the behaviour of the power system and its components. PCMs can analyse power system operations using a time step of one hour or less, which effectively handles the issue of variability in electricity generation from VRE. Therefore, it is suggested to soft-link the CEM OSeMOSYS-GR with a PCM to assess the feasibility of the derived long-term transition pathways.

9. Model license

10. Model citation

Please cite as:

Kleanthis, N., Stavrakas, V., Flamos, A. Bidirectional soft-linking of a Capacity Expansion Model with a Production Cost Model to evaluate the feasibility of transition pathways towards carbon neutrality in the power sector, Applied Energy, Volume 378, Part B, 2025, 124843, https://doi.org/10.1016/j.apenergy.2024.124843.

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