An Open Modelling Toolbox for consistent Energy and Power System Scenario Analyses

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***Abstract*— This article describes an open modelling toolbox for consistent energy and power system scenario analyses. The building blocks making this toolbox include i) open-source models of different types, ii) linkages between the relevant models, iii) a database with input datasets for these models, iv) a tool to visualize the results from the case studies, and v) instructions on how to install and use the models. Each of the models is briefly described. The data exchanged among models are structured according to a common format and nomenclature; and scripts are used to transfer data from one model to another. Finally, the article describes an example of using the toolbox, including an expansion analysis of the European energy system, application of the linkage functionalities to feed a power system model with results from the expansion analyses and a detailed analysis of the power system.**

***Index Terms* - energy, optimization models, power system modelling, system analysis and design**

I. Introduction

A. Background

Energy and power system models capture complex system interactions and are widely used to inform policy and planning decisions. A growing number of different types of open-source energy and power system models are available for use and further development, yet only a small share is offered together with complete data sets for a large region, like Europe. Even fewer models are soft linked with others. Model linkages allow selected inputs and outputs from one model to be transferred as inputs to another model in an efficient, and automatic manner, while ensuring consistency among multiple model runs. A typical example involves running an energy system model for scenario studies for a given region, transferring its inputs and results such as investments in generation and transmission capacity, and electricity demand, to a power system model and using the latter for more detailed analyses of the power system considering e.g. a higher temporal or spatial resolution, or uncertainties. The power system analyses could, e.g., produce results on power balances and prices for the given system. These linkages also pave the way for conducting sensitivity analyses whereby one or a few parameters are changed at a time, and the resulting impacts on key variables are assessed across several models.

Despite these upsides, open-source modelling remains fragmented, and multi-model workflows often require manual harmonization. To address this gap, we present an open toolbox combining multiple models, standardized data and linkages, and training materials to enable consistent and reproducible scenario analysis. The paper is structured as follows: the remainder of this section reviews the current status of open energy system modelling toolboxes. Section II introduces the OpenMod4Africa (OM4A) toolbox, and Section III provides an example application. Section IV discusses the results and concludes the paper.

B. Other open energy system modelling toolboxes

In this paper we define "An Open Modelling Toolbox for consistent Energy and Power System Scenario Analyses" as a collection of open-source energy and power system models that can exchange information with one another through a defined and standardized format. The input datasets required by these models are openly accessible. In addition to the models themselves, the toolbox may also include supporting components such as training materials, visualization tools, and documentation. Alternative terms such as "platform" or "hub" could be used instead of "toolbox",

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Many energy system models are openly available, i.e. models for long-term planning of the energy system including all energy carriers and consumption sectors. A grassroot initiative of modelers from various universities and research institutes across the world started years ago "the Open Energy Modelling initiative". On their web page, [1], there is a long list of different open energy system models, link to the models, learning material and to some degree also data for use by the models. The page also includes non-model specific datasets that could be adapted and used by various models. The page does not mention anything about linking models nor about a data format for information exchange among energy and power system models. Hence, the initiative is not a "toolbox" according to the definition above.

A web page called "Open Energy Platform" is accessible at [2]. It includes four main elements: Database, Scenario bundles, Ontology, and Academy. The Platform allows for download of available data, upload of your own data, comparison of scenarios, provides an ontology that refers to a collection of domain specific terminology and their relationships and offers courses as well as dedicated tutorials covering important topics. It is not a Platform according to the definition used in this paper as it includes nothing about linking models.

The Open Energy Modelling Framework (oemof) is a Python toolbox for energy system modelling and optimization [3]. The oemof project aims to be a loose organisational frame for tools in the wide field of (energy) system modelling. Every project is managed by their own developer team, but some developers and design rules are shared to make it easier to understand each other's tools. The oemof does not meet the definition given in this article.

The PyPSA framework is an abbreviation for Python for Power System Analysis. Since the original focus on the power system, the PyPSA framework has been extended to include coupling to transport, heating and industry sectors. However, its main strengths are related to the power system like electricity networks, hourly dispatch, generator unit commitment, and the complex interplay of renewable variability and storage across geographical regions. If other features such as sector coupling are enabled, detail in other key areas is often reduced in conjunction. According to [4] it is therefore less suited for initial long-term, holistic investment planning across an entire energy system. Still, PyPSA fulfills the requirements defined for an open modelling toolbox for consistent energy and power system scenario analyses.

In this paper, we will describe an alternative toolbox to PyPSA and give a qualitative discussion of the differences between the models.

II. THE OPEN MODELLING TOOL BOX

A. *The OpenMod4Africa toolbox*

The OpenMod4Africa toolbox has been developed with a focus on the African context. However, it builds upon a modelling toolbox originally developed for Europe. Most of the included models are modular in structure and therefore transferable, allowing analyses to be conducted in different regions provided that appropriate and context-specific input datasets are used. The building blocks making this toolbox include i) open-source models of different types, ii) linkages between the relevant models, iii) a database (the Scenario Explorer) within which data available include input datasets for these models and preliminary results of the case studies conducted in OM4A to test the modelling ToolBox, iv) a tool to visualize the results from the case studies, and v) instructions, including videos, on how to install and use the models. The Scenario explorer will soon be populated with datasets related to the openMod4Africa case studies. The data exchanged among models, and the models' outputs, are structured according to a common format and nomenclature; and scripts are used to transfer data from one model to another. Both these models and these scripts are provided with licenses for their free use and further development.

The OM4A ToolBox, including all its components, can be accessed via [5]. This Toolbox is aimed at advancing energy system modelling across the African continent, empowering its users to analyse and plan effective, sustainable energy transitions. The energy system modelling efforts conducted through the Toolbox consider critical factors such as rapid population growth, expanding economic activities, infrastructure development, and the urgent need to address climate change. It is specifically designed to support policymakers, researchers, and practitioners in developing robust, data-driven energy strategies that are aligned with Africa's unique development priorities and sustainability goals. In doing so, the platform serves not only as a technical resource hub, but also as a catalyst for building local capacity and fostering regional cooperation in the energy modelling community across Africa.

The Toolbox general structure is explained next. The main page found when accessing the Toolbox website enables the users to navigate between multiple subpages, largely corresponding to the several building blocks described above. Each of these is briefly described in the next subsections. Figure 1 shows the main elements of the Toolbox.

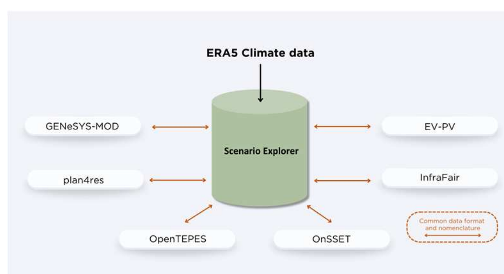

Figure 1. OM4A Toolbox

1) *Models*

Next, we provide an overview of all the models available in the OM4A ToolBox. From the page corresponding to models, users can access individual pages for each model, which offer more detailed information as well as links to the respective GitHub repositories where the models can be accessed to be installed and used.

The **GENeSYS-MOD** model is tailored to analyze long-term low-carbon energy transition pathways considering all energy sectors: electricity, buildings, industry, and transport. Its main strength lies in its ability to simultaneously optimize the capacity expansion, energy generation, and dispatch of the system for all the main energy sectors, which leads to an endogenous optimization of the entire energy system, considering interactions between all energy sectors, as well as storage, grid, and other flexibility requirements. The GitHub repository for GENeSYS-MOD is available at [6], and the model is described in [7] .

The **openTEPES** model is a decision support system for defining the integrated generation, storage, and (electricity, hydrogen, and heat) network dynamic expansion plan of a large-scale electric system at a tactical level. The user pre-defines the expansion candidates, so that the model determines the optimal decisions among those specified by the user as possible. This model considers any power-related technology focused on generation, transmission, and storage, with a high level of detail, including the main transmission ones and the hydro topology. The GitHub repository for openTEPES is available at [8], and the model is described in [9].

Plan4res is a power system model, which includes capacity expansion (adaptation of the generation and storage mix as well as of the existing interconnections of a given year), optimization of the strategies for managing seasonal storage, and simulation of the system operation. It includes all power generation technologies, electricity storage technologies, and a (usually aggregated) representation of the interconnections between regions, while the granularity of regions can be adapted to the modelling needs. The GitHub repository for plan4res is available at [10]. The model is described in [11].

The **InfraFair** model determines the network utilisation by individual consumers and generators, as well as countries as a whole and, based on this, the allocation of the cost of networks to individual network users and countries. The latter is relevant information for tariff design. Multiple representative snapshots of the annual network usage should be considered for this. InfraFair can be used to allocate the use of regional and national power transmission infrastructure, as well as networks for other energy carriers. The GitHub repository for InfraFair is available at [12]. The InfraFair model is described in [13].

The **OnSSET** tool is a GIS-based tool that enhances electrification planning for the accomplishment of energy access goals in currently unserved areas. OnSSET determines, in the medium-to-long-term, the least-expensive supply option to achieve universal electrification in each site considering population settlements and their geographical, socioeconomic, and demographic data. OnSSET allows the users to specify the spatial and temporal resolution of the analysis, GIS input data, technologies and costs. The GitHub repository for OnSSET is available at [14]. The OnSSET model is described in [15].

EV-PV determines the strategic planning for electric mobility within a region, considering the private passenger mobility demand, the electric vehicle (EV) charging needs, the potential of photovoltaic (PV) energy to meet these needs, and the required charging infrastructure. For PV generation, it supports a range of installation archetypes, such as rooftop and free-standing systems, enabling flexible assessments. The GitHub repository for EV-PV is available at [16]. The EV-PV model is described in [17].

2) Scripts for the transfer of data among models and with the toolbox central database

As aforementioned, python scripts have been developed to transfer data among models and between these and the central database of the Toolbox, the Scenario Explorer. Some of these scripts are aimed at changing the format of data to be input into these models from the common data format (IAMC) for the Toolbox to that of the input data files for each model. Other scripts are aimed at changing the format of data within input and output data files for each model to the common data format. Additionally, there are some scripts to be used to automatically download some relevant data to be used by models from the Scenario Explorer, as well as other scripts aimed at processing data by aggregating or disaggregating them, i.e. changing the granularity level of these data. Whenever needed, the scripts to be used to transfer data between each model and the central data repository, the Scenario Explorer, are available within the Github site for this model, with the exception of the scripts for the model OnSSET, which are available at [18].

3) Data

The Data page contains a link to main (public) datasets of the OM4A project, as well as information about the IAMC data format, the nomenclature of variables, and a ToolBox for processing data.

The **Scenario Explorer** is an online tool for sharing, comparing and analyzing scenario data whose public version is available at [19].

The **IAMC template** is a standardized variable template and nomenclature package making a consistent structure for variables, regions, and units used by all the models in the Toolbox. The variable template is a shared list of variables whose names are defined according to hierarchical conventions following international standards, designed for clarity and compatibility across models. Regions also follow a structured classification of geographic areas, from global and regional aggregates to individual countries and sub-national regions (e.g., NUTS levels). Guidelines for representing flows between regions are also provided, as well as the link to the GitHub repository where this nomenclature is maintained.

The **pyam package** is an open-source python library that enables users to work with IAMC–style data, generate plots, perform analysis and download data directly from IIASA Scenario Explorers [19].

4) Case Studies

The Case Studies page provides an overview of how the OM4A ToolBox is being used in real-world applications across Africa. On this page, users find detailed descriptions of the regional case studies conducted in West and East Africa—including the objectives, leading institutions, geographic focus, and key themes considered. This page outlines the scope of each study, such as mini-grids, electrification, and national and regional energy system analyses.

5) Training

The Training section provides links for users to access training materials for all the models. This GitHub organization contains individual repositories for each model, offering a wide range of resources to support users in effectively working with these models. Furthermore, videos are provided to further enable users to explore the main functionalities of each model (Installation, how to run the model etc.). These videos are hosted on a dedicated youtube channel maintained by the project's Permanent Network.

6) *Visualisation*

The Visualisation section offers an interactive way to explore the scenarios and case studies. At the centre of the page is a map-based tool that allows users to visually engage with geographic and model-based data. Users can browse available case studies and scenarios directly on the map. The page includes a button linking to the full version of the visualisation tool, allowing immersive experience in exploring data, model outputs, and energy system dynamics across multiple spatial scales.

Relevant visualisations have been integrated for all models within the ToolBox (e.g., pie charts for InfraFair cost allocation, graphs showing flows for models like openTEPES and plan4Res, and more). Some open-source geospatial data layers are also included to complement the model outputs. Users can also create an account to upload their own datasets, which can be kept private or shared with other users. The platform also includes "calculation modules" for data processing and interfacing with GIS-based models such as EV-PV.

III. AN EXAMPLE OF USE OF THE TOOLBOX

In this section, we demonstrate the use of the toolbox on an example in which we first proceed to an analysis of the European energy system using GENeSYS-MOD. We then use the linkage functionalities to feed the power system model plan4res with data and results from GENeSYS-MOD and proceed to a detailed analysis of the power system with plan4res. This example is based on a modelling exercise conducted within the Man0euvre CETP project [20].

A. *Step 1: Energy System study*

The model GENeSYS-MOD is run after creation of a dataset including the details on the set of available technologies and the demands for the different sectors which are considered, namely the buildings, transportation, and industry sectors. Each country in Europe is considered from 2018 to 2050. The results include the installed capacities per technology, and the primary, secondary, and final energies per sector and fuel. The results of GENeSYS-MOD are then converted to the IAMC format and can be easily analysed, filtered, visualised and uploaded to the scenario explorer. Figure 2 shows the results for the power system only: installed capacities, generation and demand, on the whole of Europe.

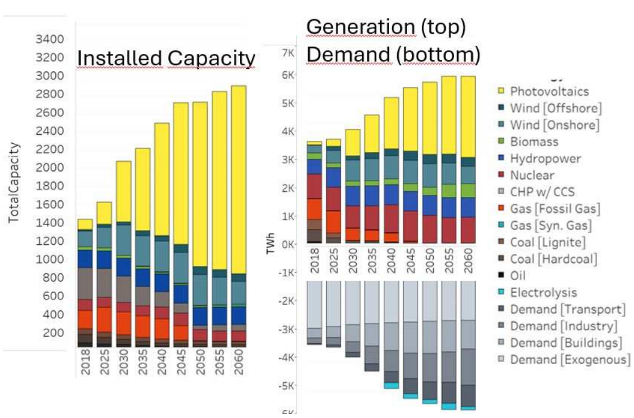

Figure 2. Development of the European power system

B. *Step 2: Power System in depth study*

In the second step, we conduct a detailed analysis focused on the power system, using the plan4res model. This model allows, including additional constraints on the operation of the different technologies, with a specific focus on the seasonal management of hydro power, accounting for system services, such as different kinds of reserves, but it also allows to include modelling of uncertainties on the power demand, the inflows to the hydro reservoirs, and the generation of solar and wind, which are all dependent of meteorological conditions.

A plan4res dataset including the electricity installed capacities and the electricity demand for a given year is created by using the linkage tools in the toolbox. The plan4res linkage uses the IAMC format data from GENeSYS-MOD to create a dataset with the native plan4res format. This dataset is complemented with timeseries describing the uncertainties, coming from the Copernicus Climate Service for Energy database CMIP6. In practice, we are using 105 timeseries representing different climatic years created using 5 different models, based on a given IPCC scenario [21]. Plan4res can then be run and compute the schedules of all generation and storage technologies, flows on the interconnections and marginal costs, with an hourly resolution. In this example, we show the results for the year 2030. Figure 3 shows the yearly average generation per technologies and Figure 4 shows an example of generation and demand schedule on 2 different climatic scenarios for one week in April in Spain.

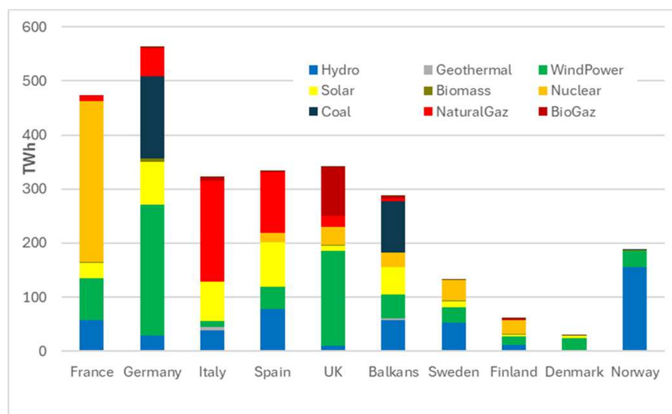

Figure 3. Examples of annual average generation per technology and country

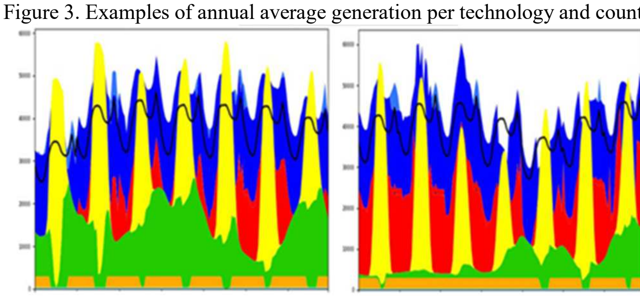

Figure 4. Generation and demand for two weeks in Spain (y-axis: MWh)

In this last figure, we can see the impact of the chosen scenario, with in particular far less wind on the right side, inducing the need for imports (the black curve: demand, Power production curves: yellow – PV, green- wind, blue – hydro, orange – nuclear, red - gas).

Finally, the results can be converted into IAMC format by using the dedicated linkage script, which allows to upload them to the OM4A scenario explorer and visualisation tool.

The openTEPES model can be soft-linked to GENeSYS-MOD in a similar way to plan4res. Installed capacities and electricity demand for a given year are outputs from the energy system expansion model and can be used as inputs to openTEPES when computing the power system operation considering a higher level of detail, or the expansion considering a higher level of spatial granularity. Analyses conducted with openTEPES can consider specific properties of the power system that are typically neglected, or represented in a largely simplified manner, in GENeSYS-MOD. Among others, these include the 2nd Kirchoff law or AC load-flow constraints, a much more detailed representation of the variability of system conditions across time and space (finer temporal and spatial granularity), and a more detailed representation of the operation of hydro generation.

Using the InfraFair model to determine the network utilisation by individual consumers and generators, or countries, can benefit from being a part of the Toolbox by being able to calculate the utilization for different future network configurations across the scenarios defined and explored with other models within the Toolbox and across time for the time horizons considered in the aforementioned analyses. Using GENeSYS-MOD, openTEPES or plan4res, the stakeholders can compute operation results for several scenarios and future years, e.g. for every fifth year and several possible future scenarios. Based on these operation results, InfraFair can calculate how the network utilization changes across scenarios as the power system evolves over time.

The OnSSET tool can be used to determine the least-expensive electricity supply options to achieve universal electrification in rural areas for different consistent scenarios. Then, considering the share of demand to be directly supplied from the central grid, system wide models like GENEeSYS-MOD, openTEPES, or plan4res can be used to determine the optimal expansion of the system. This combination of models will increase the usefulness and comprehensiveness of the results provided, by allowing users in system wide analyses to consider the fraction of demand in remote areas, to be electrified, that is to be supplied from the main grid.

Finally, the EV-PV model can be used to derive the electric vehicles development from the expansion of the energy system computed using GENeSYS-MOD and the power system development from plan4RES or openTEPES. The charging demand, fed into the EV–PV model, can be spatially disaggregated at the local level, enabling the derivation of detailed spatio-temporal charging profiles for different types of charging locations (e.g., residential, workplace, public). This allows for a refined assessment of charging behavior and load patterns and the quantification of associated charging infrastructure and PV integration. The power system should then be taken into account before deciding whether to charge vehicles from the grid or from stand-alone PV systems.

IV. DISCUSSION/CONCLUSION

This paper describes a modelling toolbox for conducting consistent energy and power system analysis of future energy systems. The toolbox integrates a set of interoperable, open-source models that enable coherent scenario development across multiple system layers. In addition to core system-wide models, the toolbox also includes specialized tools addressing specific planning and policy questions.

Most of the models are general in structure and can be applied to a wide range of regional contexts. However, certain tools are particularly relevant for specific regions. For example, the OnSSET model is especially valuable for Africa, where approximately 85% of the global population without access to electricity resides [22]. Furthermore, e-mobility planning tools—such as EV–PV integration models applied in the Addis Ababa context [17] —provide important insights for rapidly urbanizing cities seeking to align transport electrification with renewable energy deployment.

The models in the toolbox can be used for policy and investment guidance related to development of energy and power systems or for more specific questions such as the adequacy of solar irradiation for charging electric vehicles in a region. The linkage of models will provide consistent insights related to e.g., the development of energy versus power systems. The openness of the toolbox can lead to efficiency, as it avoids doing similar developments several times. The open approach also enables discussions and assessments on equal terms and can develop trust which is particularly important for public debate.

Even though this toolbox is relevant to any region, it is developed for Africa. Africa countries have relied on purchasing expensive expertise from other parts of the world to conduct analyses for Africa. These analyses have been conducted using commercial and closed models. Local capacity building has been prevented.

The toolbox may be used for different geographical scales from large regions like Africa down to very small regions with a few buildings. Not all the models are suitable for the smallest regions. Most analyses can be performed on a PC. The use of free optimisation solvers is possible for smaller problems, but commercial solvers are recommended for complex cases.

This open toolbox supports local capacity building based on its openness and available training material. The suit of models supports African experts in providing knowledge on how African regions can develop the most cost-efficient and secure energy supply to a larger share of the population.

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REFERENCES

[1] "openmod - open energy modelling initiative," [Online]. Available: https://openmod-initiative.org/.

[2] "Open Energy Platform," [Online]. Available: https://openenergyplatform.org.

[3] "Open Energy Modelling Framework," [Online]. Available: https://github.com/oemof/oemof.

[4] "Open source interoperability: integrating OSeMOSYS and PyPSA for power system analysis," 22 October 2025. [Online]. Available: https://www.transitionzero.org/technology/open-source-interoperability-integrating-osemosys-and-pypsa-for-power-system-analysis.

[5] "Africa Energy Models - Modelling Africa's energy system," [Online]. Available: https://africaenergymodels.net/.

[6] "The Global Energy System Model (GENeSYS-MOD)," [Online]. Available: https://github.com/GENeSYS-MOD.

[7] K. Löffler, K. Hainsch, T. Burandt, P. Oei, C. Kemfert, C. von Hirschhausen, "Designing a Model for the Global Energy System - GENeSYS-MOD: An Application of the Open-Source Energy Modeling System (OSeMOSYS)," *Energies,* p. https://doi.org/10.3390/en10101468, 2017.

[8] "IIT- EnergySystemModels/openTEPES," [Online]. Available: https://github.com/IIT-EnergySystemModels/openTEPES.

[9] A. Ramos, E. Quispe, S. Lumbreras, "OpenTEPES: Open-source Transmission and Generation Expansion Planning," *SoftwareX 18,* no. 10.1016/j.softx.2022.101070, 2022 June.

[10] "plan4res," [Online]. Available: https://github.com/plan4res.

[11] D. Most, S. Giannelos, I. Yueksel-Erguen, D. Beulertz, S. Charousset-Brignol U. Haus, et.al., «A novel modular optimization framework formodelling investment and operation of energy systems at european level,» *ZIB Report, 20(08), URN: urn:nbn:de:0297-zib-78079, ISSN: 1438-0064, 2020..*

[12] IIT-EnergySystemModelsModels/InfraFair, [Online]. Available: https://github.com/IIT-EnergySystemModels/InfraFair.

[13] M.A.E. Elabbas, L. Olmos, I.JL. Pérez-Arriaga, «InfraFair: Infrastructure cost allocation,» *SoftwareX. Vol. 29, pp. 102069-1 - 102069-9, https://doi.org/10.1016/j.softx.2025.102069, February 2025.*

[14] «The Open Source Spatial Electrification Tool,» [Online]. Available: https://github.com/OnSSET.

[15] D. Mentis, M. Howells, H. Rogner, A. Korkovelos, C. Arderne, E. Zepeda, er. al., «Lighting the World: the first application of an open source, spatial electrification tool (OnSSET) on Sub-Saharan Africa,» *Environmental Research Letters, 12(8), 085003, 2017.*

[16] «EV PV - simulator,» [Online]. Available: https://github.com/evpv-simulator.

[17] J. Dumoulin, D Habtu Gebremeskel, K. Gashaw, I. Graabak, N Jeannin, A Pena-Bello, et.al., «A modeling framework to support the electrification of private transport in African cities: A case study of Addis Ababa.,» *African Transportation Research, 100064. https://doi.org/10.1016/j.aftran.2025.100064, 2025.*

[18] «OnSSET - Open Source Spatial Electrification Tool,» [Online]. Available: https://africaenergymodels.net/models/onsset.

[19] «Africa Energy Models - Data treatment,» [Online]. Available: https://africaenergymodels.net/data/

[20] «Manoeuvre,» [Online]. Available: https://man0euvre.eu/.

[21] V.Masson-Delmotte, P. Zhai, A. Pirani, S.L. Connors, C. Péan, et.al. "Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change"IPCC, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. Doi:10.1017/9781009157896.

[22] International Energy Agency, « Tracking SDG 7: The Energy Progress Report 2025,» World Bank, Washington, DC., 2025.