

# clicSAND for OSeMOSYS: a user-friendly interface using open-source optimisation software for energy system modelling analysis

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## Research Article

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## Abstract

Energy models are crucial for helping governments and policymakers plan long-term investments in the energy transition context. One of the most established open-source optimisation models is OSeMOSYS—the Open-Source Energy Modelling System. This paper presents a new interface—clicSAND—for OSeMOSYS, which shortens the learning curve and supports beginner energy modellers to perform long-term investment analyses efficiently. The freely available and open-source clicSAND software consists of a user-friendly Excel interface for entering data, powerful solvers, and a dashboard for visualising results. The results, which extend to 2070, can inform policy decisions and mobilise financial resources for sustainable development measures—for example, ensuring affordable and secure energy supply and mitigating the effects of climate change. This paper describes clicSAND's main benefits, architecture, and functionalities. Furthermore, a South-African case study carried out by participants of the latest international capacity building event—the EMP-A (Energy Modelling Platform for Africa) 2021—shows the results achieved by inexperienced users following a three-week training course. Finally, current applications and future extensions of the software are also presented.

## Metadata

Nr	Code metadata description	<i>Please fill in this column</i>
C1	Current code version	<i>v.1.1.</i>
C2	Permanent link to code/repository used for this code version	<a href="https://github.com/ClimateCompatibleGrowth/clicSAND/tree/v1.1">https://github.com/ClimateCompatibleGrowth/clicSAND/tree/v1.1</a>
C3	Permanent link to reproducible capsule	<i>Not Available</i>
C4	Legal code license	CC0 1.0.
C5	Code versioning system used	None
C6	Software code languages, tools and services used	<i>C#</i>
C7	Compilation requirements, operating environments, and dependencies	<i>.NET Runtime</i>
C8	If available, link to developer documentation/manual	<a href="https://zenodo.org/record/4668816#.Yd2IHf7MJPY">https://zenodo.org/record/4668816#.Yd2IHf7MJPY</a>
C9	Support email for questions	C.Cannone@lboro.ac.uk

## 1. Motivation And Significance

### 1.1 Scientific background and motivation for developing the software

The climate change crisis requires bold and courageous action by both individuals and governments. One of these actions is the so-called 'energy transition', which implies moving away from a carbon-based economy towards less polluting options such as renewable energy sources. This shift requires multi-billion dollar investments and long-term scenario planning to 2050, 2070, and beyond. To achieve this, governments, academics, international organisations, and private sector consultancies increasingly rely on energy models for long-term investment planning. Such models provide valuable insights for efficient and reliable energy production in line with climate change mitigation action. One of the most used is the Open-Source Energy Modelling System (OSeMOSYS). Initially developed at the Royal Institute of Technology (KTH) [1] in collaboration with various institutions and organisations, OSeMOSYS is a long-term bottom-up optimisation model for energy system analysis leading to better investment planning [2], as demonstrated in [3] [4] [5].

In terms of tool development, special attention has been paid to the tool's user experience and usability, which enable skills to be developed faster and accelerate the uptake of models towards the formulation of sustainable development policies. Initially, users had to interact directly with the code and the input data file via text editor software and the command line, which was time-consuming and difficult for non-advanced users. As a result, a stand-alone open-source interface called MoManI (Model Management Infrastructure) was developed [6]. However, this interface had significant limitations in terms of data management [7]. To address this issue, users have tried to replicate the same functionality that MoManI offers with an Excel workbook. However, these efforts were scattered throughout the OSeMOSYS community, resulting in duplication of effort and scattering of resources.

Cannone [7] addressed this problem by developing an Excel-based interface for OSeMOSYS called SAND (Simple and Nearly Done). Although the Excel interface improved the collection and input of data, one significant limitation was that the user still had to interact with the command line via simple lines of code to run the models. Another limitation was the long computational time, which varied between 30 minutes to a few hours, depending on the computer's RAM (Random-access memory) size and the model's complexity. Therefore, building from the Excel SAND interface, clicSAND is a user-friendly interface for OSeMOSYS, which was developed to overcome these limitations, adding more powerful solvers, one-click installation, and a user-interface application. clicSAND provides the OSeMOSYS community with an easy-to-use interface for energy modelling analysis and has been widely used in different spheres since its creation (see Section 4.1). clicSAND software helps model alternative long-term pathways of a selected region, identifying the optimal configuration of the energy mix, including allocation of energy resources and the associated financial investment.

The remainder of the paper is as follows. Describing how clicSAND works and is utilised, Section 2 presents the software architecture and main functionalities. Section 3 provides an overview of an illustrative example of the use of clicSAND. Section 4 concludes by presenting current and past software applications, extensions, and future work.

## 2. Software Description

### 2.1 Materials and Methods

A basic overview of the clicSAND software and its main functionalities are shown in Figure 1, with the main advantages and limitations appearing in Figure 2. It uses the SAND Excel interface as the only data entry point for the user. One of the main advantages from a usability perspective is that the user does not interact with the command line at any point during the modelling process. The software works completely offline, which is particularly promising for regions with low bandwidth connections. A one-click installation package with all the necessary components of the software, including the solvers, is available for download [8], and a step-by-step online course hosted on the Open Learn Create (OLC) Platform is freely available as a public good [9]. The course combines theoretical lessons with practical exercises, teaching users the theory behind energy modelling for investment planning and the steps required to build an energy model from scratch using the clicSAND software for OSeMOSYS.

One of the main limitations of the software is the need for at least 8 GB RAM for smooth operation, and a Windows computer with Microsoft Access installed. Another weakness is detecting errors if the model fails during the run. The software platform shown in Figure 1 does not indicate the error, only that the model is not working. It should be noted that this problem also occurs when running OSeMOSYS models with other interfaces.

The clicSAND software is fully compatible with the existing OSeMOSYS architecture—the constraints, variables, and parameters are all represented. Two powerful solvers to find a model's optimal solution, GLPK (GNU Linear Programming Kit) [10] and CBC (COIN-OR branch and cut) [11], are part of the open-source and freely available clicSAND software. Moreover, the software's results are fully compatible with other tools such as the CLEWS (Climate, Land (Food), Energy and Water systems approach) [12], MUSE (ModUlar energy system Simulation Environment) [13], and other OSeMOSYS

platforms, including the OSeMOSYS Cloud Platform [14] (Online solvers available through a cloud service), as explained in Section 4.2 of this paper.

## 2.2 Software architecture

The clicSAND software and its components are licensed under a CC0 1.0 license (open-source and freely available), allowing the public to edit, copy, develop, and redistribute the material in any medium or format—even for commercial purposes. Users can do this by giving credit, linking to the license, and indicating if they changed the work. clicSAND is written using the C# language, allowing easy uptake, improvements, and adaptability.

### 2.2.1 Software Configuration

The user downloads the installation package from Cannone et al. [15], runs the executable, and follows the instructions for installing the GLPK solver and CBC solver on their machine. A step-by-step installation manual can be found in the OLC Platform [9] and Zenodo [16]. The installation package contains:

- the user platform (Figure 1),
- the Excel SAND Interface to input data,
- the Access database to import results,
- the Excel template to visualise the results,
- the OSeMOSYS code needed by the solvers.

The user populates the SAND interface on Excel using a single spreadsheet where all the OSeMOSYS Sets and Parameters can be defined. The spreadsheet uses filters to guide and help the user compile the data file. The flowchart in Figure 3 describes all the process steps, while specific functionalities of the SAND Interface are presented in Figure 4. Once completed, the user saves and closes the Excel file to open the clicSAND executable (Figure 1). The user selects the SAND Excel file and then the OSeMOSYS code. A VBA (Visual Basic for Applications) Macro in the selected SAND Excel workbook is executed by clicking 'Run'. The macro copies the last tab in SAND, named ToDataFile, into a new text file. The first solver, GLPK, will generate the matrix based on the data file and code selected. After this step, the second solver, CBC, will find the optimal solution and produce results in text file format. An Access Database stores the data, and the results are then visualised using the Excel Results Visualisation template.

## 2.3 Software functionalities

### 2.3.1 SAND Excel Interface

The clicSAND software consists of various components. Here we will focus on two of them—the SAND Excel interface and the result visualisation template—as users interact with these two when it comes to data management. As shown in Figure 4, the SAND interface is an Excel workbook consisting of four sheets: Naming, SETS, Parameters, and ToDataFile.

In Naming, the user can find the description of all the parameters used to build and constrain the model. In SETS, the user defines the names of technologies, commodities, and emissions in their model. Once the names are added, the user can return to this sheet to change it as many times as necessary without losing progress. The interface supports up to 200 technologies, 50 commodities, and five types of emissions. The naming convention added in SETS is automatically inserted in the other two sheets: Parameters and ToDataFile.

A screenshot of the Parameters sheet can be seen in Figure 4. It is a worksheet with 48,757 rows containing all the user's OSeMOSYS parameters necessary to build a model. Filters have been set up in each column to improve the interface's usability. In this way, the user can apply multiple filters to identify the data entry point of interest. For example, to add fixed costs for renewable technologies such as geothermal, solar, wind, and hydro (shown in Figure 4), the user will have to open the Parameters sheet, filter out the fixed costs in column A, then filter out the selected technologies in column C, and finally, copy the data into columns K to BN (years 2015 to 2070).

The user will repeat this process for all data inputs of their model. The interface offers a modelling period of up to 55 years (from 2015 to 2070) and up to 96 time slices. However, the user can also choose to model a shorter period or change the temporal resolution of the model (number of time slices) (see guided exercises at [17] and [18]; video recordings at [19] and [20]).

The last sheet in the Excel SAND interface is ToDataFile. The user does not interact directly with this sheet to enter modelling data. This sheet is already in the format required by the solvers; this automatically reads and copies all the data added from SETS and the Parameters sheet. When the user clicks 'Run' in the clicSAND software (Figure 1), a VBA macro embedded in the Excel SAND interface is first executed, which opens the SAND interface, reads the ToDataFile sheet, and saves it in a new .txt file that the two solvers use to find the optimal solution.

## 2.3.2 Results Visualisation Template

In the Results Visualisation Template file (a separated Excel workbook), the user can visualise the results of the modelling exercises (see detailed lists of the graphs available in the green box in Figure 4). Graphs are generated using Pivot Tables and rely on Access Database to store the data in a compatible format. We now turn to an illustrative example of an analysis using this software.

## 3. Illustrative Example

This section presents the results of a South African case study carried out by participants of the latest international capacity building event: the EMP-A (Energy Modelling Platform for Africa) 2021 [21]. The results are the output of a three-week online training course based on clicSAND for OSeMOSYS. The participants did not have any previous knowledge of OSeMOSYS before starting this training.

## 3.1 Background and modelling questions

The South African power system exhibits a significant coal dependence [22]. As a result, an exercise was undertaken to understand the potential implications of reduced coal dependence in the South African power system relative to existing policy and the least-cost scenario. To create a representative scenario, all coal capacity is decommissioned by 2040. From this, the following questions were considered:

1. How will the energy mix evolve?
2. How will CO<sub>2</sub> emissions change?
3. What roles will different technologies play?

## 3.2 Modelled scenarios and Starter Kit

The modelled scenarios are summarised in Table 1. The base model for the 'Existing Policy' scenario utilised an adjusted version of the available Starter Kits for implementation in OSeMOSYS [23][24]. Further adjustments were made from the

available Starter Kit (described in Table 1) to define the 'Least Cost' and 'Game Change' scenarios.

Table 1: Summary of scenarios modelled including description and key assumptions taken.

Scenario Label	Scenario Description	Key Assumptions
<b>Existing Policy</b>	The power sector evolves with existing policy (IRP 2019 [25])	<ul style="list-style-type: none"> <li>Coal capacity decommissions in line with existing expectations (Coal &lt; 60%, 25% renewables by 2030)</li> <li>Peak Plateau Decline (PPD) trajectory</li> </ul>
<b>Least Cost</b>	Least-cost evolution with no substantial upfront constraints	<ul style="list-style-type: none"> <li>Least-cost optimal unconstrained path</li> <li>PPD trajectory</li> </ul>
<b>Game Change</b>	No coal generation by 2040; renewable energy revolution	<ul style="list-style-type: none"> <li>All coal capacity decommissioned by 2040—linear decline (over ten years)</li> <li>PPD trajectory</li> <li>Least-cost with the above constraint</li> </ul>

### 3.3 Discussion of Results

Relative to the Existing Policy scenario, the Least Cost and Game Change scenarios show an evolution towards an increasingly diversified and clean energy mix (Figure 5). New-build capacity is dominated by solar photovoltaics and onshore wind, replacing decommissioning coal capacity (as planned) and meeting growing demand. When shifting from the Least Cost scenario towards the Game Change scenario, further solar photovoltaics and onshore wind is deployed, supplemented by gas-fired generation capacity that fills the gap left by coal capacity decommissioned by 2040.

### 3.4 Policy implications and future work

From the findings of these representative scenarios (see Figure 5a), it would be prudent to prepare early for a transitioned power sector in South Africa. The primary aim of this is to shift away from coal-fired power generation in a phased manner with geographically specific policy interventions and assessment of related socio-economic costs/benefits.

Total system costs are compared in Figure 5c across the scenarios considered with total discounted costs also provided. Considering the potentially significant role of variable renewable energy (VRE) like solar photovoltaics and wind in South Africa (see Figure 5a), localisation of as much of the VRE supply chain as possible should be a priority. However, this should be balanced with increasing electricity costs because of an over-emphasised localisation agenda and resulting increase in VRE technology costs specifically.

With the technologies considered, although CO<sub>2</sub> emissions reduced (see Figure 5b), a shift to natural gas capacity from coal means a continued reliance on thermal fuels and imported fuel dependence (leading to energy security concerns). It should be noted that storage (short- or long-duration) options were not explored as part of this exercise but could play a notable role as costs are expected to continue to decline in the future.

## 4. Conclusions And Extension

## 4.1 Impact and use of clicSAND Software

The clicSAND software has been used in teaching, research analysis, and policy evaluation. It was initially used and tested with six Imperial College London Master's students for their thesis projects in Kenya [26], Nigeria [27], Vietnam [28], Laos [29] [30], and Armenia [31]. It proved to be a flexible tool supporting national energy planning strategies. Furthermore, these theses have expanded the existing research and been incorporated into national government energy strategies (e.g., Vietnam [32]). ClicSAND has also been used to develop 69 country Starter Data Kits (for countries in Africa, Asia, and South America), which are zero-order models with complete datasets freely available for download on Zenodo and pre-print papers on Research Square (see full list in Appendix B).

Furthermore, the clicSAND software was used to train more than 200 people during international capacity building events, such as the Summer School at the International Centre for Theoretical Physics (ICTP) [33] and the EMP-A. The latter was organised, among others, by the United Nations Economic Commission for Africa (UNECA) and the University of Mauritius [34]. In these events, the skills previously taught using MoManI are now gained using the clicSAND software. Through a survey circulated to the participants of the EMP-A, we obtained results on the compatibility and usability of the software. The results are presented in Appendix A. As a result of the training event, several researchers and government energy ministry analysts utilise clicSAND to build national energy strategies [35].

clicSAND is the base of the practical exercises of the OLC Platform online course on Energy and Flexibility Modelling [9]. To date, the course has been completed by 98 people. The Github supplementary repository available on Zenodo [15] has also been viewed and downloaded by 341 and 92 users, respectively. Moreover, clicSAND will teach how to perform simple energy modelling analysis in the Climate Change Politics and Policy Master's Course at Loughborough University [36].

Finally, clicSAND was an invaluable asset in the initial phase of OSeMOSYS UI (User Interface) development as a blueprint and prototype for data structure design. OSeMOSYS UI is a web-based solution [37], also available as a stand-alone platform that enables users to create quickly, run, and analyse results produced by the OSeMOSYS model. It is being developed by the United Nations Department of Economic and Social Affairs (UNDESA) [38].

## 4.2 Extensions

### 4.2.1 OSeMOSYS Cloud and Visualisation

A second, partially web-based configuration, was developed to overcome the requirement of at least 8GB of RAM for the smooth operation of the offline version of clicSAND. The user still inputs the data in the SAND Excel interface but will run the model online using the OSeMOSYS Cloud platform [14]. The results are visualised online through an interactive dashboard or offline with the same steps as Configuration 1 (Figure 3). Instructions for running a model using the OSeMOSYS Cloud can be found in [39]. Current developments are looking at adding a new button to the clicSAND software to visualise input data in the form of a RES (Reference Energy System) [40].

### 4.2.2 clicSAND for MacOS users

A clicSAND software for the Macintosh User Group (clicSANDMac) was developed to reach a wider audience [41]. This allows clicSAND and the Starter Data Kits to be genuinely accessible and adaptable to all. Although this software will have the same principles and functionalities as clicSAND for Windows and will maintain the same source code, a few changes are required for the software to be macOS-compatible. For example, Microsoft Access was removed and replaced with a Python-based data manipulation approach (embedded in the software). Additionally, data are in a text file format rather

than an Excel spreadsheet run by clicSANDMac. A new online course only for OSeMOSYS MacOS users was released on the OLC Platform [42].

### 4.2.3 OSeMOSYS UI

As mentioned above, one of the main advantages of clicSAND is that data management is administered through spreadsheets. Part of the success is also that "What You See Is What You Get" (WYSIWYG) [43], which means a reduced level of abstraction. However, it was identified that Excel is not secure; it is error-prone, tough to keep track of, and not easy to scale. These are the reasons for developing clicSAND software as a full-scale web application, called OSeMOSYS UI. OSeMOSYS UI adds the ability to implement different units and create a model and run the solver in the same interface.

## Declarations

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

## CRedit Author Statement

**Carla Cannone:** Conceptualisation; Data curation; Investigation; Methodology; Software; Formal analysis; Validation; Visualisation; Writing – Original Draft. **Lucy Allington:** Data curation; Investigation; Visualisation; Validation; Review. **Nicki de Wet:** Software; Visualisation; Validation. **Abhishek Shivakumar:** Software; Formal Analysis; Validation; Methodology; Review. **Philip Goynes:** Software; Formal Analysis; Validation. **Cesar Valderrama:** Conceptualisation; Methodology; Review. **Vedran Kapor:** Validation; Formal Analysis; Review. **Jarrad Wright:** Formal Analysis; Validation; Visualisation; Writing – Secondary Draft. **Rudolf Yeganyan:** Formal Analysis; Visualisation; Writing – Secondary Draft. **Naomi Tan:** Formal Analysis; Visualisation; Writing – Secondary Draft; Writing – Secondary Draft. **Long Seng To:** Review. **John Harrison:** Review. **Mark Howells:** Conceptualisation, Investigation, Methodology, Validation, Review.

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## Appendix A

### Tools satisfaction

These results were obtained in a post-training survey completed by the EMP-A Energy and Flexibility Modelling track participants, using the clicSAND software. Thirty-four responses were considered. The questions asked and results are shown below:

"How would you rate the following characteristics of the clicSAND software for your modelling exercise? (0 = Not appropriate; 100 = Completely Appropriate)".

Table 2: Survey's results

Survey Question	Results
The SAND Excel Interface was easy to use and user-friendly	72/100
The clicSAND solver was easy to use and user-friendly	68/100
The clicSAND solver produced results in a timely manner	57/100
Running the data file extracted from the SAND Interface on the OSeMOSYS cloud was fast and easy to use	70/100

## Appendix B

Table 3 lists the country-specific datasets that have been created using the data described in this article. For each country, a Zenodo dataset includes the data in a set of CSV tables and a Research Square pre-print article that describes the data collection process and provides stylised example scenarios created using OSeMOSYS.

Table 3: Starter Kits countries Datasets and pre-prints

Region	Country	Zenodo Dataset	Research Square Pre-Print
Africa	Algeria	<a href="https://doi.org/10.5281/zenodo.4728143">https://doi.org/10.5281/zenodo.4728143</a>	<a href="https://www.researchsquare.com/article/rs-478421/v2">https://www.researchsquare.com/article/rs-478421/v2</a>
Africa	Angola	<a href="https://doi.org/10.5281/zenodo.4650810">https://doi.org/10.5281/zenodo.4650810</a>	<a href="https://www.researchsquare.com/article/rs-478581/v2">https://www.researchsquare.com/article/rs-478581/v2</a>
Africa	Benin	<a href="https://doi.org/10.5281/zenodo.4725486">https://doi.org/10.5281/zenodo.4725486</a>	<a href="https://www.researchsquare.com/article/rs-478594/v2">https://www.researchsquare.com/article/rs-478594/v2</a>
Africa	Botswana	<a href="https://doi.org/10.5281/zenodo.4650986">https://doi.org/10.5281/zenodo.4650986</a>	<a href="https://www.researchsquare.com/article/rs-478620/v2">https://www.researchsquare.com/article/rs-478620/v2</a>
Africa	Burkina Faso	<a href="https://doi.org/10.5281/zenodo.4650942">https://doi.org/10.5281/zenodo.4650942</a>	<a href="https://www.researchsquare.com/article/rs-478764/v2">https://www.researchsquare.com/article/rs-478764/v2</a>
Africa	Burundi	<a href="https://doi.org/10.5281/zenodo.4725445">https://doi.org/10.5281/zenodo.4725445</a>	<a href="https://www.researchsquare.com/article/rs-478806/v2">https://www.researchsquare.com/article/rs-478806/v2</a>
Africa	Cameroon	<a href="https://doi.org/10.5281/zenodo.4650822">https://doi.org/10.5281/zenodo.4650822</a>	<a href="https://www.researchsquare.com/article/rs-478850/v2">https://www.researchsquare.com/article/rs-478850/v2</a>
Africa	The central African Republic	<a href="https://doi.org/10.5281/zenodo.4650968">https://doi.org/10.5281/zenodo.4650968</a>	<a href="https://www.researchsquare.com/article/rs-478906/v2">https://www.researchsquare.com/article/rs-478906/v2</a>
Africa	Chad	<a href="https://doi.org/10.5281/zenodo.4725466">https://doi.org/10.5281/zenodo.4725466</a>	<a href="https://www.researchsquare.com/article/rs-478927/v2">https://www.researchsquare.com/article/rs-478927/v2</a>
Africa	Côte d'Ivoire	<a href="https://doi.org/10.5281/zenodo.4737634">https://doi.org/10.5281/zenodo.4737634</a>	<a href="https://www.researchsquare.com/article/rs-493226/v1">https://www.researchsquare.com/article/rs-493226/v1</a>
Africa	The Democratic Republic of the Congo	<a href="https://doi.org/10.5281/zenodo.4737640">https://doi.org/10.5281/zenodo.4737640</a>	<a href="https://www.researchsquare.com/article/rs-493235/v1">https://www.researchsquare.com/article/rs-493235/v1</a>
Africa	Djibouti	<a href="https://doi.org/10.5281/zenodo.4725462">https://doi.org/10.5281/zenodo.4725462</a>	<a href="https://www.researchsquare.com/article/rs-479210/v2">https://www.researchsquare.com/article/rs-479210/v2</a>
Africa	Egypt	<a href="https://doi.org/10.5281/zenodo.4652804">https://doi.org/10.5281/zenodo.4652804</a>	<a href="https://www.researchsquare.com/article/rs-479263/v2">https://www.researchsquare.com/article/rs-479263/v2</a>
Africa	Equatorial Guinea	<a href="https://doi.org/10.5281/zenodo.4650904">https://doi.org/10.5281/zenodo.4650904</a>	<a href="https://www.researchsquare.com/article/rs-479310/v2">https://www.researchsquare.com/article/rs-479310/v2</a>
Africa	Eritrea	<a href="https://doi.org/10.5281/zenodo.4725456">https://doi.org/10.5281/zenodo.4725456</a>	<a href="https://www.researchsquare.com/article/rs-479568/v2">https://www.researchsquare.com/article/rs-479568/v2</a>
Africa	Eswatini (formal. "Swaziland")	<a href="https://doi.org/10.5281/zenodo.4737638">https://doi.org/10.5281/zenodo.4737638</a>	<a href="https://www.researchsquare.com/article/rs-493243/v1">https://www.researchsquare.com/article/rs-493243/v1</a>
Africa	Ethiopia	<a href="https://doi.org/10.5281/zenodo.4650876">https://doi.org/10.5281/zenodo.4650876</a>	<a href="https://www.researchsquare.com/article/rs-479603/v2">https://www.researchsquare.com/article/rs-479603/v2</a>
Africa	Gabon	<a href="https://doi.org/10.5281/zenodo.4737642">https://doi.org/10.5281/zenodo.4737642</a>	<a href="https://www.researchsquare.com/article/rs-493249/v1">https://www.researchsquare.com/article/rs-493249/v1</a>
Africa	The Gambia	<a href="https://doi.org/10.5281/zenodo.4651140">https://doi.org/10.5281/zenodo.4651140</a>	<a href="https://www.researchsquare.com/article/rs-479641/v2">https://www.researchsquare.com/article/rs-479641/v2</a>
Africa	Ghana	<a href="https://doi.org/10.5281/zenodo.4725480">https://doi.org/10.5281/zenodo.4725480</a>	<a href="https://www.researchsquare.com/article/rs-479778/v2">https://www.researchsquare.com/article/rs-479778/v2</a>
Africa	Guinea	<a href="https://doi.org/10.5281/zenodo.4725454">https://doi.org/10.5281/zenodo.4725454</a>	<a href="https://www.researchsquare.com/article/rs-480013/v3">https://www.researchsquare.com/article/rs-480013/v3</a>

Africa	Guinea-Bissau	<a href="https://doi.org/10.5281/zenodo.4650850">https://doi.org/10.5281/zenodo.4650850</a>	<a href="https://www.researchsquare.com/article/rs-480393/v1">https://www.researchsquare.com/article/rs-480393/v1</a>
Africa	Kenya	<a href="https://doi.org/10.5281/zenodo.4650874">https://doi.org/10.5281/zenodo.4650874</a>	<a href="https://www.researchsquare.com/article/rs-480458/v1">https://www.researchsquare.com/article/rs-480458/v1</a>
Africa	Lesotho	<a href="https://doi.org/10.5281/zenodo.4650866">https://doi.org/10.5281/zenodo.4650866</a>	<a href="https://www.researchsquare.com/article/rs-480748/v1">https://www.researchsquare.com/article/rs-480748/v1</a>
Africa	Liberia	<a href="https://doi.org/10.5281/zenodo.4650794">https://doi.org/10.5281/zenodo.4650794</a>	<a href="https://www.researchsquare.com/article/rs-480654/v1">https://www.researchsquare.com/article/rs-480654/v1</a>
Africa	Libya	<a href="https://doi.org/10.5281/zenodo.4650920">https://doi.org/10.5281/zenodo.4650920</a>	<a href="https://www.researchsquare.com/article/rs-481132/v1">https://www.researchsquare.com/article/rs-481132/v1</a>
Africa	Malawi	<a href="https://doi.org/10.5281/zenodo.4652798">https://doi.org/10.5281/zenodo.4652798</a>	<a href="https://www.researchsquare.com/article/rs-479507/v2_">https://www.researchsquare.com/article/rs-479507/v2_</a>
Africa	Mali	<a href="https://doi.org/10.5281/zenodo.4725447">https://doi.org/10.5281/zenodo.4725447</a>	<a href="https://www.researchsquare.com/article/rs-479627/v2_">https://www.researchsquare.com/article/rs-479627/v2_</a>
Africa	Mauritania	<a href="https://doi.org/10.5281/zenodo.4650914">https://doi.org/10.5281/zenodo.4650914</a>	<a href="https://www.researchsquare.com/article/rs-479591/v2">https://www.researchsquare.com/article/rs-479591/v2</a>
Africa	Morocco	<a href="https://doi.org/10.5281/zenodo.4725482">https://doi.org/10.5281/zenodo.4725482</a>	<a href="https://www.researchsquare.com/article/rs-480023/v2">https://www.researchsquare.com/article/rs-480023/v2</a>
Africa	Mozambique	<a href="https://doi.org/10.5281/zenodo.4650902">https://doi.org/10.5281/zenodo.4650902</a>	<a href="https://www.researchsquare.com/article/rs-481070/v1">https://www.researchsquare.com/article/rs-481070/v1</a>
Africa	Namibia	<a href="https://doi.org/10.5281/zenodo.4652808">https://doi.org/10.5281/zenodo.4652808</a>	<a href="https://www.researchsquare.com/article/rs-481002/v1">https://www.researchsquare.com/article/rs-481002/v1</a>
Africa	Niger	<a href="https://doi.org/10.5281/zenodo.4725476">https://doi.org/10.5281/zenodo.4725476</a>	<a href="https://www.researchsquare.com/article/rs-480051/v2">https://www.researchsquare.com/article/rs-480051/v2</a>
Africa	Nigeria	<a href="https://doi.org/10.5281/zenodo.4728145">https://doi.org/10.5281/zenodo.4728145</a>	<a href="https://www.researchsquare.com/article/rs-480085/v2">https://www.researchsquare.com/article/rs-480085/v2</a>
Africa	Congo (Congo-Brazzaville)	<a href="https://doi.org/10.5281/zenodo.4651133">https://doi.org/10.5281/zenodo.4651133</a>	<a href="https://www.researchsquare.com/article/rs-479154/v2">https://www.researchsquare.com/article/rs-479154/v2</a>
Africa	Rwanda	<a href="https://doi.org/10.5281/zenodo.4652800">https://doi.org/10.5281/zenodo.4652800</a>	<a href="https://www.researchsquare.com/article/rs-480847/v1_">https://www.researchsquare.com/article/rs-480847/v1_</a>
Africa	Senegal	<a href="https://doi.org/10.5281/zenodo.4725484">https://doi.org/10.5281/zenodo.4725484</a>	<a href="https://www.researchsquare.com/article/rs-480122/v2_">https://www.researchsquare.com/article/rs-480122/v2_</a>
Africa	Sierra Leone	<a href="https://doi.org/10.5281/zenodo.4725544">https://doi.org/10.5281/zenodo.4725544</a>	<a href="https://www.researchsquare.com/article/rs-480371/v2">https://www.researchsquare.com/article/rs-480371/v2</a>
Africa	Somalia	<a href="https://doi.org/10.5281/zenodo.4725474">https://doi.org/10.5281/zenodo.4725474</a>	<a href="https://www.researchsquare.com/article/rs-480695/v1">https://www.researchsquare.com/article/rs-480695/v1</a>
Africa	South Africa	<a href="https://doi.org/10.5281/zenodo.4652802">https://doi.org/10.5281/zenodo.4652802</a>	<a href="https://www.researchsquare.com/article/rs-480636/v1">https://www.researchsquare.com/article/rs-480636/v1</a>
Africa	South Sudan	<a href="https://doi.org/10.5281/zenodo.4725468">https://doi.org/10.5281/zenodo.4725468</a>	<a href="https://www.researchsquare.com/article/rs-479969/v2">https://www.researchsquare.com/article/rs-479969/v2</a>
Africa	Sudan	<a href="https://doi.org/10.5281/zenodo.4725460">https://doi.org/10.5281/zenodo.4725460</a>	<a href="https://www.researchsquare.com/article/rs-479952/v2">https://www.researchsquare.com/article/rs-479952/v2</a>
Africa	Tanzania	<a href="https://doi.org/10.5281/zenodo.4652806">https://doi.org/10.5281/zenodo.4652806</a>	<a href="https://www.researchsquare.com/article/rs-481182/v1">https://www.researchsquare.com/article/rs-481182/v1</a>
Africa	Togo	<a href="https://doi.org/10.5281/zenodo.4725451">https://doi.org/10.5281/zenodo.4725451</a>	<a href="https://www.researchsquare.com/article/rs-">https://www.researchsquare.com/article/rs-</a>

			480160/v2
Africa	Tunisia	<a href="https://doi.org/10.5281/zenodo.4725458">https://doi.org/10.5281/zenodo.4725458</a>	<a href="https://www.researchsquare.com/article/rs-480566/v1">https://www.researchsquare.com/article/rs-480566/v1</a>
Africa	Uganda	<a href="https://doi.org/10.5281/zenodo.4652795">https://doi.org/10.5281/zenodo.4652795</a>	<a href="https://www.researchsquare.com/article/rs-480512/v1">https://www.researchsquare.com/article/rs-480512/v1</a>
Africa	Zambia	<a href="https://doi.org/10.5281/zenodo.4725470">https://doi.org/10.5281/zenodo.4725470</a>	<a href="https://www.researchsquare.com/article/rs-480042/v2">https://www.researchsquare.com/article/rs-480042/v2</a>
Africa	Zimbabwe	<a href="https://doi.org/10.5281/zenodo.4650816">https://doi.org/10.5281/zenodo.4650816</a>	<a href="https://www.researchsquare.com/article/rs-479655/v2">https://www.researchsquare.com/article/rs-479655/v2</a>
Asia	Cambodia	<a href="https://doi.org/10.5281/zenodo.5139538">https://doi.org/10.5281/zenodo.5139538</a>	<a href="https://www.researchsquare.com/article/rs-757472/v1_">https://www.researchsquare.com/article/rs-757472/v1_</a>
Asia	Indonesia	<a href="https://doi.org/10.5281/zenodo.4926858">https://doi.org/10.5281/zenodo.4926858</a>	<a href="https://www.researchsquare.com/article/rs-757493/v1_">https://www.researchsquare.com/article/rs-757493/v1_</a>
Asia	Laos	<a href="https://doi.org/10.5281/zenodo.4926880">https://doi.org/10.5281/zenodo.4926880</a>	<a href="https://www.researchsquare.com/article/rs-757542/v1_">https://www.researchsquare.com/article/rs-757542/v1_</a>
Asia	Malaysia	<a href="https://doi.org/10.5281/zenodo.5139480">https://doi.org/10.5281/zenodo.5139480</a>	<a href="https://www.researchsquare.com/article/rs-757581/v1_">https://www.researchsquare.com/article/rs-757581/v1_</a>
Asia	Myanmar (formerly Burma)	<a href="https://doi.org/10.5281/zenodo.5139484">https://doi.org/10.5281/zenodo.5139484</a>	<a href="https://www.researchsquare.com/article/rs-757622/v1_">https://www.researchsquare.com/article/rs-757622/v1_</a>
Asia	Philippines	<a href="https://doi.org/10.5281/zenodo.5139542">https://doi.org/10.5281/zenodo.5139542</a>	<a href="https://www.researchsquare.com/article/rs-757671/v1_">https://www.researchsquare.com/article/rs-757671/v1_</a>
Asia	South Korea	<a href="https://doi.org/10.5281/zenodo.5139512">https://doi.org/10.5281/zenodo.5139512</a>	<a href="https://www.researchsquare.com/article/rs-757722/v1">https://www.researchsquare.com/article/rs-757722/v1</a>
Asia	Taiwan	<a href="https://doi.org/10.5281/zenodo.5139520">https://doi.org/10.5281/zenodo.5139520</a>	<a href="https://www.researchsquare.com/article/rs-757733/v1_">https://www.researchsquare.com/article/rs-757733/v1_</a>
Asia	Thailand	<a href="https://doi.org/10.5281/zenodo.5139498">https://doi.org/10.5281/zenodo.5139498</a>	<a href="https://www.researchsquare.com/article/rs-757735/v1_">https://www.researchsquare.com/article/rs-757735/v1_</a>
Asia	Vietnam	<a href="https://doi.org/10.5281/zenodo.5139527">https://doi.org/10.5281/zenodo.5139527</a>	<a href="https://www.researchsquare.com/article/rs-757746/v1_">https://www.researchsquare.com/article/rs-757746/v1_</a>
Asia	Papua New Guinea	<a href="https://doi.org/10.5281/zenodo.5139488">https://doi.org/10.5281/zenodo.5139488</a>	<a href="https://www.researchsquare.com/article/rs-757653/v1_">https://www.researchsquare.com/article/rs-757653/v1_</a>
Latin America	Argentina	<a href="https://doi.org/10.5281/zenodo.5498081">https://doi.org/10.5281/zenodo.5498081</a>	<a href="https://www.researchsquare.com/article/rs-893102/v1">https://www.researchsquare.com/article/rs-893102/v1</a>
Latin America	Bolivia	<a href="https://doi.org/10.5281/zenodo.5498083">https://doi.org/10.5281/zenodo.5498083</a>	<a href="https://www.researchsquare.com/article/rs-893267/v1">https://www.researchsquare.com/article/rs-893267/v1</a>
Latin America	Brazil	<a href="https://doi.org/10.5281/zenodo.5498085">https://doi.org/10.5281/zenodo.5498085</a>	<a href="https://www.researchsquare.com/article/rs-893535/v1">https://www.researchsquare.com/article/rs-893535/v1</a>
Latin America	Chile	<a href="https://doi.org/10.5281/zenodo.5498087">https://doi.org/10.5281/zenodo.5498087</a>	<a href="https://www.researchsquare.com/article/rs-893607/v1">https://www.researchsquare.com/article/rs-893607/v1</a>
Latin America	Colombia	<a href="https://doi.org/10.5281/zenodo.5498091">https://doi.org/10.5281/zenodo.5498091</a>	<a href="https://www.researchsquare.com/article/rs-893706/v1">https://www.researchsquare.com/article/rs-893706/v1</a>
Latin America	Ecuador	<a href="https://doi.org/10.5281/zenodo.5498093">https://doi.org/10.5281/zenodo.5498093</a>	<a href="https://www.researchsquare.com/article/rs-893779/v1">https://www.researchsquare.com/article/rs-893779/v1</a>
Latin America	Paraguay	<a href="https://doi.org/10.5281/zenodo.5498099">https://doi.org/10.5281/zenodo.5498099</a>	<a href="https://www.researchsquare.com/article/rs-895567/v1">https://www.researchsquare.com/article/rs-895567/v1</a>

Latin America	Peru	<a href="https://doi.org/10.5281/zenodo.5498101">https://doi.org/10.5281/zenodo.5498101</a>	<a href="https://www.researchsquare.com/article/rs-895579/v1">https://www.researchsquare.com/article/rs-895579/v1</a>
Latin America	Uruguay	<a href="https://doi.org/10.5281/zenodo.5498103">https://doi.org/10.5281/zenodo.5498103</a>	<a href="https://www.researchsquare.com/article/rs-895585/v1">https://www.researchsquare.com/article/rs-895585/v1</a>
Latin America	Venezuela	<a href="https://doi.org/10.5281/zenodo.5498105">https://doi.org/10.5281/zenodo.5498105</a>	<a href="https://www.researchsquare.com/article/rs-895585/v1">https://www.researchsquare.com/article/rs-895585/v1</a>

## Figures

### Figure 1

Overview of the clicSAND software and main functionalities. Green button: data file selection; Blue button: OSeMOSYS code selection; Orange Button: initialise solving; Red Button: Export Templates. As described in Section 2.2.1. the "Open Log" button is not often used; however, it opens a new file in the text editor – we will disregard it in this paper.

Advantages	Limitations
<ul style="list-style-type: none"> <li>• User does not interact with the command line at any point</li> <li>• Works completely offline</li> <li>• User friendly SAND Interface based on Excel familiar to most IT users. A single spreadsheet to input all the data needed for the model.</li> <li>• Easy and fast installation</li> <li>• Fully compatible with the Starter Data Kits models</li> <li>• Open University course available for self-learning</li> <li>• Up to 96 timeslices for seasonal representations of intermittent renewable technologies</li> <li>• All OSeMOSYS parameters represented</li> </ul>	<ul style="list-style-type: none"> <li>• Time-demanding troubleshooting as the software doesn't point at the error</li> <li>• You cannot copy paste vertically if there are filters applied on the Excel file</li> <li>• At least 8GB of RAM required to run smoothly</li> <li>• Currently tested for Windows, but developments for Mac users will be released soon</li> <li>• Not yet tested for multiregional studies</li> </ul>

### Figure 2

Advantages and Limitations of the clicSAND Software

### Figure 3

Flowchart of clicSAND Software under Configuration 1 – fully offline version.

### Figure 4

Main functionalities of the SAND Interface Excel Sheets and screenshot of the "Parameters" Sheet at the bottom. In green is a list of the graphs that can be visualised with the Template.

### Figure 5

Results of the South-African case studied developed during an online capacity building event: (a) Comparison of the electricity production; (b) Comparison of the CO2 emissions of scenarios; (c) Comparison of total costs (Capital, Fixed O&M, and Fuel costs).