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# RAMP: stochastic simulation of user-driven energy demand time series

**Francesco Lombardi** [1¶], **Pierre-François Duc** [2], **Mohammad Amin Tahavori** [3], **Claudia Sanchez-Solis** [4,7], **Sarah Eckhoff** [5], **Maria C. G. Hart** [5], **Francesco Sanvito** [1], **Gregory Ireland** [2,6], **Sergio Balderrama** [7], **Johann Kraft** [2], **Gokarna Dhungel** [2,8], **and Sylvain Quoilin** [4]

**1** TU Delft, Faculty of Technology, Policy and Management, Delft, The Netherlands **2** Reiner Lemoine Institut, Berlin, Germany **3** VITO, Mol, Belgium **4** University of Liège, Integrated and Sustainable Energy Systems, Thermodynamics Laboratory, Liège, Belgium **5** Leibniz Universität Hannover, Information Systems Institute, Hannover, Germany **6** University of Cape Town, Cape Town, South Africa **7** Universidad Mayor de San Simon, Centro Universitario de Investigacion en Energias, Cochabamba, Bolivia **8** University of Applied Sciences Nordhausen, Nordhausen, Germany ¶ Corresponding author

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- @FabianHofmann
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## Summary

The urgency of the energy transition is leading to a rapid evolution of energy system design worldwide. In areas with widespread energy infrastructure, existing electricity, heat and mobility networks are being re-designed for carbon neutrality and are increasingly interconnected. In areas where energy infrastructure is limited, instead, networks and systems are being rapidly expanded to ensure access to energy for all. In both cases, re-designing and expanding energy systems in these directions requires information on future user behaviour and associated energy demand, yet this type of data is often unavailable. In fact, historical data are often either entirely missing or poorly representative of future behaviour within transitioning systems. This results in reliance on inadequate demand data, which affects system design and its resilience to rapid behaviour evolution.

## Statement of need

RAMP is an open-source, Python-based software suite that enables the stochastic simulation of any user-driven energy demand time series based on few simple inputs. In fact, the software is designed to require only a basic understanding of the expected user activity patterns and owned appliances as inputs, which are provided in tabular format (`.xlsx`). For instance, a minimal definition of a user type (e.g., a certain category of households) requires only information about which energy-consuming devices they own, when, on a typical day, they tend to use them, and for how long in total. Then, the software leverages stochasticity (using the `random` package) to make up for the lack of more detailed information and to account for the unpredictability of human behaviour (see Figure 1). This way, RAMP allows generating and visualising synthetic data wherever detailed metered data does not exist, such as when designing systems in remote areas (Lombardi et al., 2019) or when looking at future electric-vehicle fleets (Mangipinto et al., 2022).

Reliance on simple inputs distinguishes RAMP from comparable tools. For instance, other popular open-source demand simulation tools, such as CREST (McKenna et al., 2015) and demod (Barsanti et al., 2021), are based on extensive and context-specific input datasets from the UK and Germany, respectively, which populate the occupancy model at the core of their approach. Similarly, the Load Profile Generator model (Pflugradt et al., 2022), also openly available, implements a desire-driven behavioural simulation grounded on a psychological model based on German household data. Due to their data-driven nature, these models are not readily applicable to other similar contexts, such as different European countries, and are arguably inapplicable to cases, such as remote areas, with unique characteristics. Moreover, the heavy reliance on historical data serves poorly the need to accommodate modelling of future, entirely new behaviours or devices. RAMP trades off the capability of providing detailed information about users' occupancy and activity, typical of the above data-driven models, for substantially greater modelling flexibility and context adaptability. Previous attempts at generating demand time series based on a similar approach as RAMP exist (Mandelli et al., 2016), but they are neither open-source nor capable of simulating non-electric or more sophisticated energy uses.

In fact, RAMP features several degrees of customisation, enabling modellers to switch on or off features tailored to the needs of specific energy uses. For example, to represent the highly variable load profile of cooking appliances, which changes completely depending on which meal is cooked, the software allows defining many possible meal types with an associated cooking cycle; then, it leverages stochasticity to diversity which meals are cooked when. For heat-related energy uses that may be influenced by weather parameters, such as outdoor or groundwater temperature, it is possible to provide a time series of such parameters and define how they affect the default energy consumption. These and many other customisation options allow users to explicitly simulate radically different but equally plausible behaviour scenarios, including behaviours that may happen in the future and that have no relationship with past data, as a key ingredient to robust system design.

RAMP has already been used in many scientific publications, for instance, for the simulation of electricity (Dimovski et al., 2023), heating (Nicolo Stevanato et al., 2020), cooking (Nicolò Stevanato et al., 2020) and electric mobility (Secchi et al., 2023) demand time series at scales ranging from districts (Pasqui et al., 2023) or villages (Villarroel-Schneider et al., 2023) to continents (Pickering et al., 2022). It has dozens of users globally and has recently become a multi-institution software development effort, actively developed by TU Delft, VITO, Sympheny, the Reiner Lemoine Institut, the University of Liège and the Leibniz University Hannover. The joint development process has brought major improvements to the code structure, syntax and efficiency, more extensive documentation, and a web-based graphical user interface for users with no Python experience (Hart et al., 2023).

RAMP is developed openly on GitHub (github.com/RAMP-project) and each new release is archived on Zenodo (Lombardi et al., 2023).

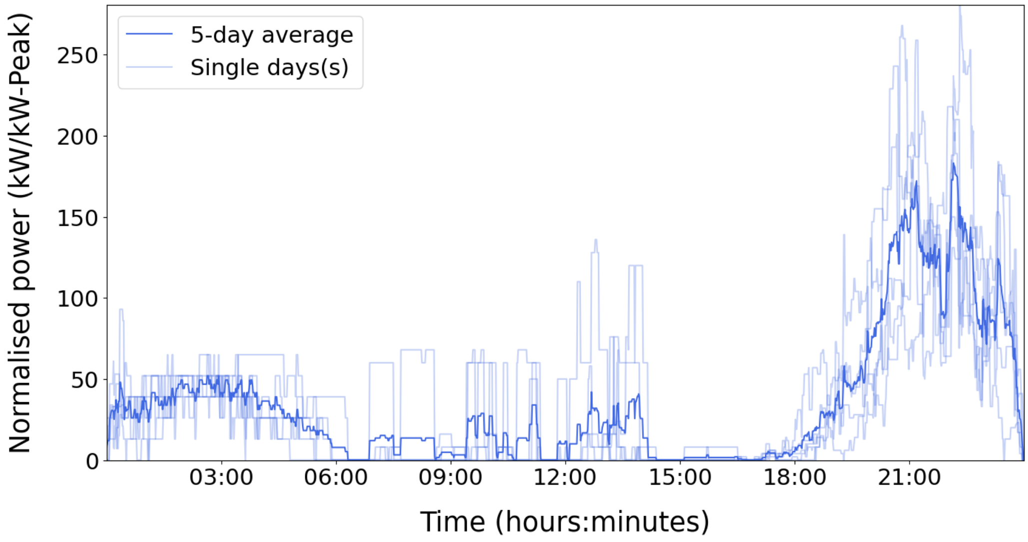


**Figure 1:** Example output (normalised by peak demand) for the simulation of the electricity load of three households in a small village over five days. The thick blue line represents the five-day average, while individual days are plotted in a lighter colour.

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