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Mat-dp: An open-source Python model for analysing material demand projections and their environmental implications, which result from building low-carbon systems.

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Summary

MAT-dp is a Python model which aims to calculate the amounts and types of materials needed for building any system or resource transformation including those found along any supply chain- but is particularly applied to studying the materials needed for building low-carbon systems- and estimate the environmental implications associated to such materials.

Mat-dp contains a linear programming library called mat-dp-core which includes the core classes of each element and their mathematical operations for obtaining results. Mat-dp-core is tailored to the needs of research around material demand for low-carbon systems, helping technically proficient users to explore scenarios and systems relating to their research in Python. Mat-dp-core has an easy-to-use structure and code base with the mathematical model to let users evaluate and optimise the environmental effects of a given set of resources that are fed into one or more processes.

In mat-dp-core, the system and its required materials are defined as a series of resources that are fed into different processes, which in turn have a defined set of outputs. The outputs can be the result of the process, e.g., energy, materials or greenhouse gas emissions. The system can then be optimised using an objective function related to a property of the system which will be minimised (e.g., number of runs or cost) subject to three possible types of constraints built into mat-dp-core, depending on the desired output of the process, e.g., a required electricity capacity of an offshore wind installation. The three types of constraints that can be defined are: a given ratio of process runs (Run Ratio Constraint), a given number of resources produced (Resource Constraint), and a given number of process runs (Run Eq Constraint) that the system has to comply with. The model results obtained can then be exported and further explored.

Statement of need

Materials are essential for creating the systems used in everyday life, yet, manufacturing materials emits important quantities of greenhouse gases (GHG). Emissions from material production have been estimated to increase from 5 gigatons (Gt) of CO2-equivalent to 11 Gt between 1995 and 2015. In turn, global emissions due to material production rose from 15 per cent to 23 per cent in the same period (Hertwich et al., 2020), while materials are estimated to contribute to over half of GHG emissions from industry (Allwood et al., 2010).
Thus, identifying and implementing options for reducing material emissions is required.

Mat-dp offers an easy-to-use structure to study material demands, where the types of processes and resources can be extended as much as the user needs. To the best of our knowledge, this is the first time that such an extensible open-source Python model to study materials has been developed. Previous models in the literature and other open-source models have focused on either only a subset of systems (e.g., materials for buildings) or a comprehensive, yet prescribed, set of systems which include some technologies and materials (e.g., ODYM-RECC model (Pauliuk, 2020)). The reusable nature of Mat-dp makes it ideal for allowing users to focus on the process(es) they want to investigate, rather than setting up code or a mathematical model from scratch. The benefits of such reusability to advancing research in this scientific discipline cannot be understated.

Mat-dp is capable of adapting the temporal and regional specifications of users by creating the processes according to prescribed names and using indices for the desired categories once the Mat-dp library has been imported to a working example. Mat-dp also allows for different material mixes, technology changes or improvements over time, and recycled material content in a given process to be included in the model. These capabilities allow for models to be built that are tailored for a specific case-study, which might benefit decision making.

Target Audience

Mat-dp is ideal for academics who work on understanding or reducing environmental effects of different processes, government officials who work on national material and emission strategies, or practitioners who work on estimating material demands for a given project. Proficiency in Python is needed, so the users can adapt their requirements in the form needed for the model.

The model facilitates the framing of resource flows and the optimisation of their flows in and out of systems which can then be easily visualised. This allows for users to explore alternative ways to build systems by either reducing or changing their inputs, maximising their outputs or by minimising their emissions or waste.

Mat-dp has been used to study the environmental implications of electricity systems, where each power plant is considered a process in the model. However, these processes can be anything along any supply chain or resource transformation, as long as the user knows the resources that are fed into the processes. Examples of questions that can then be investigated by Mat-dp include: (1) what are the material implications of changing systems, (2) what are the optimum strategies to introduce recycled materials in a system, (3) which process emissions must be minimised to achieve the highest reductions?

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