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TECHNO-ECONOMIC OPTIMISATION MODELS FOR LOW CARBON BUSINESS PARK ENERGY SYSTEMS

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Abstract. On low carbon business or industrial parks, energy-related carbon dioxide emissions are minimised by local renewable energy production, enhanced energy efficiency, and inter-firm heat exchange, combined in a joint energy system. The optimal design of such systems is a complex task and requires the holistic approach of techno-economic energy models. However, no such models custom-tailored for energy systems at business park scale are currently available. Therefore, a number of optimisation-based energy models are analysed and important qualitative features are identified. These features provide a basis for developing a new model for low carbon business park energy systems.

Keywords: low carbon business park, techno-economic optimisation, energy model

INTRODUCTION

The optimal design of a low carbon energy system exists in calculating its configuration and operation, so that energy demands are fulfilled, while limiting or minimising total costs and carbon emissions. Moreover, the designer has to take into account the techno-economic and environmental characteristics of all system components, the inter and intra-annual variations of uncontrollable renewable energy technologies and energy service demands, the dispatch strategies of energy generators, as well as the temperature levels of thermal energy demand and generation. Therefore, the holistic approach provided by techno-economic energy models is indispensable. In this paper, a number of existing optimisation-based techno-economic energy models, taken from a model review and classification by Timmerman et al. [1] are analysed. Suitable features for modelling energy systems at business park scale are identified, to form a basis on which a new energy model can be built.

OPTIMISATION-BASED TECHNO-ECONOMIC ENERGY MODELS

In an optimisation problem, decision variables x are calculated so that an objective function F(x), containing one or multiple objectives, is minimised, subject to a number of constraints g(x)=0, h(x)≤0. When objectives and constraints are linear, this leads to the (multi-objective) linear programming problem represented in (1), which has been the basis for numerous cases, e.g. [2, 3].

$$(1)\qquad \underset{\text{objective function}}{\min_x f^T x} \qquad \text{subject to} \qquad \begin{cases} A.x \le b & \textit{inequality constraints} \\ A_{eq}.x = b_{eq} & \textit{equality constraints} \\ lb \le x \le ub & \textit{bound constraints} \end{cases}$$

Decision variables represent technology capacity (expansion) and operation and import/export of commodities (energy resources, -carriers, -services, emissions). The objective function expresses system performance in terms of total discounted costs or emissions. Constraints are given by equations describing the the system's behaviour: Cost equations accumulate and discount costs related to technologies and commodities over the time horizon. Balance equations ensure that the supply of a specific commodity equals or surpasses the demand for it, and that a certain capacity margin exists. Technology equations limit the activity of technologies to a maximum corresponding to their available capacity, and express efficiency from input to output. Bounding equations impose bounds to decision variables, such as practical capacity ranges, a carbon emission cap, etc.

ETEM [4] and OSeMOSYS [5] belong to the class of Energy System Evolution models [1], that calculate the minimum cost investment path and operation over a long term time horizon. Voll et al. [6] developed an Energy System Optimisation model [1], that calculates the minimum cost configuration and operation in a single representative year. These models employ linear optimisation algorithms and use a generic mathematical description to represent technologies. In order to capture inter-annual variations in energy service demands and non-controllable renewable energy sources, years are subdivided into user-defined time slices.

In ETEM, a technology is modelled as a process converting ingoing to outgoing flows, that may contain multiple commodities, with one outflow labelled as the process's activity. In each time slice, the maximal attainable activity is proportional to the total available capacity. Conversion from a specific in- to outflow has a constant efficiency. Furthermore, in every period, specific investment and fixed as well as variable operation and maintenance costs are constant over the ranges of capacity addition, total installed capacity and activity respectively. Also, specific import, export and delivery costs of commodities are constant at time slice level.

In OSeMOSYS, all energy conversion technologies, energy imports or resource extractions are represented by a generic technology sub-model converting in- to outgoing fuels (energy carriers, -services). It can operate in different modes, so that e.g. different heat/electricity ratios for CHP can be simulated. The total activity rate over all modes of a technology is limited by its available capacity, on both time slice and annual level. The rates of all fuel in- and outputs and emissions are linked to the activity rate by constant ratios. Specific investment, variable operating costs and emission penalties are assumed to be constant. Fuel costs are included as variable operating costs of import or extraction technologies. A technology can charge or discharge a storage facility to which it is connected, in dedicated operation modes, at rates proportional to its activity rate. In the framework developed by Voll et al., technologies are represented by a generic sub-model, based on a nominal conversion efficiency between in- and outflows, part-load efficiency performance curves and an investment cost function. Functions are piecewise linearised and part-load behaviour is independent of equipment size.

OSMOSE [7] is an Energy System Integration model [1], that minimises thermal energy requirements by heat exchange and subsequently calculates the least cost configuration of the system. Unlike the previously described models, OSMOSE wields different complex technology sub-models.

IMPORTANT FEATURES FOR DEVELOPMENT NEW MODEL

Based on this analysis, features important for modelling business park energy systems can be identified. Firstly, optimisation algorithms need to be used to calculate the energy system's configuration and operation that yield minimum total costs, subject to a number of constraints (e.g. carbon emission cap, energy import/export limits, etc.). Moreover, multi-objective optimisation facilitates the trade-off between conflicting objectives, such as minimisation of both total costs and carbon emissions. Secondly, sufficient temporal detail in intra-annual time slice division is required to simulate the time-varying interactions between energy demands, uncontrollable renewable energy sources, energy storage, controllable generators and energy import/export. Thirdly, considering the relatively small scale of business parks, the techno-economic characteristics of individual technology units must be accurately represented. Therefore, size-dependent investment costs between practical capacity limits and part-load efficiency and minimum load must be modelled. Consequently also configurations with multiple redundant units of the same technology belong to the solution space. An automated superstructure generation and optimisation algorithm can avoid the a priori definition of the number of redundant units. Evenly important is the ability to simulate energy storage, in order to limit energy exchange with external networks. Finally, to correctly model heat flows in energy generation and demand, they must be represented by heat-temperature profiles. Thermal energy requirements within the energy system could be reduced by heat exchange between hot and cold streams of thermal energy demands through a heat transfer network.

CONCLUSIONS

These qualitative features serve as a basis for a new techno-economic business park energy system model, to be built in the MATLAB environment. An initial model instance simulates one year, divided into 6 time slices. Objectives are minimisation of total costs and carbon emissions. Technologies are represented by a generic sub-model, specific capital costs and technology efficiencies are considered independent of capacity and load, respectively, and thermodynamic quality of heat is disregarded.

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