STREAM manual

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DTU
Systems Analysis
Department of Management Engineering

STREAM manual

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By

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Photo: Risø wind turbine, Mikkel Adsbøl

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Preface

This manual gives an introduction to the STREAM model. The manual targets students at the course 42004 Feasibility Studies and System Assessment of Energy Technologies at DTU and other users of the tool.

The STREAM modelling tool was originally developed for a project entitled the "Future Danish Energy System" carried out from 2004-2007 by the Danish Board of Technology in conjunction with some of the most important Danish stakeholders in the energy sector. It has since then been used and developed at the Energy System Analysis Program at Risø under DTU Management Engineering and at EA Energy Analysis.

The tool provides a quick insight into the different potential energy mixes not only for the whole of Europe, but also for defined regions or countries. The model allows planners, politicians, students and others to be able to create scenarios on demand.

Thanks to my co-authors, to Anders Kofoed-Wiuff and Robert Klein at EA Energy Analysis as well to Kenneth Karlsson at DTU MAN Risø for continued constructive cooperation on development of the model. Furthermore thanks to Amalia Pizarro and Markos Romanos for contributions to the second edition.

Lyngby, October 2015

Marie Münster

Senior Researcher

1. Introduction

The STREAM model was originally built to provide fast and complete analysis of energy flow. It is a relatively simple tool. It guarantees the possibility to make analysis and changes in a quick way, also during meetings and workshops, since the time for running is reduced; compared to the calculation hours that complex and detailed models need. STREAM model is not an optimization tool, so it cannot give the optimal and low cost solutions for the future energy market, but it allows simulating different scenarios and comparing different solutions for the system.

One of the main characteristics of STREAM is the ability of modelling the whole energy system and showing the complete energy flow. Thus, it is possible to look at all sectors of a country (or region) using different combinations of fuels and conversion technologies, and considering the electricity, heat and transport systems at the same time.

The model is divided in two Excel spreadsheets, as illustrated in Figure 1, which are further described in the following sections:

1. The Energy Flow Model: demand & supply
2. The Duration Curve Model: system balancing

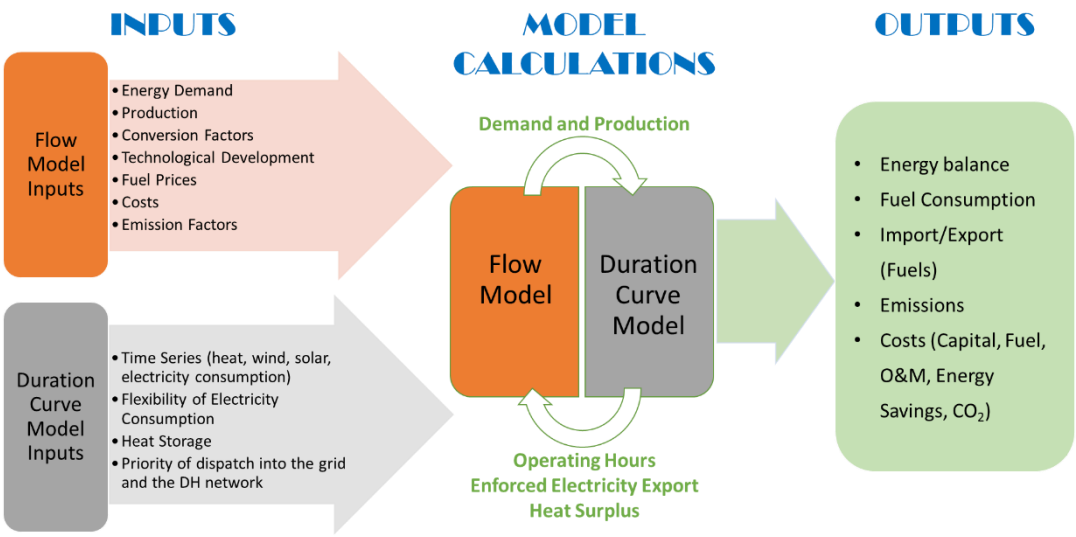

Figure 1: STREAM model flow

2. The Flow Model

The energy Flow Model is a static model, which assesses the energy system and provides information about the whole energy system for a given year. The energy demands and the supply are determined in this spreadsheet.

The Flow Model can be run independently of the Duration Curve Model in a stand-alone mode for simplified analyses using estimates of full load hours of operation of dispatchable plants, condense based production of extraction CHP plants and electricity overflow from fluctuating sources (e.g. wind).

Some of the main features of the Flow Model spreadsheet are described below.

2.1 STREAM Light

The Flow Model contains a single spreadsheet, *STREAM Light*, which gives an overview of the entire energy system. This sheet makes possible to construct scenarios and evaluate effects of e.g. changes in the share of power or heating technologies in terms of emissions and costs. The sheet is used in combination with the *Base Year Input* sheet, where energy statistics on demand and production for the base year are entered. If only simple analyses are needed to give an overview, the *STREAM Light* and *Base Year Input* sheets can be used independently of the remaining sheets in the model. In order to change efficiencies, costs or add new technologies it is necessary to modify parameters in the remaining sheets.

2.2 Final Energy Demand

The demand for energy services and, subsequently, the final energy consumption at an annual level, is calculated for a country (or region modelled) and divided into four main sectors:

- Residential: electricity and heat
- Services: electricity and heat
- Industry: electricity and process heat
- Transport: passenger, freight, fishery and agriculture

The demand for energy services in each specific sector in a given scenario is projected in the Flow Model. The baseline for the model is the sectorial economic growth as forecasted, for example, in the Danish Government's Energy Strategy. It is assumed that the demand for energy services will grow equivalently to the economic growth multiplied by a factor of energy intensity, which takes into account the fact that not all the economic growth is converted to an increased demand for energy services, as it

is not the only contribution to productivity in the given sector. Some sectors will produce more economic value added per unit of input energy than others will, because some activities require more capital, higher labour skills, technology, etc.

The demand for energy also accounts efficiency improvements in the residential, services or industrial sectors: e.g. due to structural changes in industrial processes; to the refurbishment of buildings, which would require less heating by using specific construction materials; to the use of more efficient home appliances, etc. Energy savings in the transport sector are related to changes in the allocation of transport work towards less energy consuming per km·passenger or per ton·km means or by increasing their utilization degree or stocking density.

The demand for energy services is computed as illustrated in the following Figure. The energy consumption (e.g. electricity consumption by household lighting) in the defined year at a constant (frozen) level of efficiency is firstly calculated, i.e. how will consumption develop given average annual economic growth and energy intensity if the efficiency of electrical appliances does not improve? This type of consumption (with frozen efficiency) can be said to provide an image of the growth in the energy services within a given end-use. This demand is subsequently regulated based on assumed efficiency development (which will have an associated cost) during the time period between the scenario and the base year, and the result is the actual energy required for the specific service in the given scenario.

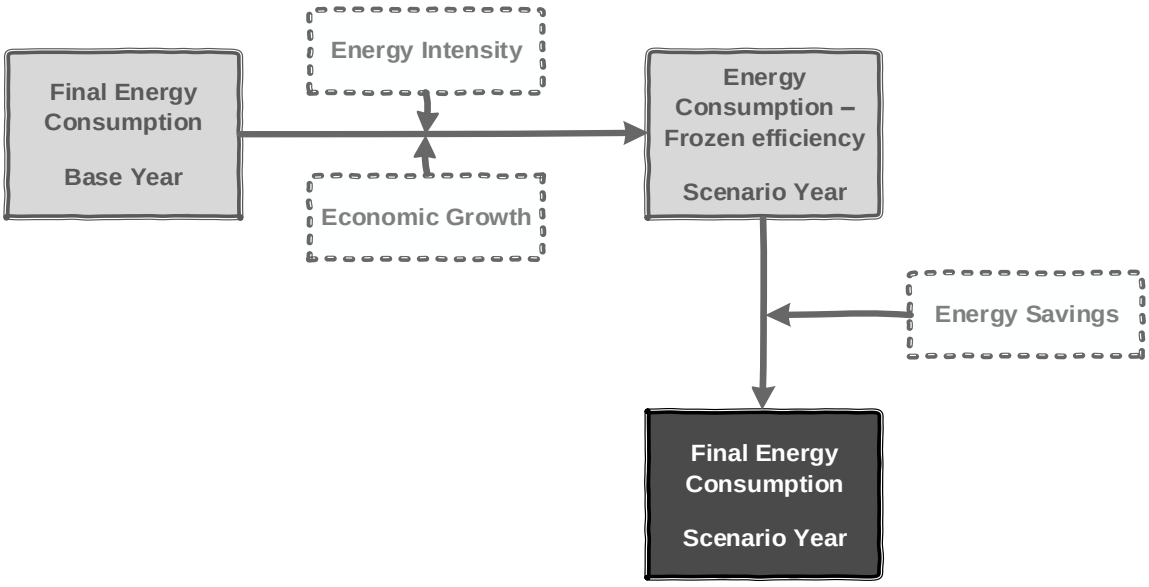

Figure 2. Forecasting of final energy demand per sector in STREAM

2.3 Energy production

An overview of the energy production is provided in the *STREAM Light* sheet, and a more detailed summary of the energy systems' resources, fuel consumption and conversion is given in the *-Tech* sheets and *Energy Balance*, *Economic Balance* and *Environmental Balance* sheets.

The Flow Model also contains estimates of investment (assuming an average full load operation time for each type of technology) and operating costs, as well as greenhouse gas emissions for the technologies used, but only for the conversion of fuel to energy services. Thus, the model can approximate annual costs and emissions related to supplying energy.

In order to ensure that the energy system is in balance with sufficient installed capacity and to adjust e.g. flexible electricity demand, heat storage or the merit order of energy production technologies it is necessary to run the Flow Model together with the Duration Curve Model.

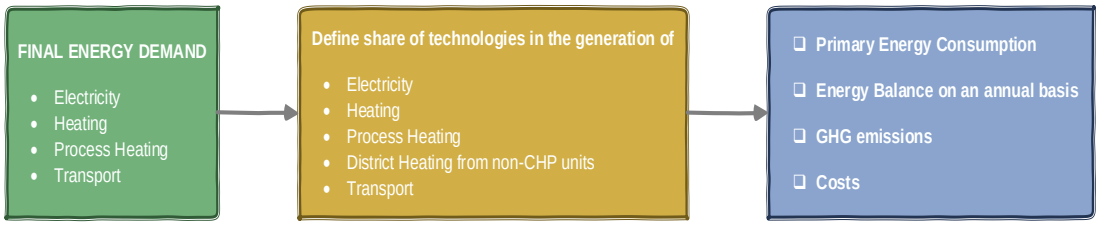

Figure 3. Flow Model Input-Output

3. The Duration Curve Model

The purpose of the Duration Curve Model is to analyse correlations in the Danish electricity and district heating systems on an hourly basis: uncontrollable vs. dispatchable electricity, combined heat and power, district heating generation, storage devices, flexible and inflexible demand, etc. Based on the analyses from the Duration Curve Model, input is provided to the Flow Model, modifying the initial overall energy flow and economic calculations, estimated through assumptions during the stand alone simulation (without linkage to the Duration Curve Model), such as full load hours of operation of thermal plants.

The Duration Curve Model does not include financial optimization, as it is a relatively simple spreadsheet model. However, it optimizes the operation of the system, minimizing the total required installed capacity of power and CHP plants and the use and capacity of boilers for district heating.

Input to the energy flow model from the Duration Curve Model includes:

- **The annual load factor for electricity and district heating production plants** (including heat pumps and electric boilers). The annual load factor for the various different plants (number of full load hours of operation in one year) is an important input parameter for the economic calculations.
- **The proportion of condensation-based electricity production**. During periods in which electricity consumption is relatively large and heat consumption relatively small, a large number of extraction combined heat and power plants are required to run condensation-based production. Extraction plants running in condensing mode only generate electricity and no heat, in order to avoid the need to cool down excess heat and to benefit from a higher electrical efficiency. The proportion of condensation-based electricity production is an important input parameter to the energy flow calculations.
- **The size of potential electricity overflows**. When wind power production (or any other fluctuating source) exceeds electricity consumption, electricity overflow occurs in the system. The electricity overflow can often be exported to the countries with which Denmark has electricity agreements (Germany 1800 MW, Norway – 1000 MW and Sweden – 2640 MW). The Duration Curve Model can assess the size of the total electricity overflow. In practice, export potential may be restricted if the neighbouring countries also experience electricity overflow caused by a large increase in wind power installations in the future. If the electricity overflow cannot be exported it is considered critical, as it could destabilize the grid. However, this model cannot make an assessment of possible bottlenecks in the system.

  It should be ensured in the Flow Model that forced electricity export and electricity import equals each other, if the modelled region should be net self-sufficient over the year.

- **The amount of excess heat that might be exported or cool down**. Heat can be produced from fluctuating sources (solar thermal) or as a by-product of a main process, as biorefinery processes or electrolysis. It might be generated when there is not enough demand and heat storage devices are full, thereby, it has to be cooled down. Furthermore, there might be some periods where electricity consumption is high and backpressure plants are in operation, generating heat along with power, even if the demand for heat is low and heat storage devices are full. This heat has to be exported or cool down. No imported heat is considered.

Both production from uncontrollable sources and consumption data for electricity and district heating are fixed on the basis of historic time series (hourly values) and are scaled with the technology improvement (efficiency increase) predicted and to the power or district heating final demand, respectively, for the analysed year in the Scenario modelled.

The supply scenario is modelled as a large combined heat and power plant, a large heat storage plant, a large heat pump and electrical boiler and a large boiler (non-electrical); as well as four types of wind turbines (2 offshore and 2 onshore wind turbines, one of each in East Denmark and West Denmark), a large run-of-river and a large flexible hydropower plant, a turbine for generation of wave power and a large panel for solar power and a large collector for solar thermal generation. Denmark is analysed as an interconnected system without domestic transmission restrictions in either district heat or electricity.

Dispatch of the electricity supply in STREAM is depicted in the following Figure and described below.

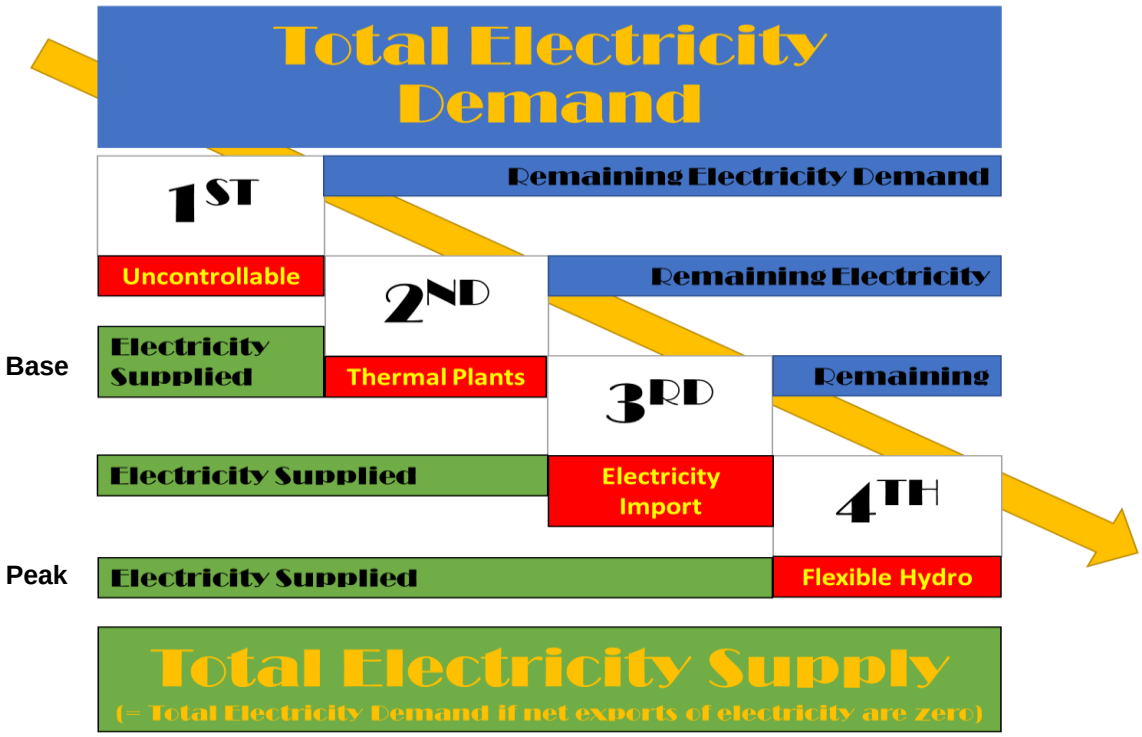

Figure 4. Electricity Supply in STREAM

Uncontrollable energy production (e.g. wind, solar, wave, run-of-river hydropower) have default priority of dispatch into the grid. No curtailment is considered. Afterwards, flexible hydropower production is used in such a way that the installed thermal capacity is minimized (it will cover the peak in the load duration curve for electricity). The production of the thermal power plants is manually prioritized, so that the plants with the highest priority get most production hours, as illustrated in Figure 5. Extraction CHP plants only run in condensing mode, if the heat cannot be utilised (neither directly used nor stored). Electricity import (equivalent to the enforced electricity export) has the last priority of dispatch in the duration curve (after hydropower), thereby covering the peak in demand and minimizing the maximum installed capacity in the system, which decreases investment costs.

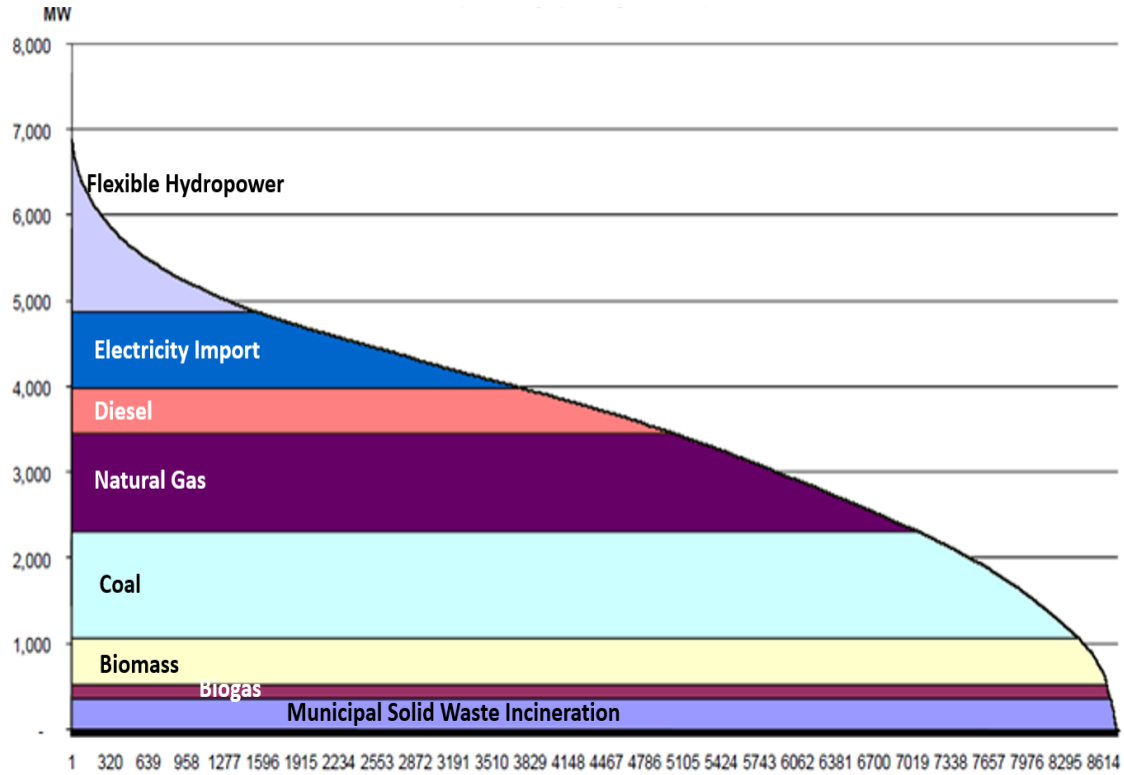

Figure 5: Duration curve for electricity consumption (wind, wave, solar and run-of-river hydro are deduced)

Similarly, heat production from fluctuating sources, i.e. solar thermal, is also prioritized in the load duration curve for heating (see Figure 6). Afterwards, by-product heat generated during bio-refinery processes or electrolysis is prioritized. The rest of the heat that has to be provided will be satisfied by heat pumps or electric boilers that use the electricity surplus (so as to minimize enforced electricity export whenever wind power production, or from any other fluctuating source, is higher than demand), by heat from backpressure cogeneration plants, by heat from extraction CHP units, by heat from storage devices, by heat pumps or electric boilers which require more electricity production (but still without increasing the thermal installed capacity) and at the end, by boilers which burn a fuel.

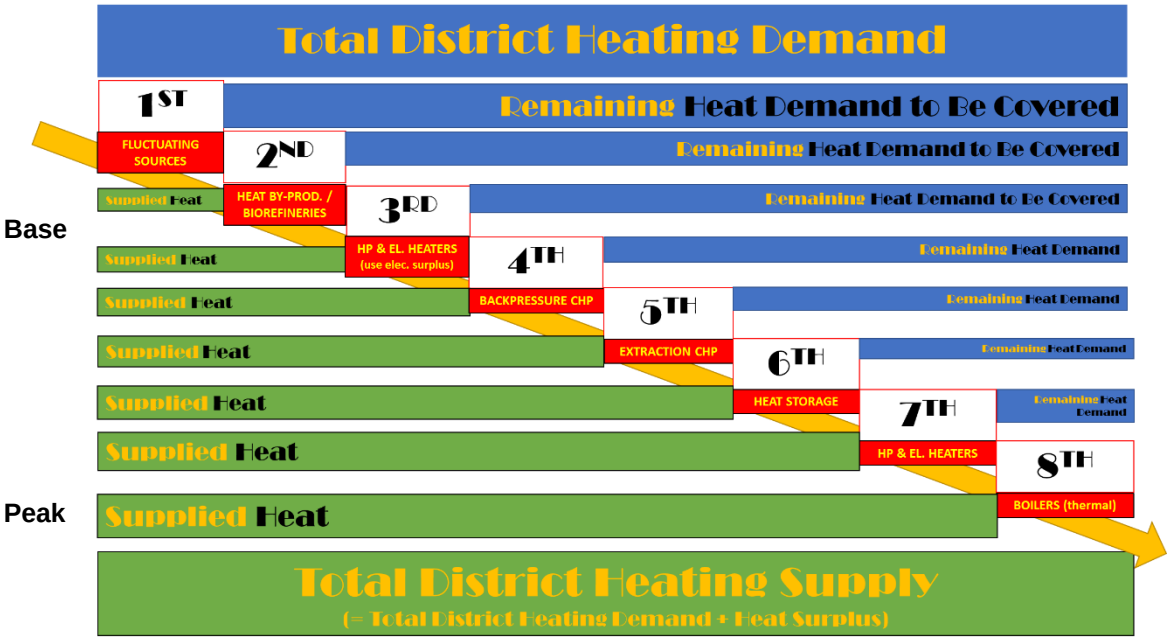

Figure 6. Heat Supply in STREAM