REPORTS OF THE FINNISH ENVIRONMENT INSTITUTE 26 | 2016

# Modeling of Finnish building sector energy consumption and greenhouse gas emissions

**– specification of POLIREM policy scenario model**

**Maija Mattinen and Juhani Heljo**

Finnish Environment Institute

REPORTS OF THE FINNISH ENVIRONMENT INSTITUTE 26 / 2016

# Modeling of Finnish building sector energy consumption and greenhouse gas emissions

## – specification of POLIREM policy scenario model

**Maija Mattinen and Juhani Heljo**

REPORTS OF THE FINNISH ENVIRONMENT INSTITUTE 26 | 2016
Finnish Environment Institute
Climate change mitigation and adaptation

Authors:Maija Mattinen and Juhani Heljo

Subject Editor: Suvi Huttunen

Financier/commissioner: Ministry of the Environment

Publisher: Finnish Environment Institute (SYKE)
P.O. Box 140, FI-00251 Helsinki, Finland, Phone +358 295 251 000, syke.fi

Layout: Maija Mattinen
Cover photo: Vesa Kuusava, Image bank of the Environmental Administration

The publication is available in the internet (pdf): syke.fi/publications | helda.helsinki.fi/syke and in print: syke.juvenesprint.fi

ISBN 978-952-11-4576-6 (PDF)
ISSN 1796-1726 (online)

Year of issue: 2016

## ABSTRACT

Monitoring needs have increased in recent years, and answers to various questions related to the energy use of the building stock are needed faster than before. POLIREM model is a calculation model that assesses the effect of different policy scenarios on the Finnish building stock. The model determines the energy consumption and greenhouse gas emissions, and its purpose is to assist in the reporting and scenario work. The model has a strong linkage with the statistical data, and a top-down approach, which makes the POLIREM different from previous bottom-up style building stock models.

The POLIREM model was originally developed at the Tampere University of Technology in MS excel environment. In this work, the model was converted into a coded version that ensures flexible scenario building, including ease of updating the input data, as well as enabling further integration of new features and/or data sources. This report provides a technical specification of the python-coded scenario model POLIREM.

This report is part of development work to establish national reporting system/evaluation scheme, and fulfils requirements for openness by describing transparently the used evaluation method for building stock modelling.



*Keywords:* Modelling, building stock, energy consumption, scenarios, climate policy, environmental reporting, greenhouse gases, emissions

## TIIVISTELMÄ

Monitoroinnin tarpeet ovat kasvaneet viime vuosina ja vastauksia monenlaisiin rakennuskannan energiankulutusta koskeviin kysymyksiin tarvitaan yhä nopeammin. POLIREM-malli on laskentamalli erilaisten politiikkaskenaarioiden vaikutusten arviointiin Suomen rakennuskannassa. Malli määrittää energiankulutuksen ja kasvihuonekaasupäästöt ja sen tarkoitus on avustaa raportoinnissa ja skenaariotyössä. Mallissa on vahva linkki tilastotietoihin ja top-down lähestymistapa, mikä erottaa POLIREM:n aiemmista bottom-up tyylisistä rakennuskantamalleista.

POLIREM-malli kehitettiin Tampereen teknillisessä korkeakoulussa alun perin MS excel-ympäristöön. Tässä työssä malli muutettiin ohjelmoiduksi versioksi, joka mahdollistaa joustavan skenaarioiden tekemisen, sisällyttäen lähtötietojen helpon päivittämisen, ja joka mahdollistaa uusien toiminnallisuuksien ja/tai tietolähteiden integroinnin. Tämä raportti tarjoaa teknisen spesifikaation python-koodatusta POLIREM-skenaariomallista.

Tämä raportti on osa kehitystyötä luoda kansallinen raportointijärjestelmä/arviointikehikko, ja osaltaan myös vastaa avoimuusvaatimuksiin kuvaamalla läpinäkyvästi rakennuskannan mallintamiseen käytetyn arviointimenetelmän.



*Asiasanat:* Mallintaminen, rakennuskanta, energiankulutus, skenaariot, ilmastopolitiikka,

ympäristöraportointi, kasvihuonekaasut, päästöt

## SAMMANDRAG

Behovet av övervakning har ökat under de senaste åren och det behövs allt snabbare svar på många olika frågor som gäller byggnadsbeståndets energiförbrukning. POLIREM-modellen är en kalkylmodell för bedömning av hur olika politiska scenarion påverkar byggnadsbeståndet i Finland. Modellen fastställer energiförbrukningen och utsläppen av växthusgaser, och dess syfte är att vara ett stöd i rapporteringen och arbetet med att ställa upp scenarion. Modellen har ett nära samband med statistikdata och en top-down approach, vilket skiljer POLIREM från tidigare modeller för byggnadsbeståndet som är av typen bottom-up.

POLIREM-modellen utvecklades vid tekniska högskolan i Tammerfors, och den var ursprungligen avsedd för MS Excel-miljön. I det här arbetet togs fram en programmerad version av modellen, som gör det möjligt att flexibelt ställa upp scenarion, inklusive att enkelt uppdatera ursprungliga data och integrera nya funktioner och/eller informationskällor. Denna rapport erbjuder python-kodning av den tekniska specifikationen av POLIREM-scenariomodellen.

Rapporten är en del av arbetet med att utveckla ett nationellt rapporteringssystem/ en utvärderingsram. Ett annat syfte är att uppfylla kraven på öppenhet genom att på ett transparent sätt beskriva den metod som använts till modelleringen av byggnadsbeståndet.



*Nyckelord:* Modellering, byggnadsbestånd, energiförbrukning, scenarier, klimatpolitik,

miljörapportering, växthusgaser, utsläpp

## PREFACE

Monitoring needs have increased in recent years, and answers to various questions related to the energy use of the building stock are needed faster than before. The ministries produce data about climate policies and measures and the respective impacts under their own administrative sector. In addition, data is compiled for various international agreements, as well as for the reporting of EU directives, monitoring mechanism regulation (MMR) and national Climate law.

POLIREM model is a calculation model that assesses the effects of different policy scenarios on the Finnish building stock. The model determines the energy consumption and emissions, and it was developed to give answers to various questions related to the energy use of the building stock and for scenario work, among other reasons. These answers support the outlining of climate politics and the related decision making, and help in the impact assessment of policies, as well as assist in fulfilling the reporting obligations that the Ministry of Environment has. POLIREM-model uses existing register and statistical information as such.

Software-based realization (with an open-source language) of the model makes the compatibility with data systems possible. Moreover, the model can be integrated in the data systems of the Finnish Environment Institute, among other system, and furthermore, the integration of various input data sources is possible. It is also usable in the context of carbon neutral municipalities (HINKU), and in applications of GIS data. The work also promotes the digitalization of the built environment and it can have various applications in smart city developments.

Software-based realization is a part of a project ensemble that enhances the utilization of various attributes data of the building stock. The ultimate goal is comprehensive advancement of the data systems and use of the data. Additionally, the model development work serves the development work of the national climate-policies reporting system, and the utilization of digitalized information from built environment and its characteristics.

Juha-Pekka Maijala, Senior Engineer,

Ministry of the Environment

## CONTENTS

# 1 Introduction

In Finland, Tampere University of Technology (TUT) has developed a family of models for assessing the energy consumption and related greenhouse gas (GHG) emissions of Finnish building stock. These models and their use have been mainly documented in Finnish (Heljo et al. 2005, 2013). The Finnish Ministry of the Environment has funded the earlier stages of the development of the models EKOREM and ISREM, as well as the newest model – POLIREM that can be used for assessing the effects of different policy scenarios on the Finnish building stock (Heljo et al. 2013).

POLIREM model uses official energy and building stock statistics of Finland, and gives as an output annual energy consumption, GHG emissions, as well as the shares of renewable energy sources and emissions belonging to the emission trading system (ETS). The main idea behind the model is to use statistical information as such and produce a forecast from the latest available data onwards (Figure 1). The main difference of the POLIREM model to the previous models is the built-in strong linkage with the statistical data. This means that the model is rather a top-down than bottom-up. The energy statistics are implemented and used by the model to calculate estimates of the future energy consumption and the related emissions.

Finland has reporting obligations on its national greenhouse gas emissions, as a member of the Europen Union. Additionally, Finland is a Party to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. According to the EU monitoring mechanism, EU Member States have an obligation to prepare every other year a report including information on national policies and measures (PAMs) for the assessment of the projected progress on climate change mitigation. Ministry of the Environment is responsible for the PAMs related to the following categories: waste management, land use planning, use of the buildings and housing, F-gases, as well as machinery. For the reporting purposes, the models of TUT have been used for delivering both the ex-post and ex-ante projections of the building sector (Hildén et al. 2012).

The POLIREM scenario model (Heljo *et al.* 2013) was originally developed in MS Excel environment. The scenario building and especially the implementation of the new statistical data as the model inputs, however, are quite inconvenient procedures with this model application. A program code would be more flexible and easier to execute and update, than the rather large spread sheet model version. A widely-used, open-source programming language, e.g. python could be used for this purpose. Moreover, some of the updating work could be easily automatized in the future, or the coded model could be linked with other models.

The aim of this project was to convert the scenario model POLIREM into a program code version and at the same time to describe the technical specification of the model, and serve as a basic reference for the reporting and other means of use of the model. The report therefore describes the structure of the POLIREM program code, defines the needed input data and the model outputs, as well as explains how different scenario analyses can be run and interpreted with the aid of the developed model. The report is structured as follows. Chapter 2 is devoted to the technical specification of the model. In Chapter 3 we briefly discuss the scenario building and show illustrative results that can be obtained with the aid of the coded model. Concluding Chapter 4 gives suggestions for future improvements.

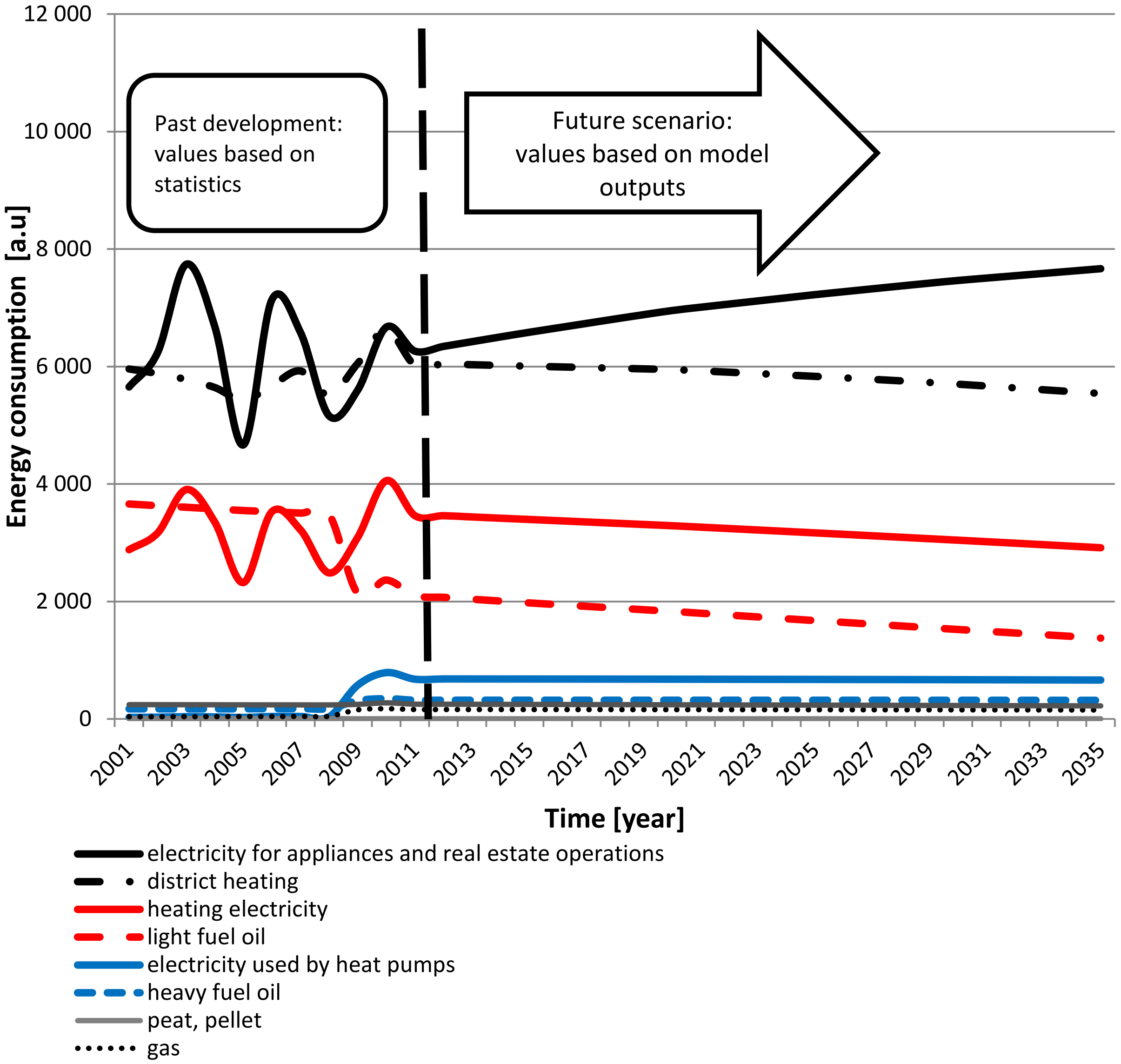


**Figure 1. Principle idea of scenario building with the POLIREM- model. The past development of energy consumption in the building stock is obtained from statistics, and the forecast is formed based on the input information. The fluctuation of the historical values is largely explained by the variation in the outdoor temperature.**

# 2 Specification of the coded POLIREM model

POLIREM is a top down scenario model that uses official energy and building stock statistics of Finland, and gives as an output the energy consumption, greenhouse gas emissions, as well as the shares of the renewable energy sources and division of the emissions between the ETS and non ETS sectors. Fig. 2 presents the schematics of the POLIREM model.

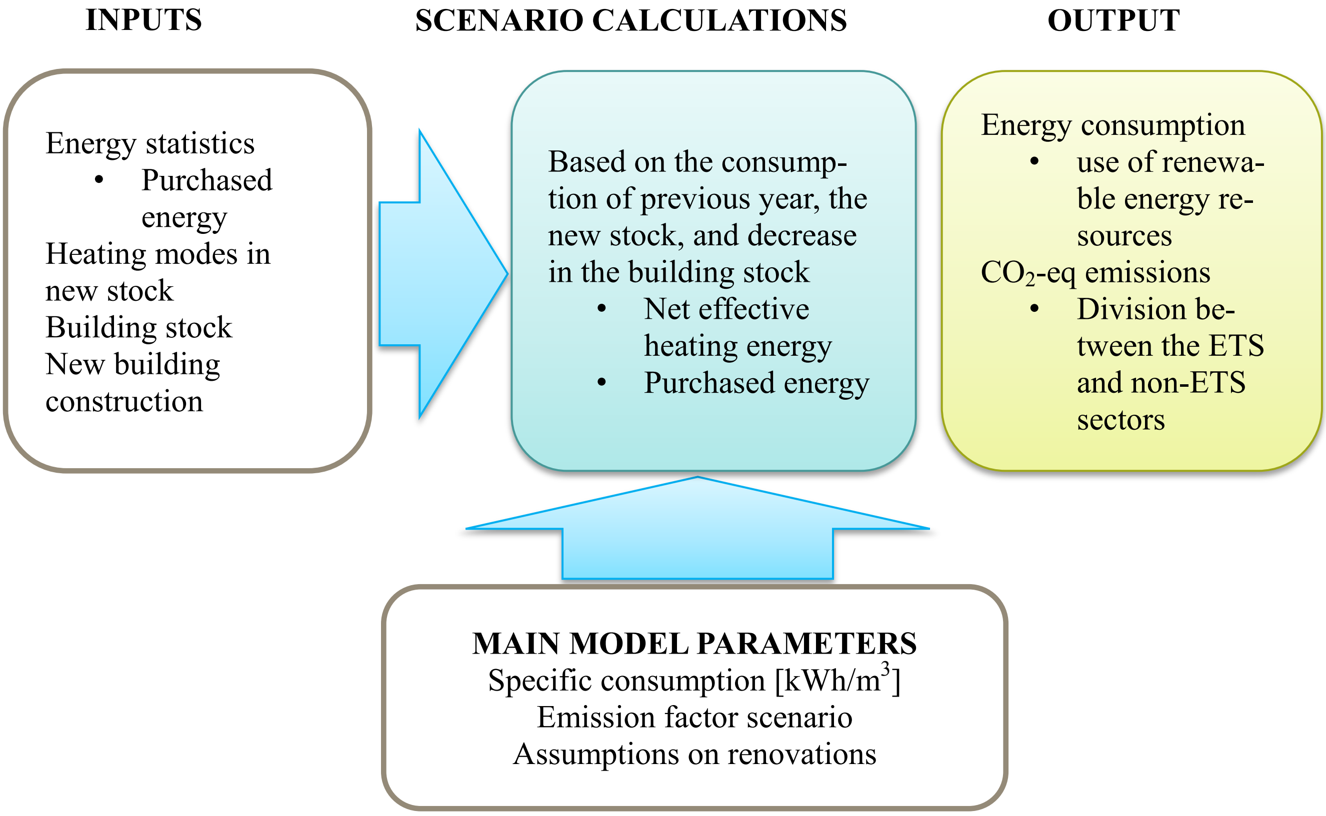


**Figure 2. Schematics of the POLIREM model.**

Numerical simulation model was developed by using python programming language, which is an open-source language that has many additional packages available in the internet. The code was written with the python version of 2.7.2, and the code makes use of the numerical calculation python package (NumPy, version 1.9). Python enables the use of computational loops, where the variables, such as the year, house type or scenario, can be changed for each round.

## 2.1 General structure of the code

In the following, a brief overall look at structure of the code and the essential steps in the calculation code is presented. The schematics and relations of essential python files as well as the input and output files are presented in Fig. 3. The actual calculation procedure (poliremCalculationsAll.py) that holds all the key calculation functions can be called from a test-procedure, for instance. This python file reads and uses values from a constant file (poliremConstantAll.py) that further reads necessary values (typically in a matrix form) from specified text files (.txt, see appendix A). The outputs are printed in comma-separated values format (csv).

Figure 4 shows simplified schematics of the main calculation file that consists of multiple functions. Here the logic of the calculation is described briefly, but all the details can be found in the commented code. The topmost function in the calculation hierarchy begins with initialization procedures, where all the necessary constants and packages are imported and variables initialized. After this, one proceeds to the for- loops, where some calculation parameters are changed; the first loop changes the calculation year in one year step, whereas the second loop changes the house type. The essential calculation steps are taken inside these two loops. The actual calculation begins with defining the emission factor set for the given year with the aid of CalcEmissionFactor(year, [set of other parameters]) function. After this, the house type-specific energy requirement for the given year is calculated with the aid of the purpose-built functions. The calculation deals with three types of stock: the new, the current and the stock that is demolished (reductions in the stock). At the end of the loop, all obtained results are saved in an array. After the loops, the results are saved in csv files.

Table 1 shows the building type classification used in the POLIREM model. The classification corresponds to the one made by Statistics Finland, with some exceptions; the POLIREM model excludes firefighting and rescue service buildings, agricultural buildings, warehouses and other buildings. The building classification of Statistics Finland is very similar to the classification of types of construction (CC) used by Eurostat. The category of other buildings has been identified as being challenging, because most of these kinds of buildings are sauna buildings or outbuildings. Other buildings include cold/unheated buildings as well, and some agricultural buildings produce energy/heat during their operation that can be utilized. The category of other buildings can be included in the analysis if needed.

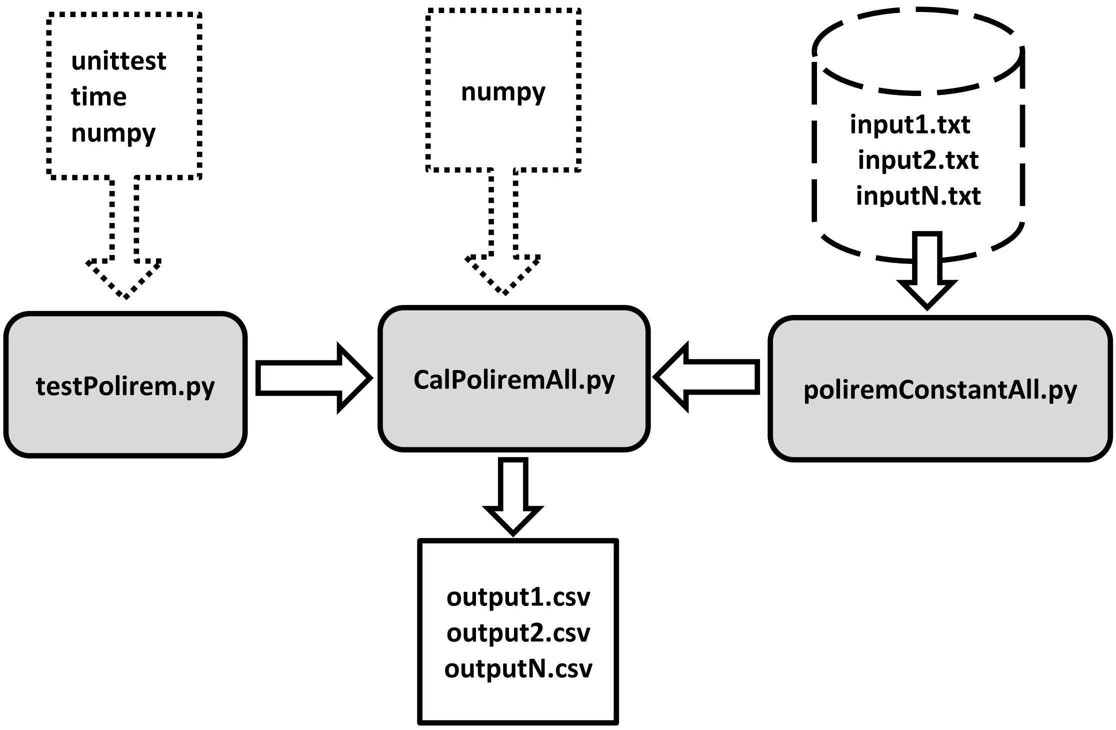


Figure 3. Schematics of the POLIREM model structure in python environment.

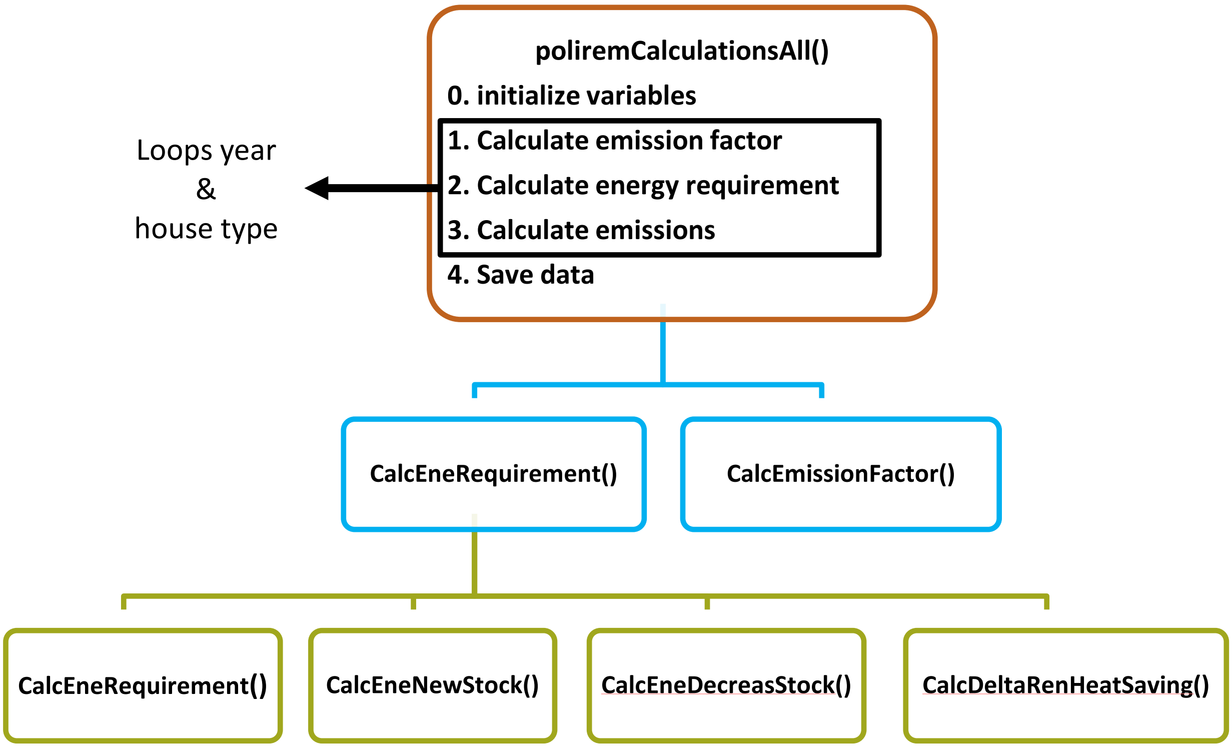


Figure 4. Schematics of the main calculation functions and their hierarchy.

| Table 1. Classification of the building types included in the model (according to Statistics Finland, 1994). | | | |
|---|---|---|---|
| **Building category** | **Building type (in Finnish in brackets)** | **Eurostat CC class**[1] | **Index in the program data structure** |
| Residential | Detached houses (Omakotitalot) | 1110 | 0 |
| | Attached houses (Rivitalot) | 1121 | 1 |
| | Blocks of flats (Kerrostalot) | 1122 | 2 |
| | Free-time residential buildings (Vapaa-ajan rakennukset) | 1110 | 3 |
| Tertiary | Commercial buildings (Liikerakennukset) | 1230 | 4 |
| | Office buildings (Toimistorakennukset) | 1220 | 5 |
| | Transport and communications buildings (Liikenteen rakennukset) | 1241 | 6 |
| | Buildings for institutional care (Hoitoalan rakennukset) | 1264 | 7 |
| | Assembly buildings (Kokoontumisra-kennukset) | Several, including: 1261,1262, 1265 | 8 |
| | Educational buildings (Opetusra-kennukset) | 1263 | 9 |
| Industrial | Industrial buildings (Teollisuusra-kennukset) | 1251 | 10 |

[1]Classification of types of constructions CC, see Eurostat: http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL_LINEAR&StrNom=CC_1998&StrLanguageCode=EN

## 2.2 Specifics of the POLIREM model

### 2.2.1 Building stock

In the calculations, building stock volumes are handled as cubic meters [$m^3$], which can be obtained by multiplying the gross floor area with the floor height.

The most recent values for the building stock volume by fuels can be obtained from the statistics (Statistics Finland, 2015). As a default case, the forecast for stock volumes are based on estimates done by VTT (see Heljo *et al.* 2005, and the references therein) and updates by Eero Nippala.

The heating modes of the new stock are forecasted separately for rural and urban municipalities (one official classification of statistics Finland). This classification also helps to understand the average distribution of heating modes, as in urban areas district heating is more common than in rural areas. The current heating mode distribution (current status of the stock) is derived from the latest statistical data available, and the forecast starts from there until 2035. From 2036 the model uses the distribution of 2035, and assumes that the heating modes remain constant. In the forecast, the findings of the study focusing on the development of heating systems by Vihola and Heljo (2012) can be used.

The distribution of heating systems in the demolished (decreasing) stock is by default assumed to correspond to the average distribution in the whole stock. In the base case, the average distribution of the revised statistics has been used.

Changes in heating types due to renovation activities are handled with the aid of distribution of the decreasing (demolished) stock. This way the POLIREM model is in agreement with the other TUT models. The effect of the use and maintenance is modelled in the renovation activities.

### 2.2.3 Calculation details

This section describes features (input parameters etc.) that enable disaggregation of certain essential parameters under various reporting schemes. There are several themes related to selecting the proper instruments and measures under climate policy and reporting: emission trading system, the use of renewable energy, renovation activities and new building. These themes represent the typical needs for disaggregation.

**Ground-source heat pumps**

Ground heat, in other words, the heat form ground-source heat pumps causes a special case, because both electricity and geothermal heat are utilized. The electricity from the heat pumps is calculated and included in the category of electricity, whereas the heat extracted from the ground is included in the category named ground heat. This classification is in agreement with the tables of Statistics Finland.

**Emission factors**

In the calculation, the emission factors for fuels are defined annually. The idea is that the historical values are updated from the energy statistics. The average emission factor for electricity is used. The use of this average value causes an error when it comes to the electricity used for heating, but for the electricity used for other purposes (electricity for household equipment etc.) the factor works fine.

The shares of renewable energy sources can be calculated with the model. One should note that the emission factors should be in line with the assumed shares of renewables in power production.

**Savings through changes in building use**

The POLIREM model calculates changes/adjustments in the building use, including the following:

- Indoor temperature
- Rate of air exchange
- Air leakage rate
- Water consumption
- Electricity consumption

Changes (reductions or savings) in these parameters are handled as percentages, and they are marked as negative values on the year they are implemented in the stock. Because the percentage has to be filled in the model, the actual estimate of the change has to be done elsewhere. Usually it is assumed that the adjustments are temporary, and their energy-savings are in effect for five years.

**Savings through renovations**

Because the actual volumes of retrofitting are poorly known, the POLIREM model estimates the volumes through costs related to retrofitting activities. The volume of retrofitting affects energy renovations as well. The volume of energy renovations can be obtained from statistics (Statistics Finland, 2016a). The data of renovation building of construction enterprises are used in compilation of statistics as well as by national accounts for estimating the total volume of renovation building (Statistics Finland 2016b). The forecast uses either the latest information about the volume or a linear extrapolation. The share of energy renovations of all retrofits is estimated to be 5%, but this default value can be varied by the model user.

The savings through energy renovation are estimated as follows. The method has been used first time by Kasanen et *al.* (1997). First the value of renovation activities are obtained from the statistics, and the share of energy-saving renovations is estimated. The final energy saving is calculated with the aid of a factor that tells the gained energy saving per monetary value (default value 0.8 kWh/€,a). This factor is the inverse of the product two terms: the energy price (€/kWh) and the average repayment period (year), and it can be modified if necessary. It is assumed that the renovations impact the whole assessment period, in other words it is assumed that the effect of renovation activities is permanent.

# 3 Application of the model

The POLIREM model is suitable for analyzing the impacts of changes on national level in:

- Building use and maintenance (impacts on energy consumption)
- Specific consumption of the building types (impact on energy consumption)
- Renovation volumes (impact on energy-savings)
- Heating modes (fuel split, impact on the greenhouse gas emissions)
- Emission factors (impact on the greenhouse gas emissions)

The main application of the model is to produce useful and essential information for various reporting obligations. The POLIREM model or its data have already been used to fulfil previous reporting demands (Table 2). The model has been used mainly to analyze and assess the impact of policies and measures, and depending on the reporting scheme, the energy savings, greenhouse gas emission or shares of renewable energy sources has been projected. The model has also been utilized in national ex-post analysis and scenario modelling

**Table 2. Relevant reporting obligations related to buildings, and the previous use of the POLIREM model.**

| Agreement/Obligation | Reports, contents | Available outputs from POLIREM |
|---|---|---|
| UNFCC/Kyoto protocol | Biennial Report, National Inventory Report[1] | With measures (WM) and with additional measures (WAM) projections for space heating |
| EU Greenhouse gas monitoring mechanism (MMD), monitoring mechanism regulation (MMR) | Policies and measures, projections, etc. | Projected emissions with and without (additional) policy measures for space heating. |
| EU Energy Efficiency related: Effort Sharing Decision (ESD), Energy Efficiency Directive (EED), Energy Performance of Buildings (EPBD) | Annual reporting and National Energy Efficiency Action Plans[2] (NEEAPs). Including estimated energy consumption, planned energy efficiency measures and the expected improvements | Energy consumption of the building stock, energy savings. |
| Renewable energy (RES) directive | Progress report biennially[3]. The shares of renewable energy in electricity, heating and cooling, and transport. | Renewable shares in electricity and heating consumption of the building stock. |

[1] National reports available at https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive/national-energy-efficiency-action-plans
[2] NEEAPs available at https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive/national-energy-efficiency-action-plans
[3] Progress reports available at https://ec.europa.eu/energy/en/topics/renewable-energy/progress-reports

The modeling can also be useful in building the national energy and climate strategies that are prepared by the Finnish Government (TEM, 2016). The programmed model is also one part of developing an open scheme for scenario making of building stock and the modeling in Finland.

Slightly different parameters and outputs are reported depending on the reporting scheme. Moreover, the reporting format is not always fixed, but can change between reports. These type of changes in the required output format creates challenges in the calculations. So far, one has needed post-processing of some calculation outputs, because the models used are not fully compatible with the required reporting format. The processing has usually been done in various spread sheets that are not well documented, and thus doubtfully easily repeated.

The program-based model enables flexible scenario building, because the core of the calculations that is essentially the equations, remain the same, and only the input files have to be defined before the execution. The selection of input files is easy, and the procedure of forming the input files can be to some extent be automatized in the future. The documentation of the scenario assumptions, input files etc. can be added to the output files, if needed. All the model files are essentially text files that are small in size, and are rarely corrupt. These qualities strengthen the transferability of the model and its results, and also enable any user, who is familiar with the execution of the code, to repeat any calculation at a later point. Moreover, quality checks can be done at any point to make sure that the calculations are in line with the methodology and/or input data. Clear documentation and version management allows that modifications or corrections in the code can be done without messing up the previous calculations. The documentation can easily be incorporated in the code itself as comments, so the code and its documentation can be treated as one package.

The POLIREM model and its coded version enable various analyses of the impacts of policy measures on national, as well as on sub-national (regional, city or even district) levels. Regional analyses are possible in a similar way that EKOREM model has been used to study building stock even on a district level (see Mattinen *et al.* 2014). The POLIREM model is an additional tool that can be used together with other modeling approaches for making relevant synthesis about the changes in the building stock, its energy consumption and the related emissions

## 3.1 Example results

The coded model prints outputs in a database-style format. Thus, the data can easily be processed and visualized in other program, by using pivot tables, for instance in MS excel. One can easily choose the relevant parameters to be presented in a table or a graph, and further aggregate to meet the output requirements. By using template excel sheets, where the graph types are already selected, it is possible to have the results in a specified format easily and quickly. Some examples of pivot style graphs produced in MS excel are shown in Figures 5 and 6.

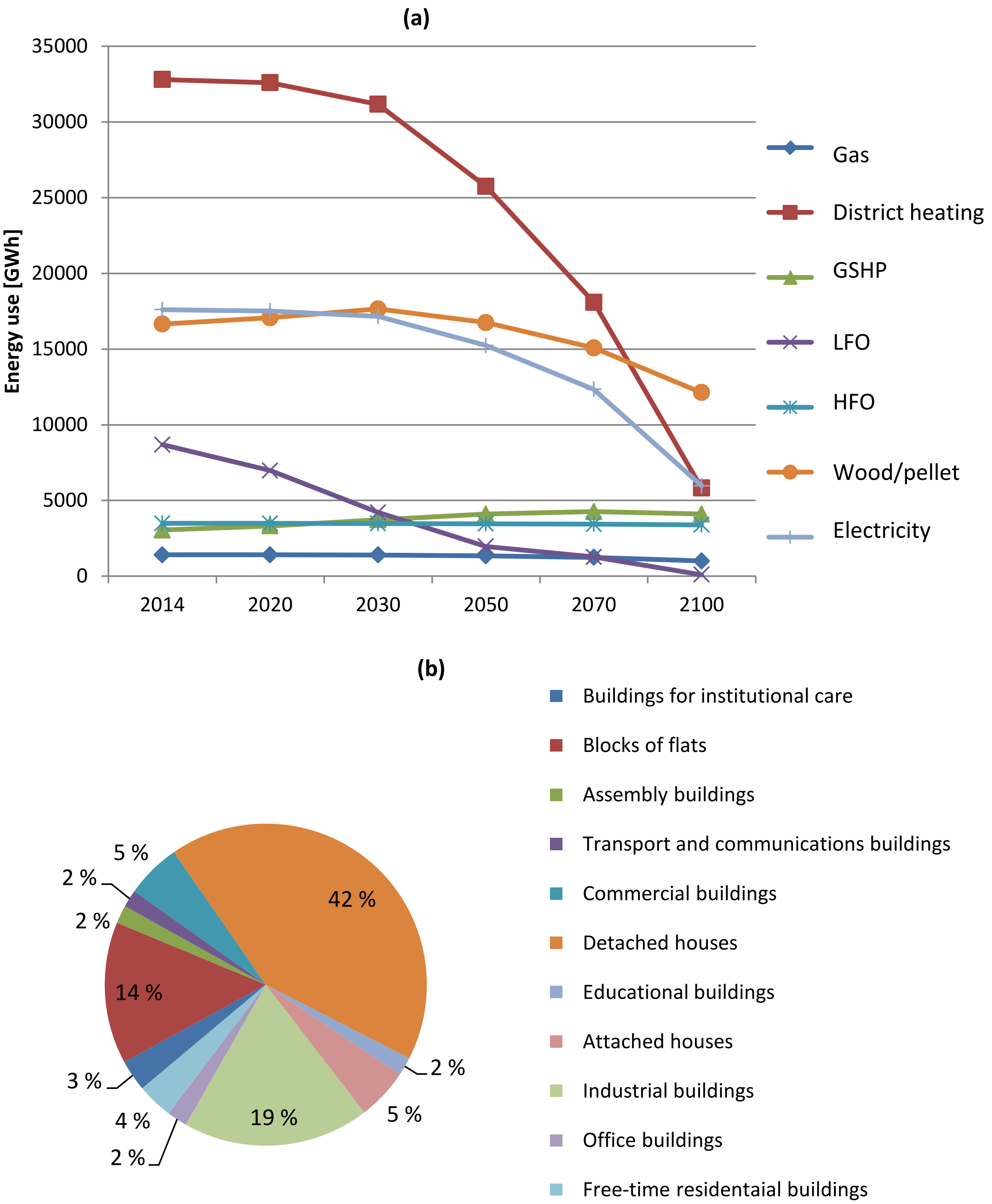


**Figure 5. Examples of pivot style result presenting: a) temporal development of energy consumption [GWh], the graphs present consumption of selected energy carriers (GSHP=ground-source heat pump, HFO=high fuel oil, LFO=light fuel oil), b) split of the energy use between the house types.**

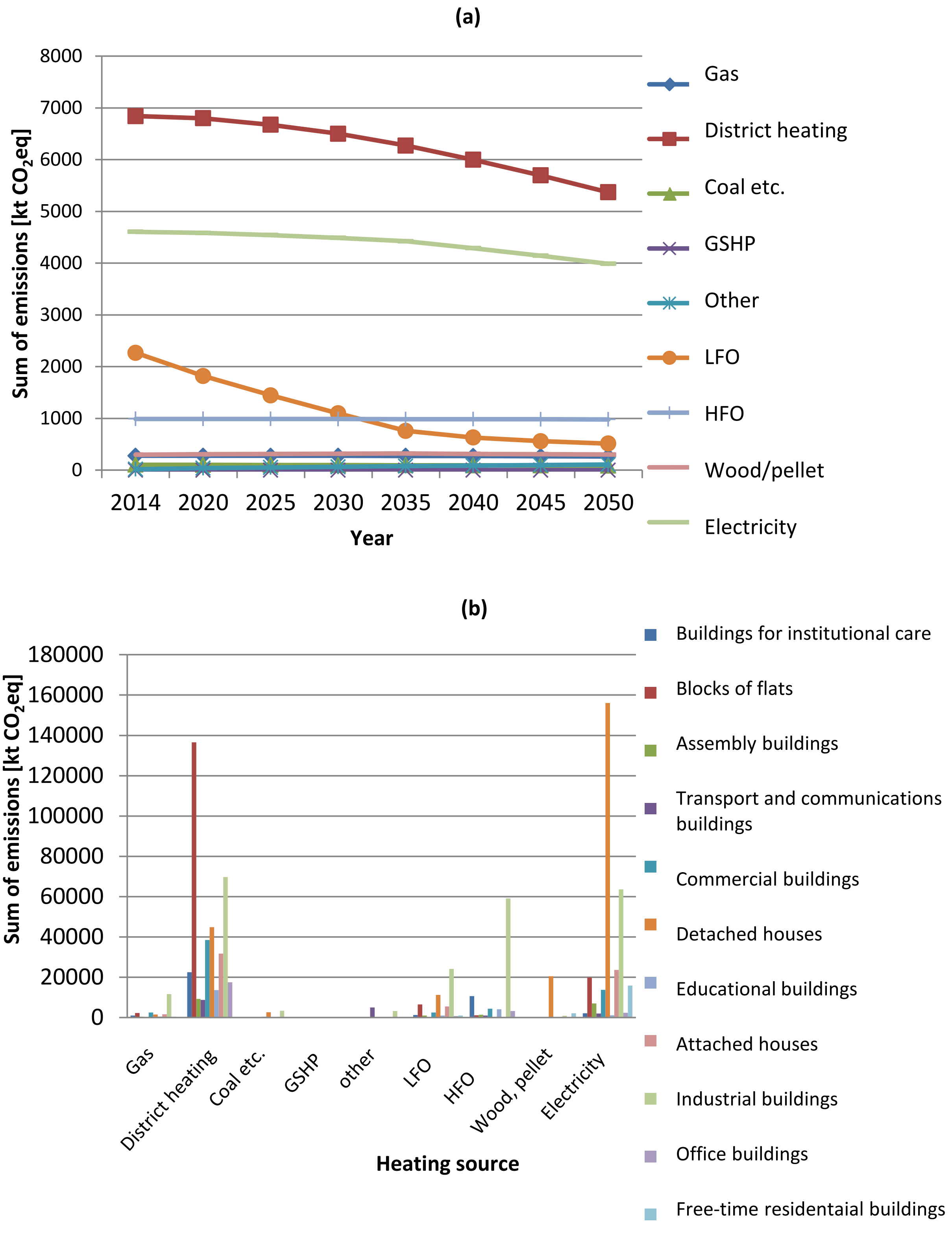


**Figure 6. Examples of pivot style result presenting greenhouse gas emissions (kilotons of carbon dioxide equivalent) [kt $CO_2$eq]: a) emission scenario shows the emissions related to selected energy carriers (GSHP=ground-source heat pump, HFO=high fuel oil, LFO=light fuel oil), and b) split of emissions by house types.**

# 4 Suggestions for future improvements

## 4.1 Improvements of calculations

Some improvements in the emission factors could be done. The electricity use could be divided based on the power duration curve into three categories (base, mid, peak, see Heljo and Laine, 2005), and the respective emission profiles of these categories (see also Kopsakangas-Savolainen *et al.* 2015). This way various electricity use profiles could be taken into account.

In the estimation of the share of renewable energy sources and ETS shares are at the moment challenging, because the values for each heating mode are absent in the official statistics. This shortage could be communicated with Statistics Finland so that in the future, the needed values could be obtained from statistics. The needed parameters, however, can be included in the coded model quite easily.

Savings through changes in building use are modeled in a simple way (percentage) that reduces the transparency. Thus, it might be more difficult to reproduce some of the scenario calculations, as the assumptions or the savings are documented elsewhere. In the future, the approach could be improved with a more detailed modeling component which would be more transparent than a bare percentage value.

In the future, the validity of the calculation code should be confirmed. This confirmation can be done by running a test scenario with the original calculation model and by comparing obtained results with the outputs of the program code. The comparing work is rather straightforward procedure, if all the input data and excel version are available. The possible deviations from the original model or errors are then to be fixed in the program code. In this type of quality check one of the already reported scenario analyses can be used.

## 4.2 Automatization of information retrieval

Some of the information retrieval has been done manually so far. The main data source is Statistics Finland, and they use an open source interface (PX-Web application programming interface). It is possible to retrieve tables with the PX-Web API in excel or in csv format (Statistics Finland, 2016c).

One could automatically retrieve, for instance, the energy sources for space heating by type of building (Energy statistics, table 7.3), the latest volumes of building and dwelling production (via PX-Web service), and the latest information about renovation activities (PX-Web service). In addition, useful information for the emission factor forecasts can be obtained from Statistics Finland, as well as Finnish Energy (an organization representing the energy companies in Finland). The trends in fuel mix in the Finnish energy production, and thus in the emission factors for electricity and district heating can be obtained from these sources.

The data being available through the free PX-Web database, it is possible to add an extension to the existing program code that would retrieve the desired data from Statistics Finland. Additionally, retrieving data from a web page can be automatized, and run even in excel-environment, assuming that the data is in a table on the page. In the case the input data is not available for free, one might need a more sophisticated program in order to retrieve the data automatically, or one even needs to develop a new interface for the data retrieval. Forming a new interface for data exchange is however resource-demanding task that should be considered perhaps in the case of a web-based calculation application in the future.

## 4.3 New model features

In the core of the model is the forecast development of the Finnish building stock, including volumes of reducing stock and new production. The forecast should be updated regularly, and even automatically. It would be advantageous, if the forecast would be generated separately, so it could be used for other purposes as well. In the future, the stock development forecast could be a separate script that is easily linked with POLIREM model. The user could then easily make detailed scenarios about the stock development and its impacts on energy consumption and greenhouse gas emissions. It would also be beneficial to produce a similar separate forecast for the emission factors, as the information is usually needed in other assessments too.

Every reporting scheme has specific needs and requirements for the scenario variables. In the future, the needs could be taken into consideration by specifying different output sets that could be selected by the user in the beginning of a calculation. In its simplest form, the user would just specify the calculation mode in the code according to the reporting needs, and the program would generate the data in desired form automatically. At the moment the model outputs (csv-files) can be processed further, for example, in excel or other calculation environments. If a different output format is known, it can be easily implemented in the program code that only requires modest coding efforts.

In the future it will be possible to integrate new data sources to the model that can be used to improve the model accuracy. The database of building energy certificates, which is maintained by ARA, is one example of such data source. Nowadays a growing number of cities and municipalities are gathering detailed data about their energy consumption. Thus, metered energy consumption in cities or blocks of buildings could be utilized in city or district level analysis.

The building stock model family (ISREM, EKOREM, and POLIREM models) developed by TUT excludes information about the costs of measures or other economic impacts. There is, however, a clear demand for this kind of information. The possibilities of adding or integrating cost assessments into the model could be considered in the future. Furthermore, the rate of economic growth (changes in gross domestic production) influences the new construction and refurbishment activities, and thus has an effect on the building stock and its energy consumption. In the future, the possibilities to integrate the dynamics between economy and the building stock in the modelling approach should at least be considered.

## APPENDIX A

Specification of the input data is collated in Table A1.

| Table A1. Specification of input data (text files) for the calculations. | | |
|---|---|---|
| Description of the input data | Size of the data | File name (.txt files)[a] |
| includes the user input of total volume of new stock for years | [n_year x n_housetypes] | userNewStockTotAll2011_2100 |
| Fuel shares in new stock | [n_fuel*n_housetype x n_years] = [99 x n_years] | userNewStockFuelShares_2011_2035 |
| includes the emission factors for 10 different fuel/energy sources for years 2001-2011 | [n_fuels x n_years] = [10 x 11] | EmissionFactors2001_2011 |
| Volume of decreasing stock by fuels (only for detached houses) | [n_fuels x n_years] = [9 x 26] | userFuelsVPoistuma |
| Volume of the whole stock by fuels | [n_fuels * n_housetypes x n_years] = [99 x n_years] | userVolumeStockAll_2001_2100 |
| Annual heating energy saving from renovation activities | [n_housetypes x n_years] = [11 x n_years] | userHeatAll2001_2100 |
| Efficiency of fuels (fuel economy) in the building stock | [n_fuels x 1] = [9x1] | Efficiencyfactors_fuels |
| Energy demand (by fuels) for the building stock in year 2011 | [n_fuels x n_housetypes] = [9x11] | userEneRequirementAll2011 |
| Specific energy consumption (use) for new stock | [n_fuels x n_housetypes] = [9x11] | userSpecificEneUseAll2012 |
| Gains from household and real estate electricity, solar etc. for all building types | [n_GainTypes x n_housetypes] = [2 x11] | userGainsAll |
| Volume of stock reduction by fuels for all building types | [n_fuel*n_housetype x n_years] = [99 x n_years] | userPoistumaVolumeAll2011_2100 |
| Specific consumption of heat for decreasing stock in 2001 for all building types | [n_fuels x n_housetype] = [9x11] | userPoistumaSpecHeat2001All |
| Indices for decreasing building stock | [n_housetype x n_years]= [11 x n_years] | userConsIndexPoistumaAll |
| Shares of renewable for fuels | [n_fuels x n_years] = [9 x n_years] | userRenewableShares2001_2100 |
| Share that is included in emission trading system (ETS) for each fuel | [n_fuels x n_years] = [9 x n_years] | userETSshares2001_2100 |
| [a] The file name can be changed by the user in poliremConstantAll.py file whenever necessary. | | |

## REFERENCES

Heljo, J., Laine, H., 2005, Electrict heating and heat pumps as electricity consuming devices and sources of emissions in Finland. Approach and model for assessing $CO_2$-eq. emissions. (in Finnish: Sähkölämmitys ja lämpöpumput sähkönkäyttäjinä ja päästöjen aiheuttajina Suomessa, näkökulma ja malli sähkönkäytön aiheuttamien $CO_2$-ekv. päästöjen arviointia varten, abstract in English). Tampere University of Technology, Institute of Construction Economics, Report 2005:2.

Heljo, J., Nippala, E., ja Nuuttila H., 2005, Energy consumption and $CO_2$-eq. Emissions of buildings in Finland (in Finnish:Rakennusten energiankulutus ja CO2-ekv päästöt Suomessa, abstract in English). Tampere University of Technology, Institute of Construction Economics, Report 2005:4.

Heljo J., Vihola J., 2013, Development of energy consumption and greenhouse gas emission of the building stock, POLIREM simulation and prediction model for energy political decision making and impact assessment of policy measures (in Finnish: Rakennuskannan energiankäytön ja kasvihuonekaasupäästöjen kehittyminen, Energiapoliittisen päätöksenteon simulointi- ja ennakointimalli POLIREM politiikkatoimien vaikutusten arviointiin ja seurantaan), Tampere university of Technology.

Hildén, M., Mattinen M., Mäenpää, I., 2012, EU-reporting of policy measures to mitigate climate change within the administrative sector of the Ministry of the Environment, Reports of the Finnish Environment Institute 14/2012.

Kasanen,P., Heljo,J., Lund, P., Mäenpää, Nippala, E., 1997, Assessment of the profitability of the energy-saving policy (in Finnish, Energiansäästöpolitiikan tuloksellisuuden arviointi), Kauppa- ja teollisuusministeriön tutkimuksia ja raportteja 11/1997.

Kopsakangas-Savolainen, M., Mattinen, M. K., Manninen, K., Nissinen, A., 2015, Hourly-based greenhouse gas emissions of electricity - cases demonstrating possibilities for households and companies to decrease their emissions, Journal of Cleaner Production, in press, DOI: 10.1016/j.jclepro.2015.11.027

Mattinen, M., Hildén M., Petäjä, J., 2012, Calculations of greenhouse gas emissions of waste sector and F-gases for policy scenarios in Finland, Finnish Environment, 18/2012.

Mattinen M., K., Maija K. Mattinen, Juhani Heljo, Jaakko Vihola, Antti Kurvinen, Suvi Lehtoranta, Ari Nissinen, Modeling and visualization of residential sector energy consumption and greenhouse gas emissions, Journal of Cleaner Production, 2014, 81: pp. 70-80. DOI: 10.1016/j.jclepro.2014.05.054

Statistics Finland, 1994, Classification of Buildings, Available: http://tilastokeskus.fi/meta/luokitukset/rakennus/001-1994/index_en.html (Accessed 16.1.2015).

Statistics Finland, 2015, Buildings and free-time residences, meta information, Availabe at: http://www.stat.fi/til/rakke/meta_en.html (Accessed 28.7.2015).

Statistics Finland, 2016a, PX-Web, Building renovation, Available at: http://pxnet2.stat.fi/PXWeb/pxweb/fi/StatFin/StatFin__rak__kora/?tablelist=true&rxid=96746eae-3a69-4a93-a15b-4c109e4503b3 (Accessed 1.6.2016).

Statistics Finland, 2016b, Data collections, Renovation building of construction enterprises, Available at: http://www.tilastokeskus.fi/keruu/rako/index_en.html (Accessed 1.6.2016)

Statistics Finland, 2016c, PX-Web API specification, Available at: http://pxnet2.stat.fi/api1.html (Accessed 19.1.2016).

TEM (Ministry of employment and the economy), 2016, National Climate and Energy Strategy, Available at: www.tem.fi/en/energy/energy_and_climate_strategy (Accessed 26.1.2016)

Vihola J., Heljo, J., 2012, Development of heating systems in 2000-2012, literature review (in Finnish: Lämmitystapojen kehitys 2000-2012 aineistoselvitys, abstract in English), Tampere University of Technology, Department of Civil Engineering, Construction Management and Economics, Report 2012:10.

MODELING OF FINNISH BUILDING SECTOR ENERGY CONSUMPTION AND GREENHOUSE GAS EMISSIONS

FINNISH ENVIRONMENT INSTITUTE

S Y K E

ISBN 978-952-11-4576-6 (PDF)
ISSN 1796-1726 (online)