WFEO energy committee
Minutes of October 20, 2018

By Daniel Favrat Vice chair replacing Sam Grossmann (absent)

List of participants (see also appendix 1)

Philip Pascall <philip.pascall@me.com>, bn.altaweel@paaet.edu.kw, Abdul Majeed Al Gassab <amalgassab@gmail.com>, president@iesf.fr, jmeegoda@gmail.com, jmriungu@yahoo.com, jean@Venablesconsultancy.co.uk, rob.curd@ice.org.uk, zeljko.vukelic@ntf.uni-lj.si, ikinuwa@yahoo.com, francois.giger@mines.org, bk.chady@gmail.com

1. **The Committee reviewed and approved** the minutes from 2017 Meeting in Rome, Italy (although very few present had attended)

2. **Review Energy Committee Activities since Rome:**
   a. *Nuclear Report – FC Chan* No show
   b. Fossil Fuels Decarbonization Technologies-Olivier Appert, proposal at end of agenda
      So far only Daniel Favrat mentioned an interest in the task force
   c. Sustainable Energy Renewal – Pradeep Chaturvedi *no show*
   d. Wind Power – Dermot Roddy *no show*
3. **Round table review of the activities in the countries represented:**

UK (Philip Pascall): presented a powerpoint summarizing UK scenarios for 2050 and described the approach taken with the model ESME which has a suite of models including 400 technologies. Some key challenges and opportunities are offshore renewables potential, heating need for poor quality building stock, deeper decarbonization of the transport sector. See appendix 1 for more. The city of Leeds is also mentioned for actions regarding H_2.

Switzerland (Daniel Favrat) pointed out the strong interest in the UK approach presented and indicated that another calculator was made in Switzerland that included not only yearly average but also the average monthly distribution (see appendix 2 and/or go to the site www.energyscope.ch for more). Mention was also made that there is presently a strategy to encourage short movies on energy to be made by young directors. One in particular deals with the social issues of wind power and will soon be available with English subtitles.

Kuweit (Bader Altaweel): mentions that a “problem for renewable development” is that the electricity is cheap. 2 key points are highlighted (see appendix 3) are for PV the cooling of the panels and the resistance/performance in stormy weather. He mentions a conference on Key driver for clean energy transition…to take place on December 2-3, 2018

Bahrain (Abdul Majeed Gassab): Among others noted that hindrance of promoting renewable energy in Arabian Gulf States due to substantial subsidizations on energy products. New models based on feed-in tariff should be introduced to promote the concept. Wind energy is now looked at very seriously and pilot schemes now in operations. A new conference on Energy management will be organized in October 2019 in Bahrain. He encouraged Energy Committee members to submit their candidates to support the conference technical committee and submit papers. He also offered the Energy Committee members a free conference attendance.

Slovenia (Željko Vukelic): 30% of electricity is produced from hydroelectric power plants, 35% from thermal power plant (coal), 30% from nuclear power plant and the other 5% from wind, solar. After 2030, people from Slovenia will be able to buy only electric cars and they would start to close coal mines in 2025. There are however doubts about how Slovenia will be able to provide enough electricity after 2025 for households, transport and industry. Mention is made of the future World Construction to take place in April in Slovenia (see wfeo.org)

Sri Lanka (Jayavilal Meegoda) highlighted the financial difficulties for the implementation of renewable

Kenya (Julius Riungu): has 92% of renewable for electricity -based on geothermal and biomass. Initially it was encouraged by feed-in tariffs but now the trend is to go for an auctioning system.

France (François Giger) presented the following detailed content

- Present CO_2 content of French electricity is <30 g/kWh, with 75% nuclear and 16% hydro
- All oil-fired power plants >20 MW will be shut down and the coal fired plants are planned to be offline by 2022.
- He estimates that the development of non-dispatchable renewables (wind and solar) as requested by the EU targets would imply an increase of CO_2 emissions due to the need of fossil fired backup peaking units. The question remains however subject to the technological development of inexpensive electricity storage (beyond pump-turbine STEPs: "Station de Transfert d'Energie par Pompage")
- The next 5 years French energy policy plan (PPE= "programmation pluriannuelle de l'énergie") is due still this year
- To be noticed: The CO_2 emission rights in EU have jumped from a very low level of €5/ton to €18-20/ton now (with even a peak value of €25/ton on Sept 13,2018)
- Transport sector is a significant emitter of Greenhouse gas (GHG) and there is a strong push for electric vehicles at least seen from the recent Paris Auto show. Apart from that, there is a switch from Diesel to gasoline cars that is likely to result in an increase of GHG.
- He finally addresses the problem of what he calls biased public information in particular on the relative importance of Life Cycle Analysis of competing energy sources (Nuclear versus Wind in particular)

4. *Update from the WFEO Executive Office– Jacques de Méreuil*

   Jacques was not present but Théophane Bélaud briefly attended the meeting and insisted on the wish from the secretariate to have more input from the Energy committee in particular for the website.

   One suggestion made was to develop short movies on some remarkable realization in our countries.

   The idea of a reward for the best engineering projects in energy is also another idea to be worked out.

5. CEE Activity on Climate Change Mitigation – Andy Webster
   The CEE wishes to develop more activities on the mitigation aspect of climate change and since the energy sector is the major contributor **it would make sense to have more joined activities with a task force between CEE and CE**.

6. World Construction Forum 2019 in Ljubljana
   Everyone is invited to contribute to this forum
7. Review of Task Force Chairs
   a. Replacement of Geraldo Tavares-Wind Chair- we have been trying for 4 years to find a replacement. *No solution yet*
   b. Replacement of Carsten Ahrens – Solar Chair- we have been trying for 4 years to find a replacement. *No solution yet*
   c. Other Chairs leaving?

   jmeegoda@gmail.com would volunteer for any activity related to Energy, especially in Transmission and distribution Engineering and electric utility management.

8. Possible New Task Force
   a. Energy Hierarchy (conservation, efficiency, renewable and low carbon) – this was mentioned by the committee members as a new group, but no one has stepped up to lead the effort. *No solution yet*

9. Bahrain Energy Management Conference – Leading Alternatives- Abdul Majeed Al Gassab
   a. Date has been changed to October 2019

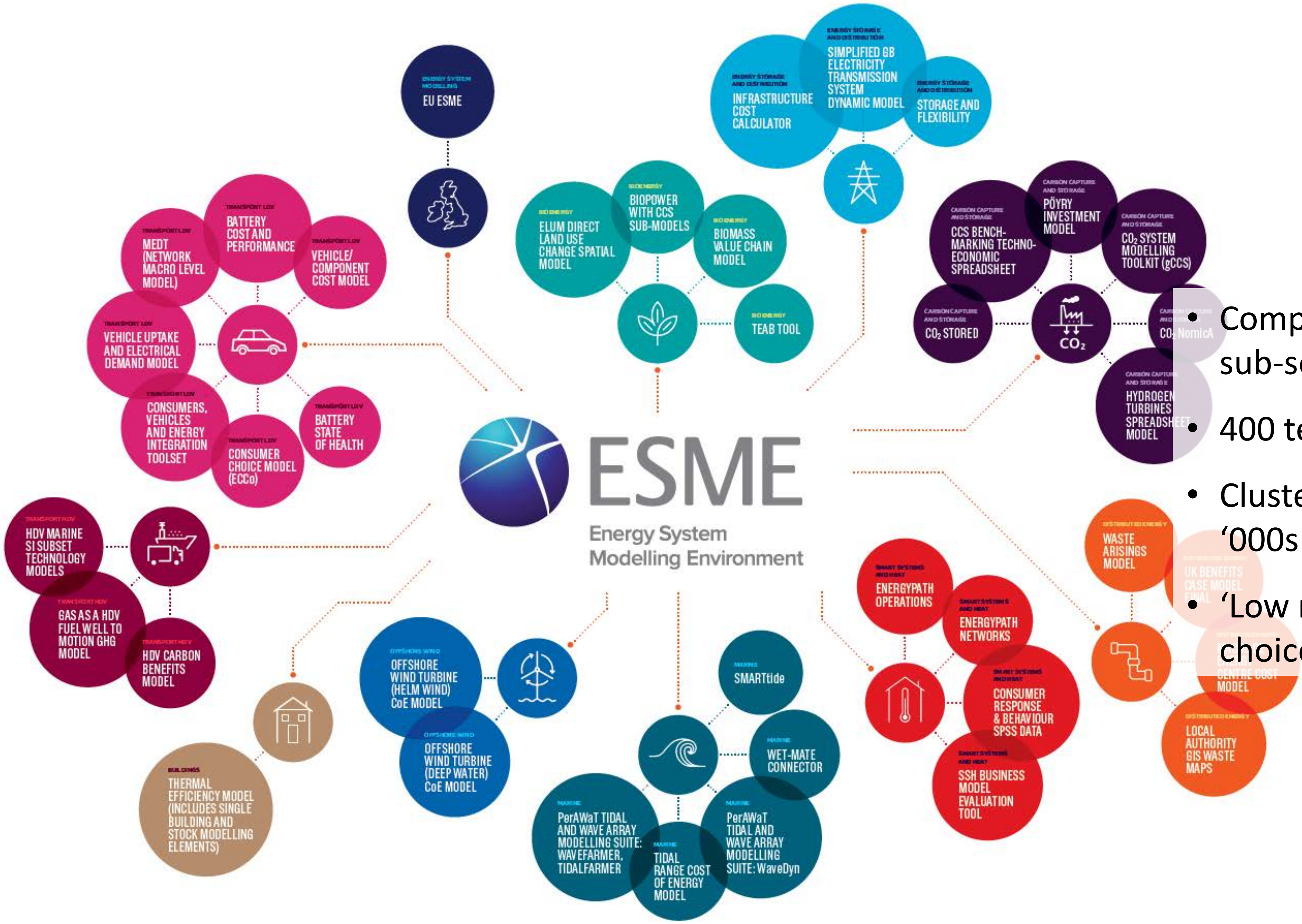
Appendices

1. Presentation form UK by Philip Pascall
2. Paper on another scenario calculator by D.Favrat
3. Powerpoint from Kuweit (Bader Alajmi)
4. Energy committee London Oct 2018 attendance list

OPTIONS, CHOICES, ACTIONS

UPDATED 2018

- New report Oct-18, updates 2015 report
- Energy Technologies Institute and Energy Systems Catapult
- Whole UK energy system
- Least cost optimisation to 2050
- In depth analysis: real data, '000s simulations
- Many man-years and £multi-M
- Peer reviewed
- Used by BEIS, CCC, academia, industry
- ***Aim:*** stimulate discussion with stakeholders



- Comprehensive suite of sub-sector models
- 400 technologies
- Clusters of results from ‘000s simulations
- ‘Low regret’ technology choices

CLOCKWORK

Well-coordinated national strategy

PATCHWORK

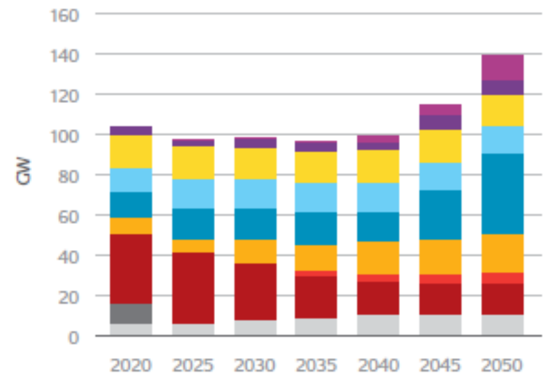
Regional strategies; societal engagement

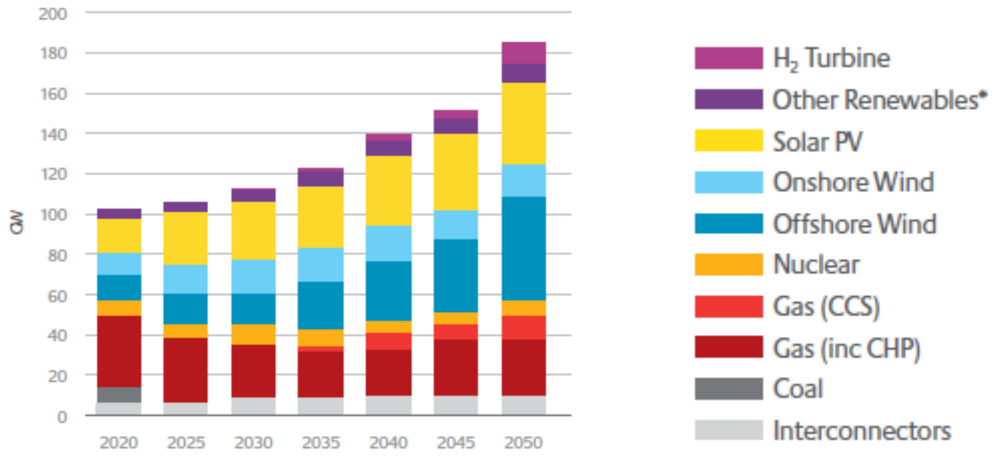
- Not forecasts: two plausible scenarios, many pathways
- Challenges and opportunities for UK, eg:
  - Offshore renewables potential
  - Heating needs for poor quality building stock
  - Hydrogen for heat; not silver bullet
  - Deeper decarbonisation of transport, mix of same solutions

Example output: electricity generation

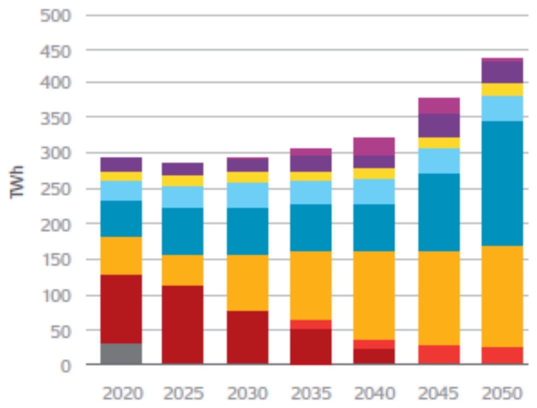
CLOCKWORK | PATCHWORK

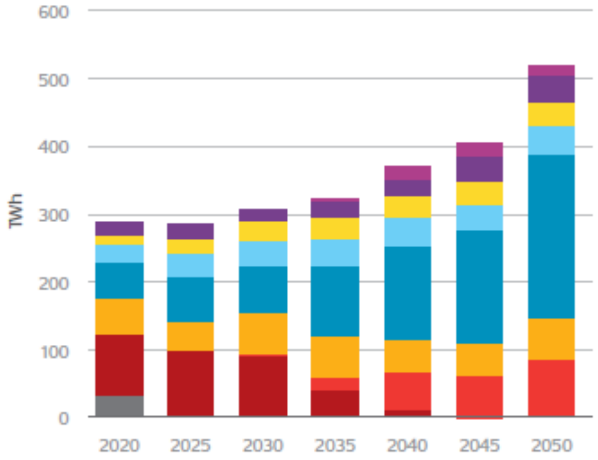
Electricity CAPACITY (GW)





Electricity GENERATION (TWh)





* Other renewables include Biomass, Energy from Waste, Hydro and Tidal

Key Messages

01 A balanced, multi-vector approach can deliver an affordable, low carbon UK energy transition, with costs rising to around 1% of GDP by 2050. Without certain key technologies, meeting carbon targets would be much harder, jeopardising industry and severely limiting lifestyle choices.

Affordable low carbon

02 The potential for innovation across a range of technologies means we cannot be prescriptive about the precise mix over a 30-year period. Developing a basket of the most promising solutions offers strategic flexibility, as opportunities and barriers become clearer.

Mix of technologies

03 Sustainably grown Biomass has the potential to become a critical resource for the UK energy system. It can be burned directly for heat and power, or converted into low carbon gases and liquid fuels to decarbonise hard-to-treat sectors.

Biomass

04 Carbon Capture and Storage (CCS) offers a versatile solution with applications across power, industry and hydrogen production. Without CCS, UK carbon abatement costs could be double by 2050.

CCS

Key Messages

CATAPULT Energy Systems

05 Bioenergy and CCS are especially valuable in combination. Together, they offer the potential for negative emissions to counterbalance the continued use of fossil fuels in difficult sectors like aviation. Without negative emissions generated in the UK, achieving a 'net zero' emissions target will require the prohibition of certain industrial activities and lifestyle choices or reliance on imported carbon credits from other countries.

Negative emissions

06 System flexibility requirements will change, and new approaches will be needed. Storage of electricity, heat and gas (including hydrogen) will all have a role to play, along with backup generation in power and hybrid systems for heat.

System flexibility

07 Low carbon heat solutions exist but consumer experience is key. Most UK households have relied on gas boilers for more than a generation. Low carbon alternatives will require powerful consumer propositions that match, if not exceed, current experiences.

Low carbon heat

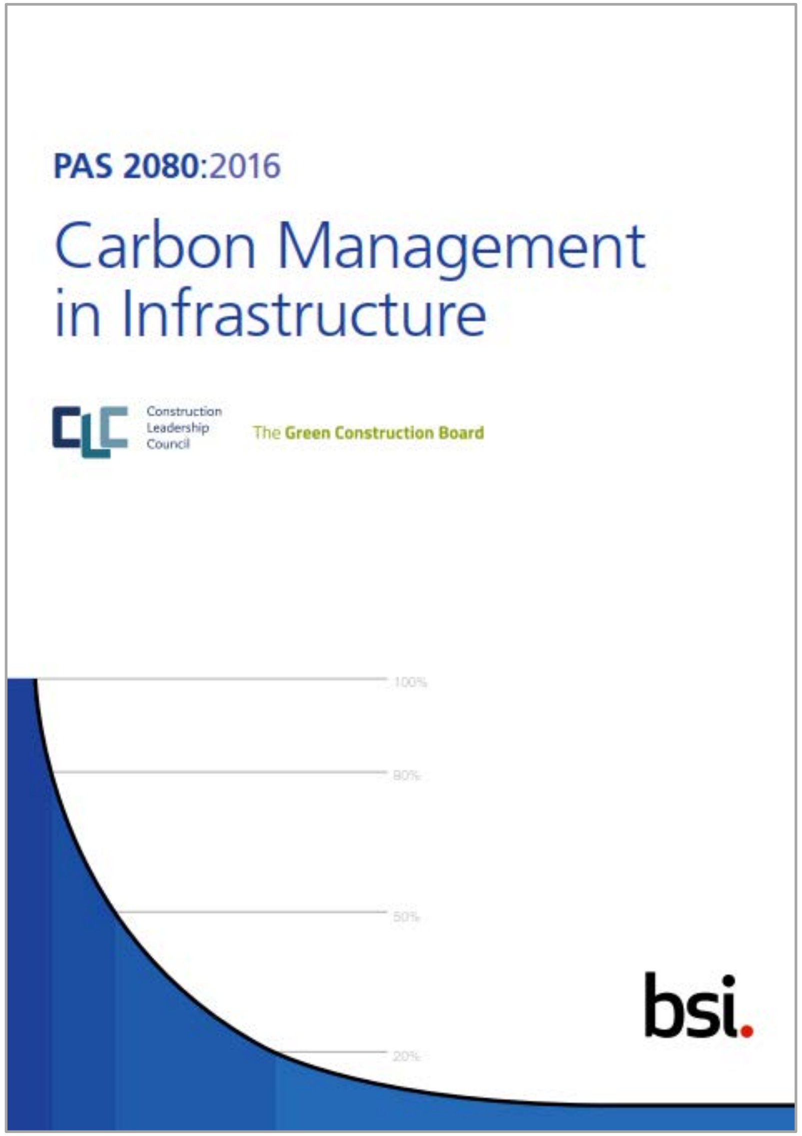
08 Electrification of transport can begin to deliver significant carbon reductions from 2020 onwards. The speed of transition remains uncertain, but whole system coordination can ensure we make best use of existing electricity system capacity, minimising the need for investment in upgrades to support mass adoption of plug-in electric vehicles.

Electrification of transport

https://www.eti.co.uk/options-choices-actions-2018

https://d2umxnkyjne36n.cloudfront.net/insightReports/Options-Choices-Actions-Updated-Low-Res.pdf?mtime=20181003113219

PAS 2080: 2016 Carbon Management in Infrastructure



Methodology for whole life cycle carbon reduction

- 75% reduction in carbon over whole life cycle
- Anglian Water: -54% ‘capital carbon’ & -22% cost since adoption to 2016
- Principles:
  - ➢ Leadership
  - ➢ Quantification
  - ➢ Target setting
  - ➢ Monitoring
  - ➢ Reporting
  - ➢ Continuous improvement
  - ➢ Responsibility through supply chain

What does PAS 2080 mean for our industry?
https://www.ice.org.uk/eventarchive/carbon-management-in-infrastructure-london

Cut carbon to cut cost

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Strategic energy planning for large-scale energy systems: A modelling framework to aid decision-making

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ABSTRACT

Concerns related to climate change and security of energy supply are pushing various countries to make strategic energy planning decisions. This requires the development of energy models to aid decision-making. Large scale energy models are often very complex and use economic optimization to define energy strategies. Thus, they might be black-boxes to public decision-makers. This work aims at overcoming this issue by proposing a new modelling framework, designed to support decision-makers by improving their understanding of the energy system. The goal is to show the effect of the policy and investment decisions on final energy consumption, total cost and environmental impact.

The modelling approach and the model structure are described in detail. Final energy consumption is represented as the sum of three main components: heating, electricity and transportation. In this framework, a sequential modelling strategy allows the assessment of the competition between electricity and fuels in the heating and transportation sectors without increasing the model complexity. A monthly resolution is chosen in order to highlight seasonality issues of the energy system. Developed with the goal of being easily adaptable to any large-scale energy system, the modelling approach is currently implemented within an online energy calculator for the case of Switzerland.

1. Introduction

Extending current trends to the year 2050, the IEA (International Energy Agency) projects a 70% increase in global energy demand and a 60% increase in greenhouse gas emissions compared with 2011. This would imply potentially devastating consequences related to climate change. Measures to constrain the expected increase in global temperatures to a 2 °C threshold show the need of limiting the increase in energy demand to 25% and to radically cut emissions by 50%. Thus, various countries are in the process of making strategic energy planning decisions in order to reach these ambitious goals [1].

Switzerland is one of the countries facing this energy transition. Although autonomous on a yearly balance, the country today already relies on electricity imports to face higher demand in winter months. Switzerlands governmental decision to phase out nuclear power plants by 2034 [2], which accounted for 40.7% of the electricity production in 2011 [3], will have as a consequence a further increase in the seasonal energy deficit, raising as well issues related to energy security.

In this context, large-scale energy models can be developed to support public decision-makers in the definition of the energy strategy. A new modelling approach is proposed for this purpose. The modelling approach is currently implemented in the energy calculator of Swiss-Energyscope [4], an online platform developed by the Energy Center of EPFL [5] to spread energy literacy and help citizens and public decision-makers to understand and contribute to the debate about the Swiss energy strategy.

1.1. Literature review

Climate change and security of energy supply are among the key challenges modern society is facing. As a result, a considerable effort has been made in order to gather a better understanding of the energy sector. A large number of techno-economic models for national energy systems have been developed [6]. Techno-economic energy models simulate the configuration and operation of a given energy system, investigating trade-offs between energy efficiency, cost and emissions.

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Nomenclature

$D_{j,k}$	annual energy demand of type k in sector j
SpD_k	specific energy demand for energy demand type k
GDP	gross domestic product
Pop	population
Sf	inhabited surface per capita
$SpaceHeating_i$	heat demand for space heating for the three sectors in month i
$HotWater_i$	heat demand for hot water for the three sectors in month i
$ProcessHeat_i$	process heat demand for the industry sector in month i
$Engines_i$	electricity demand for engines for the industry sector in month i
$Lighting_i$	electricity demand for lighting for the three sectors in month i
$OtherElec_i$	electricity demand for other uses for the three sectors in month i
$BusCoachDemand$	annual passenger transport demand to be covered by bus & coach
$ptBus_i$	annual passenger transport demand for bus&coach with power train i
L	heating load
P	installed power
$Group_j$	percentage of total installed power for the technology group j
$Tech_j,k$	percentage of total installed power for the technology k of group j
$TechFuel_{j,k,l}$	percentage of total installed power for the combination of group j, technology k and energy vector l
$HeatI_{i,k,l}$	heat supplied by technology k with energy vector l during month i in industry sector
$HeatC_{i,m}$	heat supplied by combination of technology m during month i
$PowerC_m$	installed power of the combination of technology m
$Price_i$	price for fossil fuel in year i
C	economic cost in CHF
i	interest rate
n	lifetime in years
E	emissions

In the literature the words “tool”, “model”, “modelling framework” and “model generator” are used interchangeably to refer to these models. Nonetheless, [7] states that “an energy model is a simplified representation of a specific energy system, whereas a tool, modelling framework or model generator refers to the computer program enabling the creation of various models”. From the authors' point of view, a modelling framework is the methodology applied for the development of the model. This methodology can be adapted to countries or cities to respectively develop national or urban energy model. The word “tool” refers to the type of interaction between users and the model. Users select the tool depending on the question they want to answer.

Based on the performed literature review a classification of models and tools is proposed. Models can be divided into two categories: “evolution” and “snapshot”. Evolution energy models analyse the evolution of a national energy system over a time horizon. The time horizon extends from the initial year to the end year and is broken down into a series of multiple-year or single-year periods. Each period is in turn subdivided into time-slices. Time-slices represent time intervals with similar conditions (i.e. weekends in winter, Monday mornings in summer, etc), with the purpose of better capturing seasonal, weekly or daily variations in energy supply and demand. Chronology is not taken into account in the use of time-slices. Three representative models of this category are MARKAL [8], OSeMOSYS [9] and 2050 Pathways model [10].

Snapshot models are used to evaluate the energy system configuration and operation over a timespan. “Energy system configuration” refers to the key characteristics of a national energy system, i.e. mix of technologies for electricity and heat supply, building stock, among others. The configuration of the energy system remains unchanged over the considered time span. The most common duration for the time span is one year, which is divided into chronological time-steps of 1 h or less. Two examples of this type of models are EnergyPlan [11] and HOMER [12].

Tools can follow two approaches: optimization and simulation. Often a model can be used for both purposes. Optimization tools provide the best solution for a defined objective. MARKAL [8] and OSeMOSYS [9] are optimization tools. Based on initial conditions and a set of assumptions (i.e. evolution of the prices of the fuels), these tools optimize the energy system evolution to meet minimum cost. Simulation tools are designed to evaluate hypothetical scenarios. They evaluate different configurations and operations of the energy system from an energetic, economic and environmental point of view. The 2050 Pathways tool [10] shows the impact of certain decisions on the evolution of UK's national energy system. The decisions are linked to several energy domains such as power supply approaches or the measures to reduce demand. EnergyPlan [11] evaluates the consequences of different national energy investments and regulation strategies.

The main shortcomings of most of these tools are the complex user interaction and the computation time. The majority of the tools for modelling national energy systems requires a training period that can vary between one day and one month [6]. This creates a barrier between the decision making tools and the decision makers (politicians and citizens). Therefore the expert that has developed the model is typically the person in charge of building and presenting the possible energy scenarios to the decision markers [15]. The 2050 Pathways tool [10] breaks the mentioned barrier due to its reduced number of inputs, simplified outputs and low calculation time. Thus, under the ease-of-use point of view, the 2050 Pathways tool represents the state-of-the-art in this domain. Furthermore it does not require any download or installation as it is available under the form of a webtool [16].

Besides the ease-of-use shortcoming, simulation tools are considered to be a better option for users that are not specialists of the energy domain in comparison to optimization tools. The main limitation of optimization tools is that they offer a solution without guiding users in the understanding of the problematics of national energy systems. Furthermore, the optimization is often based on economic assumptions such as fuel prices evolution [13] or investment cost data [14], which tend to be highly uncertain. This uncertainty is very often not taken into account in the optimization.

Regarding the model type, the main gap of evolution models such as the 2050 Pathways model [10] is the fact that the concept of seasonal variation for supply and demand cannot be clearly studied as output data are aggregated to an annual level. Also, the implementation of technologies for heat and electricity storage cannot be investigated due to the lack of connection between the time slices. This is considered to be a key aspect since future energy scenarios will be characterized by high percentages of stochastic electricity

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sources in their electricity production mix. Snapshot models are a good alternative since they evaluate the energy system configuration and operation over a timespan. The timespan can be adapted depending on the type of time variation to be studied. Furthermore the timespan is divided into time-steps allowing for the evaluation of technologies for heat and electricity storage.

Based on the performed analysis, the authors consider that the best strategy for the development of a tool whose targeted users are not specialists of the energy domain consists in the combination of a snapshot model with a simulation tool, giving special attention to the ease-of-use of the tool and the low computation time of the model. In the performed literature review no combination of snapshot model and simulation tool respecting these characteristics has been identified.

1.2. Goals and structure of the paper

The goal is to develop a modelling approach for a tool supporting decision-making at public level. The tool consists of an online energy calculator, belonging to the simulation category. The main users of the tool are expected not to be specialists of the energy domain. Thus it shall allow users to analyse different energy scenarios while introducing them to some of the key aspects of the energy sector.

The quality of the modelling approach is directly proportional to the degree of simplification that is possible to achieve. Key challenges to face in this regard are the choice of the level of detail, the identification of the key variables impacting the system, the definition of the model structure, the distinction between the demand and supply, the inclusion of technologies producing or requiring both heat and electricity (e.g. heat pumps and cogeneration).

The goals and innovative aspects of the developed modelling approach follow from the gaps identified in the literature:

- Achieving a general formulation allowing adaptation to any regional or national energy system.
- Showing the effect of choices on the key performance indicators of the energy system without proposing a specific solution.
- Favouring ease-of-use by a low number of input parameters.
- Allowing change of input parameters in any sequence without the need of introducing iteration loops.
- Keeping a low computation time of the model.
- Emphasizing the issues related to the seasonality of some resources.

To describe the modelling framework, section 2 firstly presents the approach and its advantages. Section 3 depicts the implementation of the model and the sub-models are described in detail, highlighting the main assumptions and formulas in order to ensure reproducibility. Lastly, in section 4 the methodology used for environmental impact calculations is presented.

2. Modelling approach

The modelling approach consists of the definition of the key methodological assumptions, inputs and outputs of the model, the model structure, information and data flow. In this section only the energy model is considered, while the cost and emission calculations are described in the dedicated sections.

The classical representation of a country's final energy consumption as the sum of the four main sectors (households, services, industry, transportation) is replaced by a tripartition into electricity, heating and transportation. This distribution has the advantage of highlighting the competition between electricity and fuels for heating and transportation end-uses.

The user's inputs into the energy model are divided into five categories:

- General: macro-economic (population, economic growth) and behavioural (eco-friendly behaviour) parameters.
- Efficiency: energy efficiency in buildings, industry, appliances, lighting.
- Transport: defining the share between transportation technologies, as well as the penetration of public transportation, of freight trains and of biofuels.
- Heating and CHP: allowing the choice between centralized and decentralized heating systems, and also of the technology and fuel mix for both cases.
- Electricity: installed power of renewable and non-renewable electricity production power plants.

The full list of input parameters is available in Table 1, specifying for each input the meaning, the units and the allowed values. The table also includes inputs belonging to the “Cost” category, which will be described in section 3.5.

Fig. 1 shows the conceptual modelling approach, i.e. how information flows across the model structure from the inputs to the output graphs. The energy model is structured into four sub-models: end-uses demand, transport, heating and CHP (cogeneration of heat and power), electricity supply. The main feature of the modelling approach is the sequential flow of information across the various sub-models.

The “End-uses demand” model calculates the end-uses energy requirements for heating and electricity in the household, industry and service sectors, based on the inputs belonging to the categories “Efficiency” and “General”.

The heating end-uses demand is the input into the “Heating and CHP” sub-model, which translates these end-uses into fuel consumption, electricity demand (from heat pumps and direct electric heating) and electricity production (from CHP plants), based on the input choices in the category “Heating and CHP”.

The “Transport” model calculates the end-uses demand for transportation based on the “General” inputs, and translates it into fuel and electricity demand taking into account the input of the “Transport” category.

The “Electricity supply” model calculates the electricity production from the installed technologies as defined by the “Electricity” inputs. Although the electricity demand and supply are independently defined, the electricity demand is also taken into account by this model in order to define the operation of NGCC (Natural Gas fired Combined Cycle) power plants, as further detailed in section 3.4.

The fuel consumption and the electricity demand are displayed in the final energy consumption graph, showing the previously mentioned tripartition into electricity, heating and transportation. The electricity graph shows the calculated energy demand and the supply from the chosen technologies.

The sequential approach presents several advantages.

First, a distinction is introduced between modelling demand and supply. Energy demand modelling concerns the definition of the end-uses, i.e. the requirements in energy services (e.g. mobility, heating, …). Energy supply modelling concerns the choice of the energy conversion technologies to supply these services, and it is therefore related to the final energy consumption. Based on the technology choice, the same end-use energy requirement can be satisfied with a different final energy consumption, depending on the efficiency of the chosen energy conversion technology. In the presented methodology this distinction is also made clear in the input categories in such a way that “General” and “Efficiency” inputs influence

Table 1
Model input parameters.

Category	Input	Description	Units	Values 2035	Values 2050
General	Population (*Pop*)	Number of inhabitants.	[Million inhabitant]	[7.80; 9.80]	[7.20; 10.70]
	Economic Growth	GDP increase rate per year: the rate of GDP increase is constant over the years.	[%]	[0.00; 3.00]	
	Ecofriendly Behaviour	An increase reduces the passenger transport demand and the inhabited surface per capita.	[−]	[1.00; 3.00]	
Efficiency	Building: specific demand (*SpD*)	Annual average heating demand per unit of inhabited surface.	[kWh/m^2]	[41.00; 57.00]	[21.00; 43.00]
	Industry: specific demand (*SpD*)	Average energy consumption of the industry for producing an amount of goods equivalent to 1 CHF.	[kWh/CHF]	[0.20; 0.25]	[0.15; 0.20]
	Appliances: specific demand (*SpD*)	Annual average electricity consumption of the appliances in a household.	[kWh/household]	[2429.00; 2661.00]	[2436.00; 2851.00]
	Lighting: specific demand (*SpD*)	Annual average electricity demand per unit of illuminated surface.	[kWh/m^2]	[0.60; 0.90]	[0.40; 0.60]
Transport	Vehicle fleet for passengers ($ptFleetPer_i$)	5 input parameters summing 100% that define the vehicle fleet composition. Each input parameter represents one type of vehicle.	[%]	[0.00; 100.00]	
	Public transport use	% of the passenger transport demand covered by public transport.	[%]	[10.00; 70.00]	
	Biofuels	% of the transport fuel demand that is supplied with biofuels.	[%]	[0.00; 100.00]	
Heating and combined heat & power	Heat for industry ($TechPer_{Ind,k}$)	3 input parameters summing 100% that define the technology mix. Each input parameter represents one technology.	[%]	[0.00; 100.00]	
	Heat for buildings: Centralized or Decentralized ($GroupPer_{Cen}$), ($GroupPer_{Dec}$)	% Repartition between centralised and decentralised technologies.	[%]	[10.00; 70.00]	
	Heat for buildings: Centralized technologies ($TechPer_{Cen,k}$)	4 input parameters summing 100% that define the technology mix. Each input parameter represents one technology.	[%]	[0.00; 100.00]	
	Heat for buildings: Decentralized technologies ($TechPer_{Dec,k}$)	7 input parameters summing 100% that define the technology mix. Each input parameter represents one technology.	[%]	[0.00; 100.00]	
	Energies ($EnPer_l$)	5 input parameters for defining the energy mix used in the heating and CHP technologies.	[%]	[0.00; 100.00]	
Renewable electricity	Solar photovoltaic	Solar photovoltaic installed power.	[GW]	[0.00; 24.00]	
	Wind	Wind turbines installed power.	[GW]	[0.00; 5.00]	
	Hydro large dam	Hydro large dams installed power.	[GW]	[8.10; 9.80]	
	Hydro run-of-river	Hydro run-of-river installed power.	[GW]	[3.80; 5.40]	
	Deep geothermal	Deep geothermal installed power.	[GW]	[0.00; 0.70]	
	Seasonal storage	Use of the power-to-gas technology: 0 ≡ no use of the technology, 1 ≡ All surplus of electricity is stored.	[−]	[1.00; 3.00]	
Non-renewable electricity	Nuclear	Nuclear plants installed power.	[GW]	[0.00; 10.00]	
	Gas power plant	Combined cycle gas turbine installed power.	[GW]	[0.00; 10.00]	
	Coal	Coal power plant installed power.	[GW]	[0.00; 10.00]	
	CO_2 storage	Use of the CO_2 capture and storage technology in fossil power plants. 0 ≡ None, 1 ≡ All.	[−]	[0.00; 1.00]	
Cost	Fuel prices	It determines the fuel prices evolution. An increase represents higher fuel prices.	[−]	[1.00; 3.00]	
	Investment cost	It determines the specific investment cost evolution. An increase represents higher specific investment cost.	[−]	[1.00; 3.00]	
	Interest rate	It determines the interest rate for the investment annualization. 1 ≡ 1.73% and 3 ≡ 4.70%.	[−]	[1.00; 3.00]	

demand modelling, while the other inputs affect only the supply side. This allows decision-makers to understand that actions can be taken on both the supply and demand sides of the energy system.

Second, some technologies affect more than one of the three components of the final energy consumption (electricity, heating and transportation). These technologies, such as heat pumps, cogeneration, and electric cars, can be difficult to include in an energy model, since a change in the associated inputs would cause a change in the other sub-models. A solution to this problem can be the automatic balancing of supply and demand, or forcing a sequentiality in the model inputs. The first option, for example, is used in the DECC energy model. The sequential model approach has the advantage of avoiding these options, simplifying the model and allowing a greater level of control to the decision-maker.

An additional advantage is that, in this framework, electricity is left as a free variable, therefore automatic balancing of supply and demand is replaced with the possibility of having a deficit or an oversupply in the electricity sector. This is an asset for decision-makers in countries facing seasonal deficit problems, as it is the case of Switzerland and of various other countries.

3. Model description

As introduced in section 1.1, the model falls into the "snapshot" category. The model evaluates different energy system configurations for a target year (2035 or 2050). The time horizon is one year divided into 12 time steps (months). The use of time steps rather than time-slices allows the implementation of technologies for electricity storage. The model is developed on Microsoft Excel™ (Fig. 2).

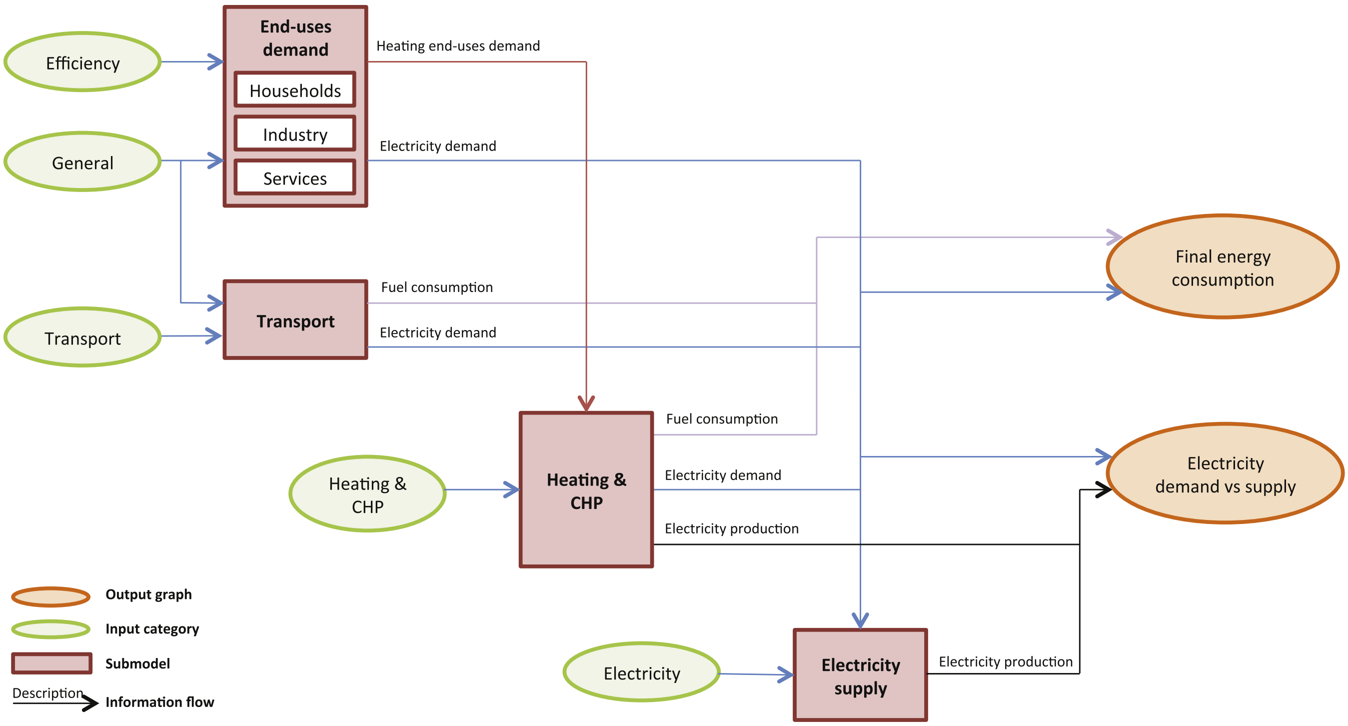

Fig. 1. Conceptual modelling approach: sequential flow of information across the four sub-models.

3.1. "End-uses demand" sub-model

The "End-uses demand" sub-model computes the electricity and heat demand for the households, industry and services sectors. The inputs for this model fall into the General (population, economic growth and eco-friendly behaviour) and Efficiency (building, industry, appliances and lighting specific demands) categories.

The model is based on data from a report commissioned by the Swiss government [17]. The report presents three energy scenarios for Switzerland: "BaU" (Business as Usual), "PMF" (Political Measures of the Federal Council) and "NEP" (New Energy Policies). These three scenarios represent the evolution of the Swiss energy sector from 2010 to 2050, sharing common assumptions about population and economic growth. They consider different

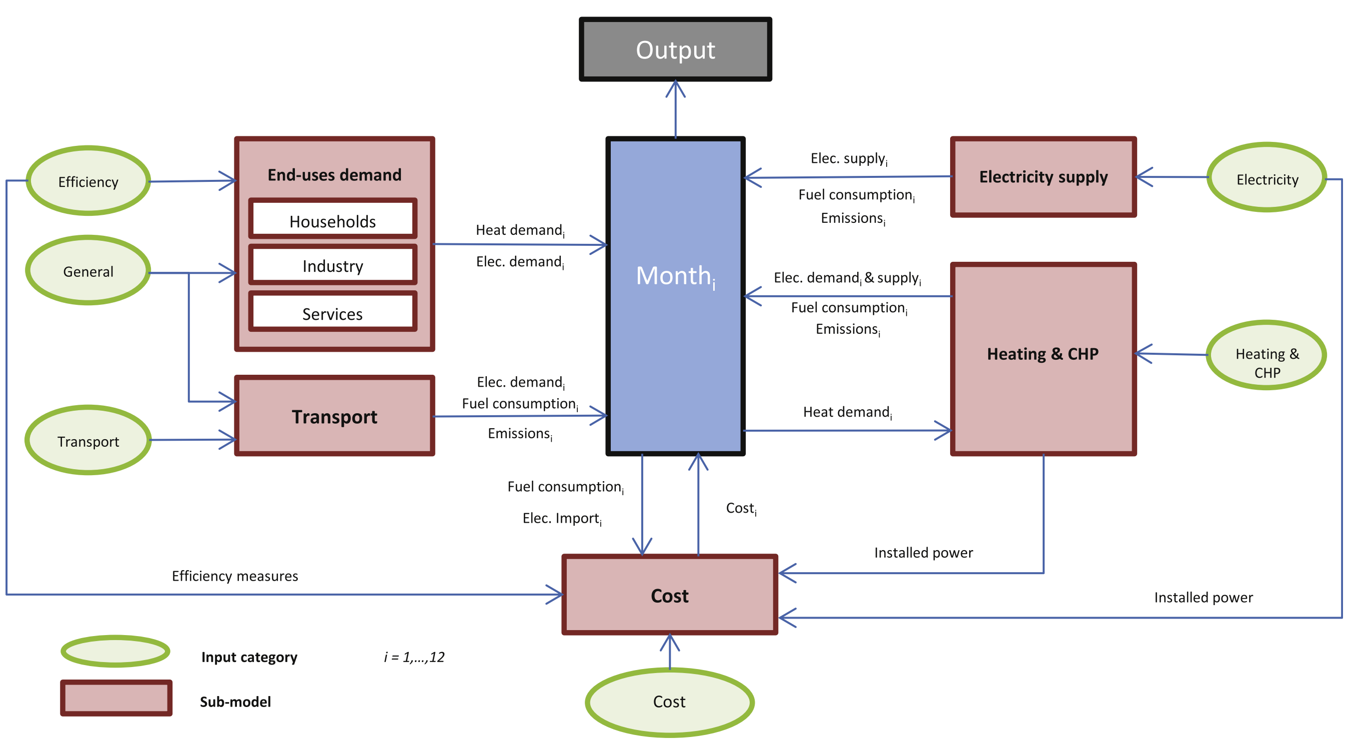

Fig. 2. Model structure.

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evolutions for efficiency in each sector, "New Energy Policies" being the scenario with the highest effort in terms of specific energy demand reduction, and "Business as Usual" presenting the most conservative hypotheses. The values of specific energy demand assumed by these two scenarios have been used to respectively define the minimum and maximum limits for the "Efficiency" inputs.

Table 2 contains the six types of energy demands (k) considered in the model, together with the sector they belong to (j). The "Specific Demand" column shows which specific demand from the input (SpD_k^{in}) is used in Eq. (1) for calculating each $D_{j,k}^{pr}$. Hot water demand (Hw) is considered to be constant, it is not scenario dependent.

$$k \in \{Sh, Ph, En, Li, Oe\}$$

$$D_{j,k}^{pr} = D_{j,k}^{NEP} + \frac{SpD_k^{in} - SpD_k^{NEP}}{SpD_k^{BaU} - SpD_k^{NEP}} * \left(D_{j,k}^{BaU} - D_{j,k}^{NEP}\right), \quad \forall j \in \{H, I, S\} \tag{1}$$

Eq. (1) is used to do a linear regression between the energy demand of the two extreme scenarios ($D_{j,k}^{BaU}$ and $D_{j,k}^{NEP}$) considering the specific demand given as input (SpD_k^{in}). Thus the efficiency improvements in each sector are adapted to the input. For the household sector, $D_{H,k}^{pr}$ is then adapted to the population in the input (Pop^{in}) as in Eq. (3). For the industry ($D_{I,k}^{pr}$) and services ($D_{S,k}^{pr}$) sectors, the demand is adapted based on the Gross Domestic Product (GDP^{in}) as in Eq. (2).

$$D_{j,k} = D_{j,k}^{pr} * \frac{GDP^{in}}{GDP^{pr}}, \quad \forall j \in \{I, S\}, \quad \forall k \in \{Sh, \ldots, Oe\} \tag{2}$$

$$D_{H,k} = D_{H,k}^{pr} * \frac{Pop^{in}}{Pop^{pr}}, \quad \forall k \neq Sh \tag{3}$$

The space heating demand for the households sector ($D_{H,Sh}$) is calculated as in Eq. (4). It depends on the inhabited surface per capita (Sf^{in}), which is defined by the eco-friendly behaviour value, as shown in Table 3.

$$D_{H,Sh} = D_{H,Sh}^{pr} * \frac{Pop^{in}}{Pop^{pr}} * \frac{Sf^{in}}{Sf^{pr}} \tag{4}$$

The outputs of the demand sub-model are the monthly heat and electricity demand ($HeatDemand_i$ and $ElecDemand_i$), which are two vectors containing respectively the heating and electricity demand divided by type, as in Eqs. (5) and (6). The monthly values for *SpaceHeating* are calculated using the HDD (Heating Degree Days) for Switzerland. The remaining monthly heating and electricity demand values are computed taking into account the number of days of each month.

Table 3
Inhabited surface per capita values depending on the "Eco-friendly behaviour" value.

Eco-friendly behaviour	Inhabited surface per capita (Sf)		
	2011	2035	2050
1		67.0 [17]	69.9 [17]
2	57.7 [17]	57.7	57.7
3		46.2	46.2

$$HeatDemand_i = [SpaceHeating_i, HotWater_i, ProcessHeat_i] \tag{5}$$

$$ElecDemand_i = [Engines_i, Lighting_i, OtherElec_i] \tag{6}$$

3.2. Transport

The transport sector is divided into passenger and freight transport. These two parts of the sub-model are independent from each other.

3.2.1. Passenger transport

The starting point for the passenger transport energy demand is the annual transport demand per inhabitant, expressed in [km/inhabitant]. This value depends on the eco-friendly behaviour input parameter, as shown in Table 4. This is multiplied by the population to obtain the annual passenger transport demand [pkm].

Based on user input, the annual passenger transport demand is distributed among the different technologies. As shown in Fig. 3, it is at first divided into public and private transport. The demand for private transport is distributed among different types of vehicles based on the fleet composition chosen by the user.

The public transport demand is attributed to "bus&coach", "tram&trolley" and train. If in the target year (2035 or 2050) there is an increase of the percentage of public transport demand in comparison to 2011, 35% of this increase is covered by train. The remaining 65% is equally assigned to "bus&coach" and "tram&trolley". If the percentage of public transport demand is lower than the percentage in 2011, then the reduced demand for train, "tram&trolley" and "bus&coach" is assigned based on their relative distribution in the year 2011.

Table 4
Transport demand: values per capita for the "Eco-friendly behaviour".

Input Value	Transport demand per capita [km]		Reference
	2035	2050	
1	16.4	16.7	Business as Usual scenario [17]
2	15.4	15.5	New Energy Policies scenario [17]
3	14.6	14.6	Constant demand since 2011 [17]

Table 2
Specific demand for the interpolation of each demand and sector to whom each demand belongs.

Demand type (k)	Specific demand (SpD_k^{in})	Sector (j)
Space heating (Sh)	Building: specific demand	Households, Industry and Services
Hot water (Hw)		Households, Industry and Services
Process heat (Ph)	Industry: specific demand	Industry
Engines (En)	Industry: specific demand	Industry
Lighting (Li)	Lighting: specific demand	Households, Industry and Services
Other electricity (Oe)	Appliances: specific demand	Households, Industry and Services

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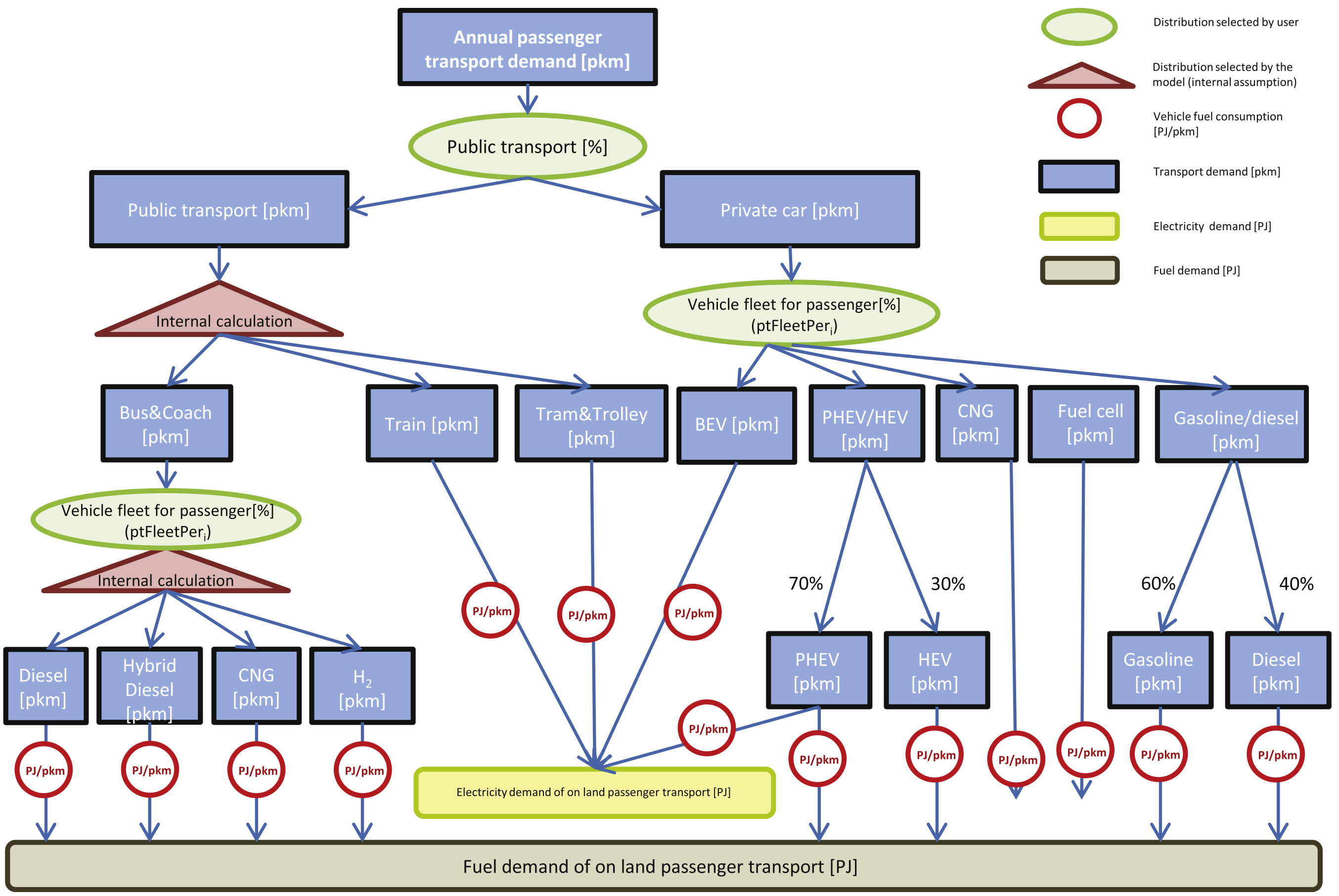

Fig. 3. Passenger transport model structure: Flows of information across the passengers transport model.

The “bus&coach” can have four different types of powertrain as shown in Fig. 3. The demand attributed to each powertrain ($ptBus_i$) is calculated with Eq. (7), where m is the number of possible powertrains for “bus&coach” (diesel, hybrid diesel, CNG and H_2), and $ptFleetPer_i$ is the percentage for each kind of powertrain in the vehicle fleet.

$$ptBus_i = BusCoachDemand*\frac{ptFleetPer_i}{\sum_i^m ptFleetPer_j}, \quad \forall i \in \{1, \ldots, m\} \tag{7}$$

Once the annual passenger transport demand has been divided according to the transport mode and powertrain, it is multiplied by the fuel consumption of each technology, thus providing the fuel and electricity consumption for the on-land passenger transport sector. Table 6 shows the energy consumption for each vehicle and powertrain for 2010 and 2050. The 2050 energy consumption data that do not have a source have been computed with data from

Table 6
Fuel and electricity consumption for 2010 and 2050 [MJ/pkm].

Vehicle type	2010		2050	
	Fuel	Electricity	Fuel	Electricity
Gasoline conventional car	1.80 [21]		1.40	
Diesel conventional car	1.58 [21]		1.28	
CNG conventional car	2.00 [21]		1.58	
Gasoline HEV car	1.07 [22]		0.78	
Gasoline PHEV car	0.78 [22]	0.20	0.55	0.14
BEV car		0.45 [23]		0.34
FCV car	0.83 [24]		0.54	
Tram & Trolley				0.59 [17]
Diesel conventional bus & coach	1.08 [21]		0.88	
Diesel HEV bus & coach	0.79 [25]		0.88	
CNG conventional bus & coach	1.27 [26]		1.00	
FCV bus & coach	0.95 [25]		0.73	
Train				0.31 [17]

Table 5
Fuel consumption reduction in the year 2050 compared to 2011 [20].

Powertrain	Fuel				
	Gasoline	Diesel	CNG	H_2	Electricity
Conventional vehicle	22.5%	19.5%	21%		
Hybrid electric vehicle (HEV)	27%				
Plug-in hybrid electric vehicle (PHEV)	30%				30%
Battery electric vehicle (BEV)					23.5%
Fuel cell vehicle (FEV)				35.5%	

Table 5. The 2035 energy consumption data are calculated with a linear interpolation between 2010 and 2050 values, except for those that are available in [17], such as "Tram&Trolley" and Train. The fuel consumption is further divided into fossil fuel and biofuel respecting the percentage established by the user. It is assumed that the substitution of fossil fuels with biofuels does not have any impact on the efficiency of the powertrains.

The presented methodology only computes on-land transport energy consumption, i.e. it does not include flights. The quantity of km travelled by planes in the target year (2035 or 2050) is connected to the eco-friendly behaviour input. Three pre-set values have been selected: 109 km/ca [18], 97 km/ca (−15% compared to 2011) and 84 km/ca (−30% compared to 2011), which are associated to the positions 1, 2 and 3 of the eco-friendly behaviour input parameter. The total fuel consumption is calculated by taking into account the Swiss population and the airplane fuel economy: 4.39 l/p100 km in 2005 and 2.46 l/p100 km in 2050, assuming a linear evolution [19].

3.2.2. Freight transport

For this part of the model, only the on-land transport by train and road has been considered. The annual freight transport demand [tkm] is based on the values forecast in [17]. The value is adapted based on the Swiss gross domestic product defined by the input GDP_{in}, as in Eq. (8), where $TransportFreight_{Report}$ and GDP_{Report} are respectively the annual freight transport demand and gross domestic product forecast in [17] for the target year (2035 or 2050).

$$TransportFreight = TransportFreight_{Report} * \frac{GDP_{Calc}}{GDP_{Report}} \tag{8}$$

The "Freight train" input sets the distribution between train and road transport demands. Trains are considered to be only electric [27]. Their electricity consumption values for 2035 and 2050 are an average of the values forecast in Ref. [17] for the three aforementioned scenarios: 0.25 MJ/tkm in 2035 and 0.23 MJ/tkm in 2050. Road freight transport is assumed to be shared between three types of vehicles, whose shares and fuel economies are presented in Table 7. The distribution among the different types of vehicles is assumed to be the same for the years 2011, 2035 and 2050. To compute the fuel consumption for 2035 and 2050, data from Ref. [21] are used for 2011 and extrapolated to 2035 and 2050 assuming the same efficiency evolution as in Ref. [17]. The values are presented in Table 7.

3.3. Heating and cogeneration

The input parameters for this sub-model are divided into three groups: "Heat for industry", "Heat for buildings" and "Energies". "Heat for industry" inputs define the technology mix for supplying the heat required by industrial processes. "Heat for buildings" inputs establish the combination of technologies for covering the load of space heating and hot water. "Energies" inputs determine the share of the energy vectors (i.e. fuels and electricity) for heating and cogeneration technologies. This approach is favoured over the option of letting users select the energy mix for each technology. This choice allows a lower number of inputs.

Table 7
Share and fuel consumption for trucks and vans based on their total weight (vehicle and freight weight) in 2010, 2035 and 2050.

Total weight	Share [28]	Fuel consumption [MJ/tkm]		
		2011 [21]	2035 [17]	2050 [17]
<3.5 t	6%	14.19	9.84	8.19
[3.5 t, 28 t]	42%	2.70	1.87	1.56
>28 t	52%	1.24	0.86	0.72

3.3.1. Installed power

The goal of this sub-section is to describe how the total installed power is calculated and divided among the different combinations of groups of technology, technology and energy vector that can be used for covering the heating demand in industry and buildings.

There are three groups of technologies: Industry (*Ind*), Centralized (*Cen*) and Decentralized (*Dec*). Each group of technologies can include up to eight different technologies: Cogeneration (*Cogen*), Advanced Cogeneration (*AdvCogen*), Heat Pump (*HP*), Thermal Heat Pump (*ThHP*), Boiler (*Boiler*), Solar Thermal (*Solar*), Geothermal (*Geo*) and Direct Electric Heating (*DirElec*). Each of these technologies can use nine different energy vectors: Gas (*Gas*), Wood (*Wood*), Oil (*Oil*), Waste (*Waste*), Coal (*Coal*), Hydrogen (H_2), Solar radiation (*Solar*), Geothermal Heat (*Geo*) and Electricity (*Elec*). Fig. 4 shows the technologies included in the three groups. Each technology uses a different mix of energy vectors.

Eqs. (9) and (10) calculate the heating load for buildings ($L_{Building}$) and industry ($L_{Industry}$), where 12 is the number of months of the year. These two values are combined in Eq. (11) to compute the total installed power (P_T). Eq. (11) takes into account the fact that the installed solar thermal panels require backup systems with the same installed capacity. $TechFuel_{Dec,Solar,Solar}$ is the percentage of total installed power for decentralized solar thermal panels.

$$L_{Building} = \max_i \left\{ \frac{SpaceHeating_i + HotWater_i}{Days_i * 24} \right\}, \quad i \in \{1, \ldots, 12\} \tag{9}$$

$$L_{Industry} = \frac{\sum_{i=1}^{12} ProcessHeat_i}{365 * 24} \tag{10}$$

$$P_T = \frac{L_{Industry} + L_{Building}}{1 - TechFuel_{Dec,Solar,Solar}} \tag{11}$$

The percentage for each group of technologies ($Group_j$) is calculated with Eq. (12), where $GroupPer_{Cen}$ and $GroupPer_{Dec}$ are the values from the input parameters that define the ratio between Centralized and Decentralized technologies for buildings. $P_{Building}$ is the installed heating power in buildings, which is equal to the sum of the heating load for buildings $L_{Building}$ plus the back-up installed capacity for the solar thermal panels (see Eq. (13)).

$$Group = \left[\frac{L_{Industry}}{P_T}, \frac{P_{Building}}{P_T} * GroupPer_{Cen}, \frac{P_{Building}}{P_T} * GroupPer_{Dec} \right], \quad \sum_j GroupPer_j = 1, \quad \forall j \in \{Ind, Cen, Dec\} \tag{12}$$

$$P_{Building} = L_{Building} + TechFuel_{Dec,Solar,Solar} * P_T \tag{13}$$

The share of each technology is calculated by Eq. (14), where $TechPer_{j,k}$ is the value of the input parameter for the technology k in the group j. If the technology k is not included in the group j, $TechPer_{j,k} = 0$.

$$Tech_{j,k} = Group_j * TechPer_{j,k}, \quad \sum_k Tech_{j,k} = Group_j, \quad \forall j \in \{Ind, Cen, Dec\}, \quad \forall k \in \{Cogen, \ldots, DirElec\} \tag{14}$$

Finally $TechFuel_{j,k,l}$ is calculated, where j is the group, k the

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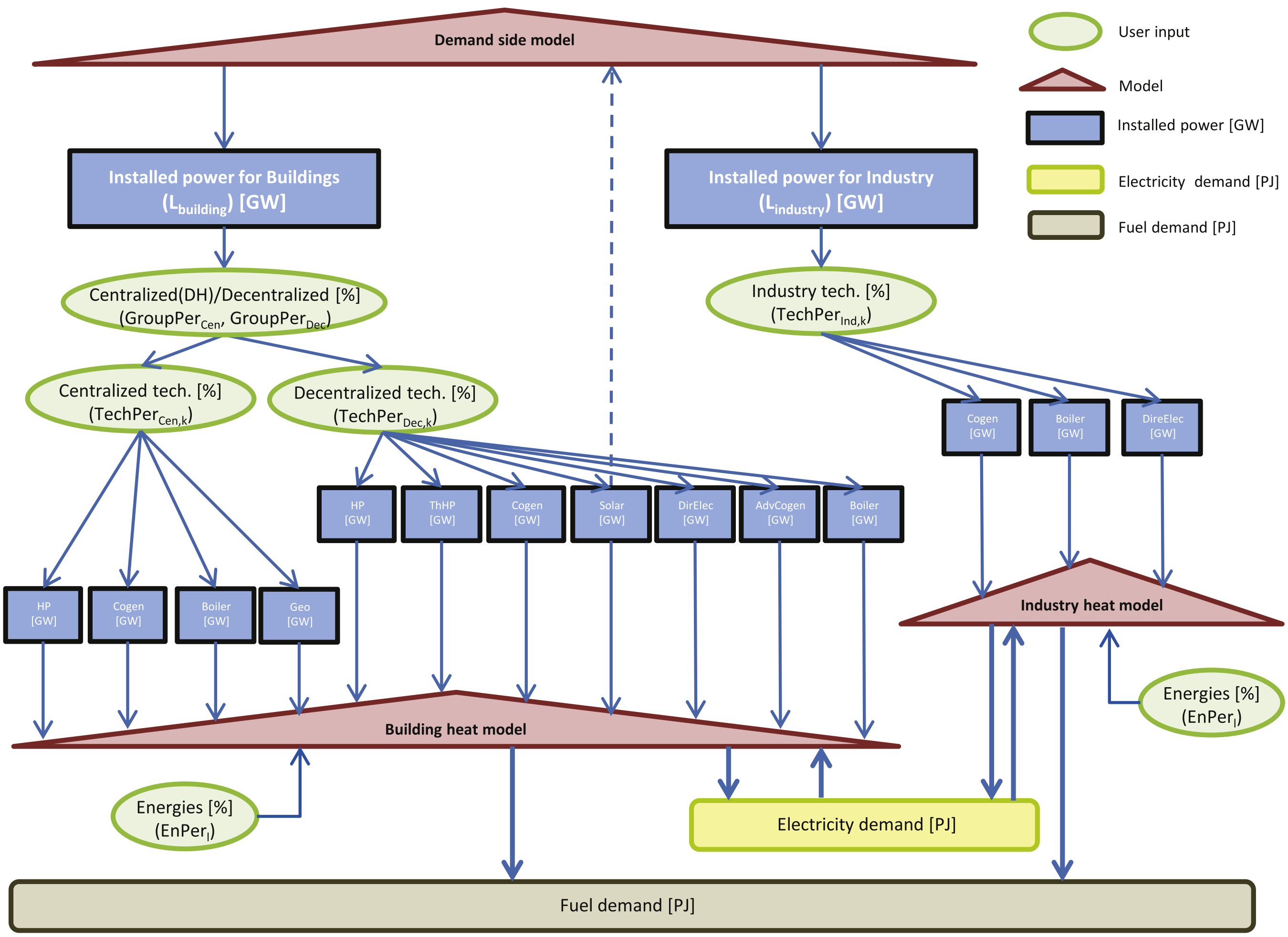

Fig. 4. Heating and cogeneration model structure: Flows of information across the Heating and cogeneration model.

technology and l the energy vector. The sum of $TechFuel_{j,k,l}$ over all the indices is equal to 1. The global mix of energy vectors is distributed among the different technologies, as in Eq. (15)–(19), where $EnPer_l$ is the value of the input parameter for the energy vector l, and $C_{j,k,l}$ is a binary variable: if $C_{j,k,l}$=1, then there is a possible combination between the group j, the technology k and the energy vector l in the model. If $C_{j,k,l}$=0, the combination is not feasible.

Eq. (15) is used for all combinations of groups and technologies whose fuel is natural gas or wood, except for those having Advanced Cogeneration (*AdvCogen*) and Thermal Heat pumps (*ThHP*) as technology.

$$
\begin{aligned}
TechFuel_{j,k,l} = {} & \Big(Tech_{j,k} - EnPer_{Coal}*C_{j,k,Coal} - EnPer_{Oil}*Oil \\
& - EnPer_{Waste}*Waste\Big)*\frac{EnPer_l}{EnPer_{Gas}+EnPer_{Wood}}*C_{j,k,l} \\
Oil = {} & \frac{Tech_{j,k}*C_{j,k,Oil}}{\sum\limits_j \sum\limits_k Tech_{j,k}*C_{j,k,Oil}} \\
Waste = {} & \frac{Tech_{j,k}*C_{j,k,Waste}}{\sum\limits_j \sum\limits_k Tech_{j,k}*C_{j,k,Waste}} \\
& \forall j, \quad \forall k \notin \{AdvCogen, ThHP\}, \quad \forall l \in \{Gas, Wood\}
\end{aligned}
\tag{15}
$$

75% of *AdvCogen* systems are assumed to have natural gas as energy vector. The remaining 25% uses hydrogen (see Eq. (16)). The only energy vector supported by *ThHP* is natural gas (see Eq. (17)).

$$
\begin{aligned}
& TechFuel_{Dec,AdvCogen,Gas} = 0.75*Tech_{Dec,AdvCogen} \\
& TechFuel_{Dec,AdvCogen,H2} = 0.25*Tech_{Dec,AdvCogen} \\
& TechFuel_{j,AdvCogen,l} = 0, \quad \forall j, \quad k = AdvCogen, \quad \forall l \notin \{Gas, H_2\}
\end{aligned}
\tag{16}
$$

$$
TechFuel_{j,ThHP,l} = Tech_{Dec,ThHP}*C_{j,k,l}, \quad \forall j, \quad \forall l \tag{17}
$$

Eq. (18) is used for all combination of group and technology whose energy vector is oil, waste or coal.

$$
\begin{aligned}
& TechFuel_{j,k,l} = EnPer_l*\frac{Tech_{j,k}*C_{j,k,l}}{\sum\limits_j \sum\limits_k Tech_{j,k}*C_{j,k,l}}, \\
& \forall j, \quad \forall k, \quad \forall l \in \{Oil, Waste, Coal\}
\end{aligned}
\tag{18}
$$

Combinations of groups and technologies that have solar, geothermal heat or electricity as energy vector cannot use any other energy vector (see Eq. (19)).

$$
TechFuel_{j,k,l} = Tech_{j,k}*C_{j,k,l}, \quad \forall j, \quad \forall k, \quad \forall l \in \{Solar, Geo, Elec\} \tag{19}
$$

$$j \in \{Ind, Cen, Dec\}, \quad k \in \{Cogen, \ldots, DirElec\}, \quad l \in \{Gas, \ldots, Elec\} \tag{20}$$

Eq. (21) calculates the installed power ($P_{j,k,l}$) for each combination of group, technology and energy vector. This, together with the monthly heating requirement $SpaceHeating_i$, $HotWater_i$ and $ProcessHeat_i$ is used to calculate the supplied heat. The use of the heating and cogeneration technologies follows two different operation strategies depending on the sector (industry or building).

$$P_{j,k,l} = TechFuel_{j,k,l} * P_T, \quad \forall j \in \{Ind, Cen, Dec\}, \quad \forall k \in \{Cogen, \ldots, DirElec\}, \quad \forall k \in \{Gas, \ldots, Elec\} \tag{21}$$

3.3.2. Operation strategy in industry

The heat supplied by each combination of groups, technologies and energy vectors during a month ($Heat_{i,j,k,l}$) is proportional to the corresponding installed power. It is calculated with Eq. (22).

$$HeatI_{i,k,l} = FuelTech_{I,k,l} * ProcessHeat_i, \quad \forall i \in \{1, \ldots, 12\}, \forall k \in \{Cogen, \ldots, DirElec\}, \forall l \in \{Gas, \ldots, Elec\} \tag{22}$$

3.3.3. Operation strategy in buildings

As renewable heat source, solar thermal is assigned the highest priority. Hence monthly heating demand for buildings is defined as follows:

$$HeatBuilding_i = SpaceHeating_i + HotWater_i - Heat_{i,Dec,Solar,Solar}, \quad \forall i \in \{1, \ldots, 12\} \tag{23}$$

where $Heat_{i,Dec,Solar,Solar}$ is the heat supplied by the solar thermal panels during the month i.

Boilers can be installed on their own or as peak boilers when combined with cogeneration systems and heat pumps. Cogeneration systems and heat pumps are always combined with peak boilers, representing 15% of the total power (85% *Cogen* or *HP* + 15% *Boiler*). This condition is respected as long as the percentage of *Boiler* in inputs is high enough. This approach defines 11 combinations of technologies:

- Centralized Heat Pumps + Centalized Boiler (*CenHP_CenBoiler*)
- Centralized Cogeneration + Centralized Boiler (*CenCogen_CenBoiler*)
- Centralized Boiler (*CenBoiler*)
- Geothermal (*Geo*)
- Decentralized Heat Pumps + Decentalized Boiler (*DecHP_DecBoiler*)
- Decentralized Thermal Heat Pump (*DecThHP*)
- Decentralized Cogeneration + Decentralized Boiler (*DecCogen_DecBoiler*)
- Decentralized Advanced Cogeneration + Decentralized Boiler (*DecAdvCogen_DecBoiler*)
- Decentralized Boiler (*DecBoiler*)
- Decentralized Direct Electric Heating (*DecDirElec*)

The monthly heat demand ($HeatBuilding_i$) is shared among these different combinations proportionally to their installed power as shown in Eq. (24), where $PowerC_m$ is the installed power for each combination of technologies.

$$HeatC_{i,m} = HeatBuilding_i * \frac{PowerC_m}{\sum_m PowerC_m}, \quad \forall i \in \{1, \ldots, n\}, \quad \forall m \in \{CenHP\_CenBoiler, \ldots, DecDirElec\} \tag{24}$$

The installed power of every combination of technologies ($PowerC_m$) is higher than the average monthly load due to the back-up power for solar thermal panels. In addition the system is sized taking into account the month of the year with the highest heat demand (see Eq. (9)). Therefore there is an operation strategy for the combinations of technologies that include peak boilers, since the use of both technologies at full capacity would result in an excess of heat supply. The operation strategy is based on the following list of conditions, which are ordered from higher to lower priority:

1. To cover the heat demand.
2. To maximise the efficiency.
   (a) Not to produce electricity when there is no demand for it.
   (b) To maximise the use of efficient systems (heat pumps and cogeneration).

Thus, heat pumps always have preference over peak boilers. Peak boilers are only used when the heating demand cannot be covered only by heat pumps. Cogeneration and Advanced cogeneration also have priority over peak boilers, as long as the electricity supplied by these systems does not contribute to an overproduction of electricity (higher supply than demand of electricity in month i). Therefore peak boilers for cogeneration systems are used under two circumstances:

- Heating demand cannot be covered only by cogeneration systems.
- The use of cogeneration systems gives an overproduction of electricity.

3.4. Electricity

Each of the "Electricity" inputs of the electricity sub-model represents the installed power of one technology. For some technologies, such as solar photovoltaic, wind power, hydro run-of-river and deep geothermal for the renewable group, nuclear and coal for the non-renewable group, the electricity production depends only on the chosen installed capacity. The monthly distribution of electricity production by these six technologies is based on pre-defined seasonal profiles. Renewable technologies, except for deep geothermal, present seasonal variations, while the two non-renewable technologies (coal and nuclear) are treated as base load supply. Table 8 lists the capacity factors and the seasonal distribution for these technologies.

The electricity supply by large hydro dams is also directly proportional to the installed power; however, the monthly distribution can change. The model takes into account the possibility of increasing the height of the dams. It is assumed that the storage capacity that could be gained by increasing the height of a certain number of dams in Switzerland is 2400 GWh [38]. The model input range is from 8.1 GW to 8.2 GW. The first value represents the actual installed capacity, i.e. no dam increase is accounted for, 8.2 GW corresponds to the deployment of the additional 2400 GWh storage capacity. For intermediate inputs a linear interpolation is made. The new storage capacity is used for shifting electricity production from summer to winter, reducing the need for turbining water during summer and storing it for the winter months with electricity

Table 8
Electricity supply technologies: assumptions for capacity factor and seasonal distribution.

Technology	Capacity factor	Seasonal distribution [winter, spring, summer, autumn]
Solar photovoltaic	0.113 [29]	[0.131, 0.318, 0.354, 0.197] [30]
Wind power	0.230 (2011), 0.250 (2035), 0.270 (2050) [31]	[0.338, 0.234, 0.155, 0.273] [32]
Hydro run-of-river	0.507 [33]	[0.155, 0.237, 0.390, 0.218] [34]
Hydro large dam	0.244 [33]	[0.256, 0.201, 0.289, 0.254] or Variable [34]
Deep geothermal	0.850 [35]	[0.250, 0.250, 0.250, 0.250]
Nuclear	0.850 [36]	[0.250, 0.250, 0.250, 0.250]
Coal	0.850 [37]	[0.250, 0.250, 0.250, 0.250]
CCGT	0.800 Max [37]	Variable

deficit. Thus, in case of storage, the seasonal distribution could be different from the one shown in Table 8.

CCGT (Combined Cycle Gas Turbine) is another technology whose monthly distribution is not fixed. CCGT plants are modelled to produce electricity only if the other technologies cannot cover the electricity demand, and as long as there is enough CCGT installed power. Thus, CCGT plants do not supply electricity in case of overproduction.

Seasonal storage consists in the production of synthetic fuels from the excess of electricity. In this case the fuel is methane, which is stored in a liquid form. The efficiency and cost of the system is based on the CO_2–CH_4 closed loop presented in Ref. [39], reaching a roundtrip efficiency of 54.5%. In this case the input does not represent the installed power, since its range is [0, 1]. If 0 is chosen, no seasonal storage is implemented, whereas if the position of the input parameter is 1, all the excess electricity is converted into fuel, as long as this stored electricity can be used in other months with electricity deficit.

The CCS (CO_2 capture and storage) input concerns the CCGT and coal power plants. It has a similar definition to the seasonal storage input parameter: 0 means no implementation of the technology, while 1 means that all the fossil fuel power plants use CO_2 capture. The use of CCS technologies implies lower CO_2 emissions, but the considered drawbacks are lower efficiencies, higher specific investment costs and increased deposited waste.

3.5. Cost

The inputs of the cost sub-model are the “Fuel Prices”, “Investment cost” and “Interest rate” defined in Table 1. The extreme values of these three inputs are “1” and “3”, with “1” assuming the lowest value for the costs, and “3” the highest values.

The “Fuel prices” input defines which of the 3 discrete price levels is selected for the cost calculation. Table 9 shows the production prices, or prices at the Swiss border, if the resource is imported. The “Investment cost” input determines which of the 3 levels of specific investment cost is considered. More information about the considered specific investment costs is available in Ref. [40]. The “Interest rate” input parameter sets the interest rate. The defined range for the interest rate is [1.73, 4.70] %. Taxation is not accounted for in the cost calculations.

The prices for fossil fuels in 2035 and 2050 are calculated by Eqs. (25)–(27), taking into account the 2010 prices and the three evolution paths forecast by the European Commission [49].

$$Price_{2035/2050_1} = \frac{Price_{2010} * Price_{EuropeanCommission2035/2050_{Low}}}{Price_{EuropeanCommission2010}} \tag{25}$$

$$Price_{2035/2050_2} = \frac{Price_{2010} * Price_{EuropeanCommission2035/2050_{Ref}}}{Price_{EuropeanCommission2010}} \tag{26}$$

$$Price_{2035/2050_3} = \frac{Price_{2010} * Price_{EuropeanCommission2035/2050_{High}}}{Price_{EuropeanCommission2010}} \tag{27}$$

Bioethanol and Biodiesel are considered to have the same price evolution as the fuel they substitute (gasoline and diesel respectively). The price for wood in 2035 and 2050 is calculated following the same methodology used for the fossil fuel prices, but the evolution is based on the wood price forecasts in Ref. [17].

The graph legend in Fig. 5 shows the elements of the national energy system that are taken into account for computing the “Annual total cost”. For each of these elements the annual total cost (C_{TOT}) is calculated as shown in Eq. (28), where C_{fuel} is the cost of all consumed fuels and imported electricity for one year, $C_{O\&M}$ is the annual Operation and Maintenance cost and C_{inv} is the annualised investment cost for each element. Some elements only include one cost component, e.g. “Transport fuels” has only the C_{fuel} or “Elec.

Table 9
Prices evolutions for the different input values.

		2010	2035			2050		
			MIN(1)	MID(2)	MAX(3)	MIN(1)	MID(2)	MAX(3)
Gasoline	ctsCHF/kWh$_{fuel}$	8.59 [41,42]	9.18	11.30	14.76	8.55	12.90	16.51
Diesel		8.41 [41,42]	8.99	11.07	14.46	8.38	12.64	16.18
Bioethanol		7.36 [43]	9.18	11.30	14.76	8.55	12.90	16.51
Biodiesel		11.93 [43]	8.99	11.07	14.46	8.38	12.64	16.18
Heating fuel oil		6.99 [41,42]	8.60	11.24	6.52	9.83	12.58	
Kerosene		5.91 [44]	6.32	7.78	10.16	5.89	8.88	11.37
Gas		6.50 [45]	6.15	10.07	13.00	6.62	12.07	15.87
Wood		3.01 [17]	6.82	7.81	8.80	7.41	8.96	10.50
Coal		3.60 [46]	3.76	5.34	7.26	3.68	5.43	6.51
Nuclear fuel	ctsCHF/kWh$_e$	11.86 [47]	6.67 [47]	13.51 [47]	17.45 [47]	6.52 [48]	13.14 [47,48]	19.48 [47]
Imported electricity		15.90 [45]	15.90	24.00	32.10 [17]	15.90	24.75	33.60 [17]

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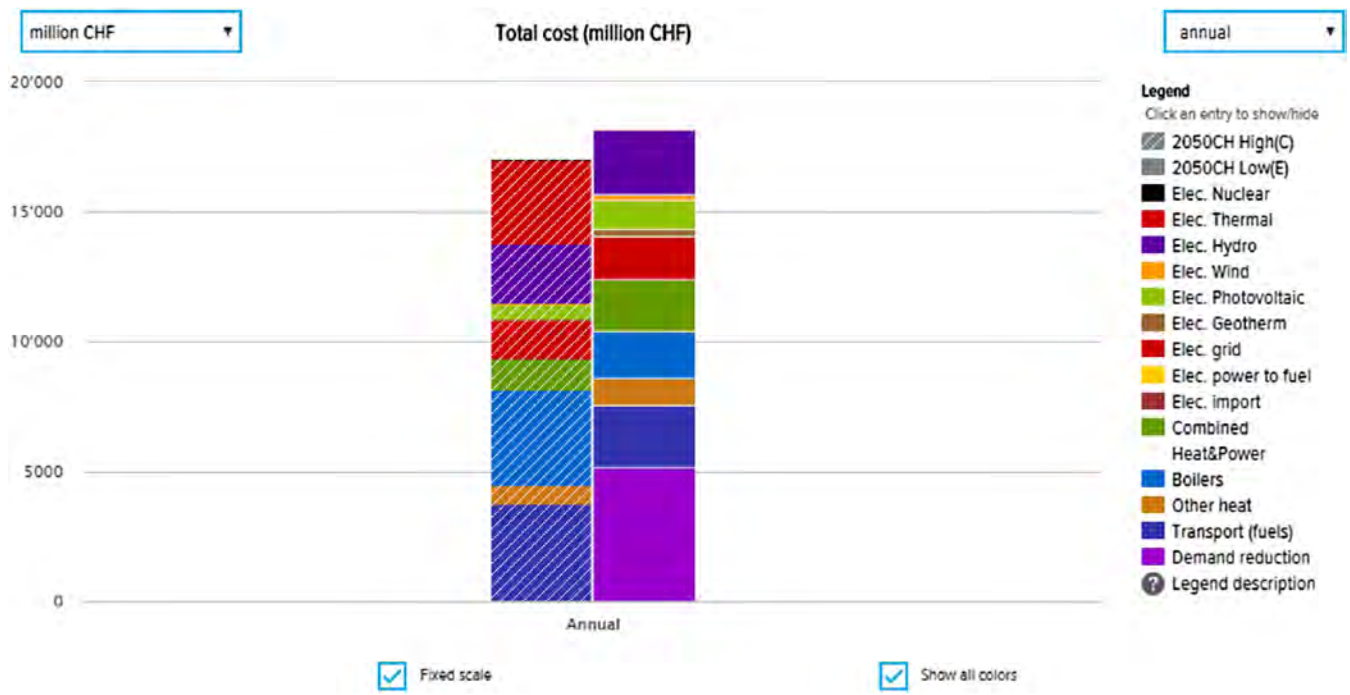

Fig. 5. Annual total cost for the 2050CH High(C) and 2050CH Low(E) scenarios.

Grid" with C_{inv}. In this approach, cogeneration systems are represented by a single element in the legend:"Combined Heat&Power". This avoids calculating the relative cost allocation to electricity and heat production, which is an advantage in comparison to the approaches based on the levelized cost of electricity and heat.

$$C_{TOT} = C_{inv} + C_{fuel} + C_{O\&M} \tag{28}$$

$$C_{inv} = C_{invT} * \frac{i*(1+i)^n}{(1+i)^n - 1} \tag{29}$$

The investment cost is calculated for each year (2011, 2035 and 2050) by assuming that the complete energy system is entirely replaced during the selected year, taking into account the relative prices and the technology development status. The investment cost is annualised based on the interest rate as in Eq. (29), where C_{invT} is the total investment cost, i is the interest rate and n is the technology life time in years. This assumption allows the comparison between the investment cost of 2011 with those for 2035 and 2050, without having to consider any installation/decommissioning pathway.

4. Environmental impact analysis

The environmental impact is calculated with a LCA (Life Cycle Assessment) approach. The two selected environmental indicators are "CO_2 equivalent emissions" and "Deposited Waste". The "CO_2-equivalent emissions" is based on the "IPCC 2007 - GWP (Global Warming Potential) 100years" impact assessment method, while "Deposited Waste" corresponds to the "ecological scarcity 2006 - deposited waste" method. "IPCC 2007 - GWP 100years" method takes into account the emissions of all the gases contributing to the greenhouse effect and quantifies them as the amount of CO_2 that would have the equivalent global warming potential. The "ecological scarcity 2006 - deposited waste" method considers the volume occupied for disposal of radioactive waste and the amount of TOC (total organic carbon) dumped into the water. The unit is the "UBP" ("Ecopoint") [21].

The emissions related to electricity imports are included in the emission balances, while those attributed to the electricity exports are not subtracted. This approach complicates the comparison of the results from the models with data from other sources, as national emissions inventories are usually computed following a production based approach [50]. The production based approach only accounts for greenhouse gas emissions and removals taking place within national territories.

To facilitate this comparison the "CO_2 equivalent emissions" data are displayed as in Fig. 6: the legend includes 7 fossil fuels (Gas, Fuel Oil, Diesel, Gasoline, Kerosene, Waste and Coal) and an entry for "Indirect emissions". The emissions included under the fossil fuel entries follow the production based approach as they derive from the combustion of fossil fuels on the national territory. "Indirect emissions" (E_{ind}) are calculated in Eq. (30), where E_{LCA} are the emissions calculated following the life cycle approach, E_{comb} are the direct emissions from fuel combustion and $E_{ElecImp}$ are the emissions linked to the imported electricity (calculated also with LCA).

$$E_{ind} = E_{LCA} - E_{comb} + E_{ElecImp} \tag{30}$$

The legend for the deposited waste follows a different approach. The legend contains 9 entries: "Elec. Nuclear", "Elec. Hydro", "Elec. Other renew", "Elec. Thermal", "Elec. Import", "Combined Heat&-Power", "Boilers", "Other Heat" and "Transport (fuels)". In this case there is no differentiation between direct and indirect emissions. "Combined Heat & Power" includes all the emissions related to generation of both electricity and heat. This avoids the problematic of emission allocation to heat or electricity production.

5. Conclusion

A new modelling framework for large-scale energy systems is developed in order to support decision-makers by improving their understanding of the energy system.

The Swiss-EnergyScope tool and its model can be classified in the simulation and snapshot categories, respectively. The

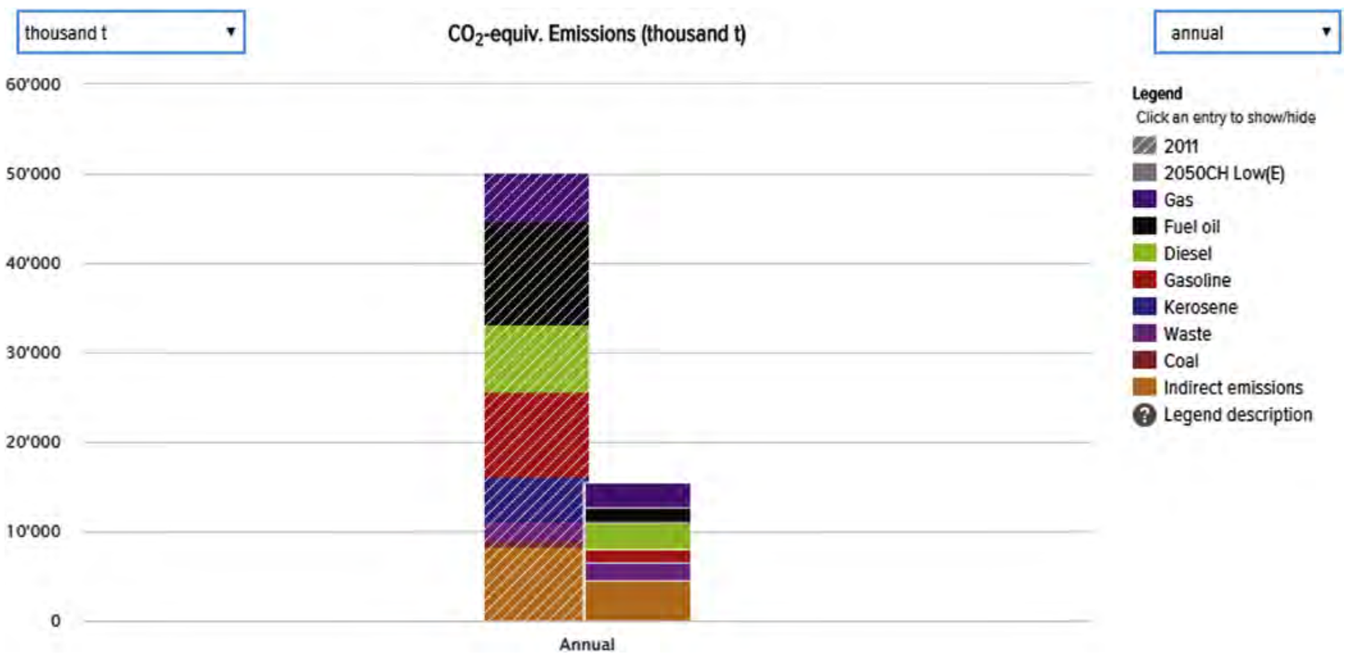

Fig. 6. Annual total CO_2 emissions for 2011 and the 2050CH Low(E) scenario.

development of a simulation tool allows users to evaluate the effect of a list of possible choices in terms of final energy consumption, total cost and environmental impact.

The choice of a snapshot model allows a clear access to monthly distributions, thus the concept of seasonal variation for supply and demand is made obvious. A sequential modelling approach is applied for the development of the model. This approach presents several advantages:

- A clear distinction between the demand and supply sides, highlighting the fact that actions can be taken in both sides, supply and demand.
- The easy integration of technologies affecting more than one of the three components of final energy consumption (electricity, heating and transportation) without the need of iteration loops.
- Highly responsive model (calculation time below 1 s).
- Highlighting the competition between electricity and fuels in heating and transportation.
- The possibility of emphasising the issues related to the seasonality of some resources.
- Leaving electricity as a free variable for helping to understand the necessity of balancing supply and demand, and highlighting the concept of seasonal variation.

The approach used for the development of the cost model provides an estimation which allows users to compare two energy scenarios in terms of economic cost. It also reduces the model complexity and calculation time since no installation/decommissioning pathway is computed. The cost sensitivity to assumptions is made obvious by the use of the “Cost” inputs.

The model structure and sub-models, along with the methodology for cost and environmental impact calculations, are described in detail in order to ensure reproducibility and adaptation to other energy systems.

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Renewable Energy Committee

Dr. Bader Alajmi

Kuwait Society of Engineers

Introduction:

- Kuwait has plans to produce 15 percent of power from renewable energy by 2030.
- Currently Kuwait is generating around 1.6 GW from renewable energy.
- The Renewable energy committee at Kuwait Society of Engineer was established in 2013 to participate on achieving the country vision

Activities:

The activities of the Renewable Energy committee were divide into different area:

1- Organizing Conference and workshops.

2- Training programs.

3- Participate in local projects.

4- Signing MOU with international companies and organizations.

5- Research and solutions

1- Organizing Conference and workshops :

2-3 of December 2018
Kuwait city, Kuwait

Training programs :

The committee provides different training courses through the Kuwait Society of Engineers training center

1- Photovoltaics Solar Systems Design (KSE & SMA academy).

2- Smart Electrical installations (KSE & Smart-bus home G4).

3- Renewable Energy (KSE).

4- Energy auditing (Smart-bus home G4).

Participate in Local Projects. :

The committee has been involves in many community services

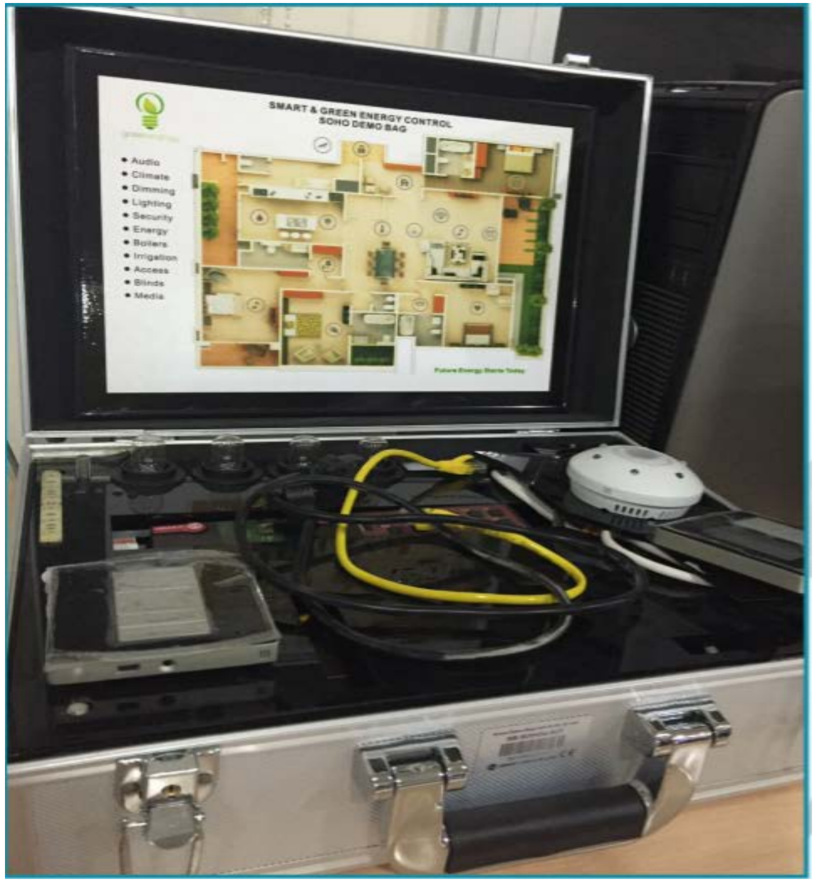
such as:

Public Training

Smart Mosques

Participate in Local Projects. :

Green Camp



Smart Lab

4- Signing MOU with international companies and organizations

The Renewable Energy committee was successfully able to sign A memorandum of understanding **(MOU)** with different international companies such as:

1- Smart-bus G4

2- SMA

3- Shanghai electric power

4- EU-GCC network

5- Research and Solutions

Our committee members are active in research and seeking solutions for the problems in applying renewable energy systems in Kuwait environments.

1- Maximum power point tracking for dusty weather conditions. (research)

2- A Modular Multi-Terminals PV Interfacing System. (research)

3- Solar bankers. (Technology can be used to prevent solar cell from UV degradation).

Thank you

WFEO EXECUTIVE COUNCIL MEETINGS – LONDON – 20 / 24 October 2018

MEETING ATTENDANCE SHEET

MEETING NAME C-Energy LOCATION Palmer DATE 20/10

Name	Institution	Email address	Signature
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