Designing an explainable techno-economic assessment software for household energy system: A case study for the newTRENDs project

In partial fulfilment of the requirement for the degree of

MASTER OF SCIENCE

in

Human Computer Interaction

by

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Under the supervision of

Prof. Dr. Gunnar Stevens

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ABSTRACT

Text...

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Notations and Abbreviations

EU European Union. 2, 15

GHG greenhouse gas. 1, 2

PV photovoltaic. 7

Chapter 1

Introduction

Human-induced climate change is causing dangerous and widespread disruption in nature and affecting the lives of billions of people around the world [9]. To tackle climate change and its negative impacts, two main strategies are addressed: climate change mitigation and adaptation. Mitigating climate change means cutting and sequestering emissions of greenhouse gases (GHG) to prevent further increases in their atmospheric concentrations [12]. Related projects are in the areas of farming, land use, peatland management, renewable energies and energy efficiency; as well as integrated projects that implement climate change mitigation strategies and action plans at regional or national level [6]. Adaptation means finding ways that can help reduce the impacts of climate change on society, the various sectors of its economy, and the places in which we live [12]. Related projects are in the areas of urban adaptation and land-use planning, resilience of infrastructure, sustainable management of water in drought-prone areas, flood and coastal management, resilience of the agricultural, forestry and tourism sectors, etc. [6]. The newTRENDs project falls into the category of climate change mitigation.

1.1 The newTRENDs project

The historic Paris Agreement sets long-term goals to guide all nations to substantially reduce global GHG emissions to limit the global temperature increase to 2 degrees Celsius in this century [13]. On European Union (EU) level, "Energy 2020. A strategy for competitive, sustainable and secure energy", published in November 2010, and "Energy Roadmap 2050", published at the end of 2011, are the most important strategy papers currently, pointing the direction for energy developments in the EU [11]. The aim is to confirm Europe's commitment to lead in global climate action and to present a vision that can lead to achieving net-zero GHG emissions by 2050 through a socially-fair transition in a cost-efficient manner [5].

To achieve these ambitious goals, the world is facing an unprecedented imperative to a rapidly transition in the energy sector. Transitioning towards a sustainable energy system necessitates significant effort on both the demand and supply sides. However, previous research has shown that in many areas energy efficiency gains were counteracted by societal trends that increased corresponding activities, leading to much smaller decreases (or even increases) of energy demand than technologically feasible, it is therefore important to access current and (foreseeable) future societal trends concerning the impact that they might have on future energy demand [4]. The aim of newTRENDs is to increase the qualitative and quantitative understanding of impacts of new societal trends on energy consumption and to improve the modelling of energy demand, energy efficiency and policy instruments [7].

1.1.1 New societal trends on energy demand

Researchers and organisations are paying increasing attention to how new societal trends are affecting energy demand. They believe new societal trends have the potential to shift energy demands between sectors and might reinforce or diminish one another when they occur at the same time. Heike Brugger et al. [4] established four arising societal trend clusters that are likely to shape future energy demand in European countries (and worldwide):

- **Digitalization of Life**
  the digitalization of the economy and of private life;
- **New Social and Economic Models**
  new social and economic models, including the sharing economy and prosumaging (combination of producing, consuming and managing of energy);
- **Industrial Transformation**
  the industrial transformation, including decarbonization of industrial processes and the circular economy (including a stronger focus on material efficiency);
- **Quality of Life**
  changes in the quality of life, including health effects, urbanization and regionalization.

The newTRENDs project develops the analytical basis for a "2050 Energy Efficiency Vision" by considering new societal trends in energy demand modeling [15].

1.1.2 Household

With increasing renewable generation integrated into the power system, supply-side fluctuations must be balanced by demand-side flexibility. Electrification and demand response (DR) are becoming increasingly relevant to the heating transition of buildings, which demands the diffusion of

- heat pumps (HPs),
- photovoltaic (PV) and energy storage (e.g., battery and hot water tank),
- smart energy management systems (SEMSs).

Combining the three technologies is also beneficial from an individual household (or building) perspective. The household can optimize the heat pump operation to reduce energy costs by saving energy in the tanks or pre-heat the building when the electricity price is lower. Besides, the energy-saving benefit could be further increased with PV and battery system. From a market perspective, DR flexibility and PV generation also facilitate the concept of "energy community". The households can trade electricity with each other (peer-to-peer, P2P) within a local micro-grid or even trade with the other side of the country through the national grid, depending on the infrastructure, business model, and policies. In addition, households can also buy the services from an "aggregator", who bundles and manages the flexibility of small consumers and producers and participate in the market activities (Kerscher and Arboleya 2022). Promoted by the declining costs of technologies and support policies, more and more household "consumers" are expected to become ”prosumers” (with PV) and ”prosumagers” (plus energy storage and SEMS) (Fereidoon Sioshansi 2019).

FLEX models

The FLEX-Operation and FLEX-Community models were built to improve the building modeling suite and to analyze the societal trends of prosumaging and energy communities. The figure 1.1 shows how FLEX interacts with other bottom-up models involved in the newTRENDs project.

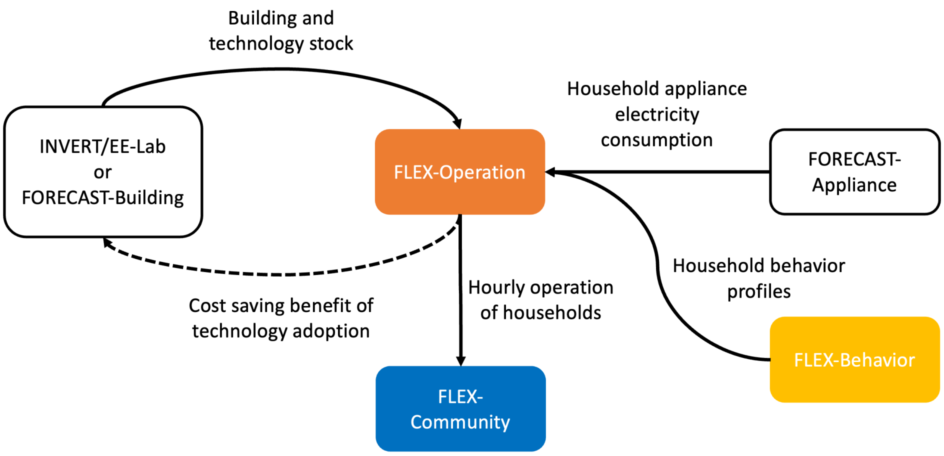

Figure 1.1: FLEX modeling suite

INVERT/EE-Lab and FORECAST-Appliance are the two models that can cover the energy consumption of residential buildings. The two models complement each other and cover the total energy consumption of households. However, both INVERT/EE-Lab and FORECAST-Appliance calculate the energy consumption at the annual resolution and cannot model the prosumaging behavior and energy community, which requires an hourly resolution to consider the impact of household behavior, PV generation, and energy storage (thermal and battery) on energy consumption. In this regard, we developed the FLEX- Operation and FLEX-Community models to improve the building modeling suite and support relevant policy analysis.

FLEX-Community

FLEX-Community models the operation of an energy community, i.e., household interaction, aggregator optimisation. It can be applied to support the aggregators designing and evaluating business models, as well as making investment decisions, for example, the self-owned battery, PV panels, etc.

FLEX-Behavior

FLEX-Behavior models the behavior (activity profile) of households' and corresponding load profiles. It generates the hourly activity and energy demand profile of a pre-defined individual household. The results include

1. appliance electricity demand,
2. domestic hot water demand,
3. driving profile, and
4. building occupation.

FLEX-Operation

FLEX-Operation models the energy system operation of an individual household in hourly resolution. It calculates the energy consumption of each representative building, including operation of technologies (e.g., battery, PV, heat pump, etc.) and load profiles in hourly resolution.

Data is considered by the model

- building,
- heating system (heat pump, fuel-based boiler, electric heater),
- thermal storages for space heating and domestic hot water,
- space cooling technology,
- PV,
- battery, and
- electric vehicle.

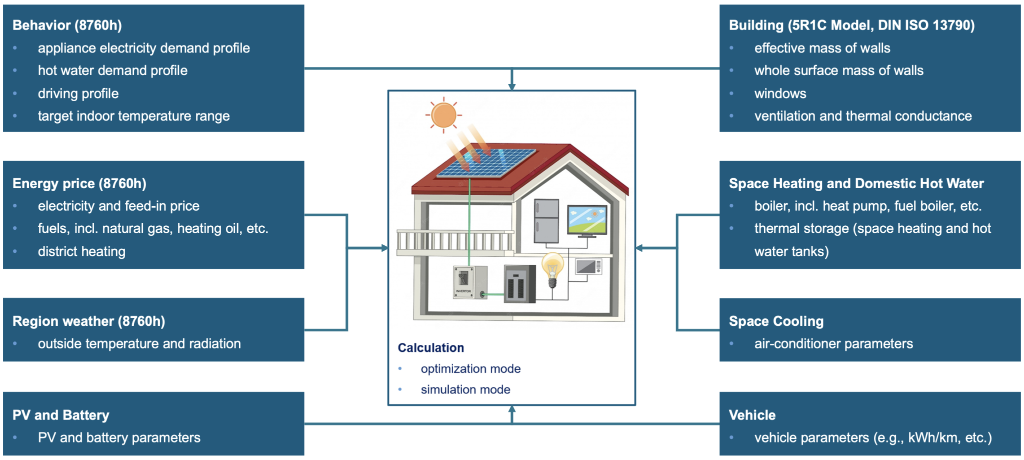

Figure 1.2: FLEX-Operation

1.2 Motivations

As a part of the newTRENDs project, the proposed thesis will focus solely on the implementation of the FLEX-Operation model. By employing the model to suggest reliable, cost-effective energy optimisation solutions while giving households with comparable predicted statistics on their energy consumption for the time frame. Despite the fact that the model primarily responds to societal trends for 2030, which means it provides more flexible suggestions when a household already owns a photovoltaic (PV) system, this could be as well an opportunity to nudge the European households who currently rely on other energy resources to switch to renewable energy when feasible. And it will be beneficial not only to the environment but also to consumers.

1.2.1 Research gaps and questions

There is a lack of case study research of promoting energy optimisation solutions. The aim of this proposed thesis is to design and develop a user-friendly web application for recomanding energy optimisation solutions.

The following criteria should be taken into account while building a software application from a user's perspective:

- It should be easy and effortless for using.
- The interactions should be intuiative.
- The recommandations should be clear explained to users.

Objectives:

- Investigate the data of the FLEX-Operation model to build an energy optimisation recommendation system.
- Determine the typical European household types.
- Design the web application with user-centred approaches.
- Use data visualisation techniques to provide explainable suggestions.
- Develop the frontend and backend web application.
- Evaluate the explainability of the smart energy optimisation recommender at the user level and measuring the impact of the households perceptions towards energy optimisation solutions.
- Allow long-term event tracking for iteration.

Resaerch questions:

1. What are the data required by the FLEX-Operation model from households?
2. What are the typical European household profiles?
3. How to build a trustworthy and user-friendly energy optimisation recommendation system?

Is there any literature review to add?

1.3 Supervision agreements and time planning

Introductory lines...

1.3.1 Justification for 30 ECTS

Research + design + develop very practical.

1.3.2 Supervision

This master thesis project will be supervised by Prof. Dr. Gunnar Stevens (gunnar.stevens@uni-siegen.de) at Siegen University and Dr. Songming Yu (songmin.yu@isi.fraunhofer.de) from The Fraunhofer Institute for Systems and Innovation Research.

1.3.3 Time planning

Some text

1	Investigate the data of the FLEX-Operation model to build an energy optimisation recommendation system.
2	Determine the typical European household types.
3	Design the web application with user-centred approaches.
4	Use data visualisation techniques to provide explainable suggestions.
5	Develop the frontend and backend web application.
6	Evaluate the explainability of the smart energy optimisation recommender at the user level and measuring the impact of the households perceptions towards energy optimisation solutions.
7	Allow long-term event tracking for iteration.

Table 1.1: Objectives

		1	2	3	4	5	6	7
	w1							
Feb	w2							
	w3							
	w4							
	w5							
	w6							
Mar	w7							
	w8							
	w9							
	w10							
Apr	w11							
	w12							
	w13							
	w14							
May	w15							
	w16							
	w17							
	w14							
	w15							
Jun	w16							
	w17							
	w18							
	w19							
Jul	w20							
	w21							
	w22							

Table 1.2: Time planning

Chapter 2

Methodology

Introductory lines...

2.1 Design case studies

Some text here ...

2.2 Grounded design

Appendices

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