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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ABSTRACT

Text...

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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 [12]. To tackle climate change and its negative impacts, two main strategies are addressed: climate change adaptation and mitigation. Climate change 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 [17]. 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]. Climate change mitigating means cutting and sequestering emissions of greenhouse gases (GHG) to prevent further increases in their atmospheric concentrations [17]. 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]. The newTRENDs project falls into the category of 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 [19]. To achieve this ambitious goal, the world is facing an unprecedented imperative to a rapidly transition in the energy sector. 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 [14]. 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].

Renewable energy (RE) and energy efficiency (EE) are two central strategies pursued by the EU and its Member States concerning the energy system.

Investments into low-carbon power generation accounted for 15% recently are expected to rise to more than 30% by 2030, corresponding to a quadrupling in absolute volumes [3]. Solar, wind, and the investments for enabling the integration of these technologies to the grid dominate the investments into low-carbon power generation [3]. Measures to increase energy efficiency, including investments in energy savings and the consolidation of consultancy and information services, are promoted by The National Action Plan on Energy Efficiency (NAPE) [7].

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 [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 [9].

1.1.1 New societal trends on energy demand

Researchers 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 [4]. It is therefore important to access current and (foreseeable) future societal trends concerning the impact that they might have on future energy demand [4].

Four arising societal trend clusters that are likely to shape future energy demand in European countries (and worldwide) were established by Brugger et al. [4]: *(i) the digitalization of the economy and of private life; (ii) new social and economic models, including the sharing economy and prosumaging (combination of producing, consuming and managing of energy); (iii) industrial transformation, including decarbonization of industrial processes and the circular economy (including a stronger focus on material efficiency); (iv) quality of life, including health effects, urbanization and regionalization.*

Considering the impact of these new societal trends on energy demand from a closer sectoral perspective, Yu et al. [21] identified four energy sectors:

- industry,
- transport,
- tertiary,
- residential.

This proposed thesis will focus on residential sector while taking scenarios of "consumers" becoming "prosumers" (with PV) and "prosumagers" (adding energy storage and SEMS) [18] into account.

1.1.2 The modeling of residential buildings

The FLEX models of the newTRENDs project are referred to as "RC models", that calculate (simulate or optimize) the building energy demand at the hourly resolution, considering the trends of prosumaging households and energy communities, which significantly supports the analysis of relevant policies promoting the diffusion of heat pumps (HP), PV, batteries, and SEMS [21].

The figure 1.1 shows how FLEX interacts with other bottom-up models involved in the newTRENDs project.

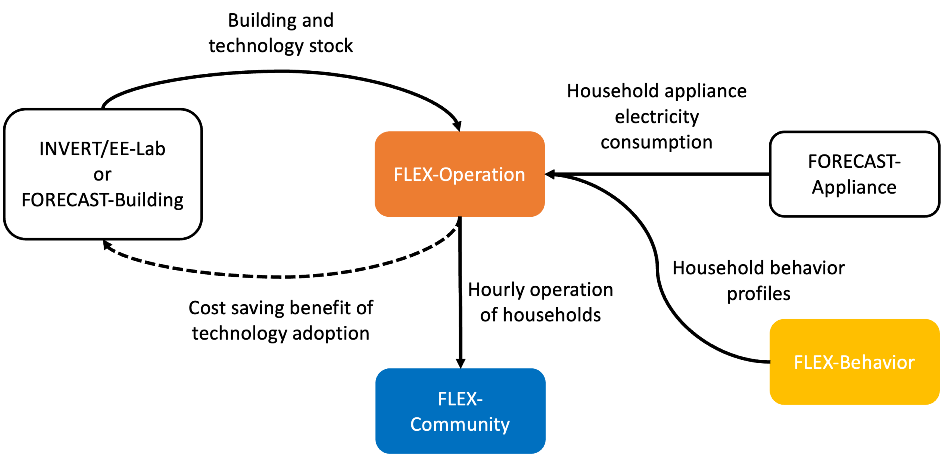

Figure 1.1: FLEX modeling suite

INVERT/EE-Lab and FORECAST-Appliance

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, the FLEX-Operation and FLEX-Community models were developed to improve the building modeling suite and support relevant policy analysis [21].

FLEX-Operation

FLEX-Operation models the energy system operation of an individual household in hourly resolution. It can be used to calculate the energy consumption of each representative building, including operation of technologies (e.g., battery, PV, HP, etc.) and load profiles in hourly resolution. Furthermore, FLEX-Operation can also provide implications for investment decisions, i.e., the energy-saving benefit of technology adoption [21].

As shown in figure 1.2, FLEX-Operation considers following five energy services [21]:

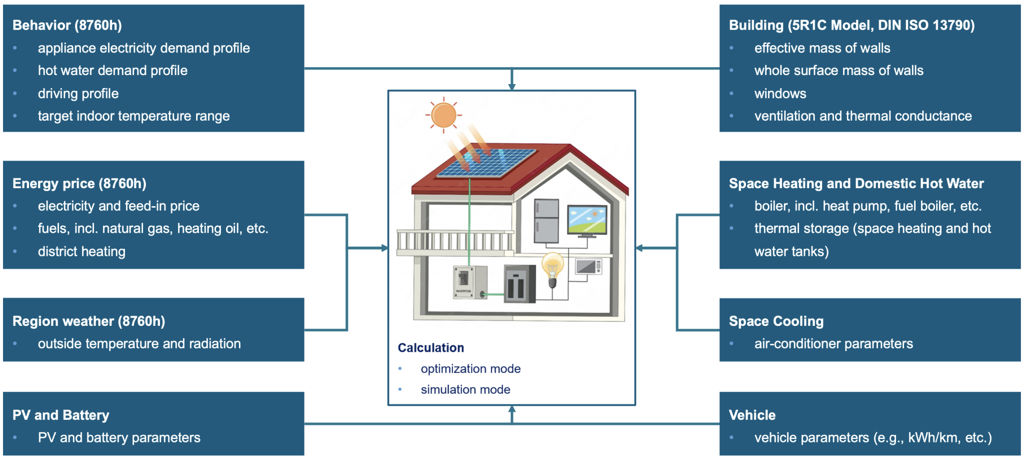

Figure 1.2: Model structure for individual households

1. electric appliances, e.g., television, refrigerator, lighting, etc.;
2. space heating;
3. domestic hot water;
4. space cooling;
5. vehicle.

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. [21].

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 [21]. The results include [21]:

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

1.2 Motivation and aim

Buildings will play a central role in the clean energy transition [10]. High-performance buildings construction and energy renovations reduce the sector's energy use, digitalisation and smart demand-side management further reduce energy use in buildings [10]. As a part of the newTRENDs project, the proposed thesis will focus solely on the implementation of the FLEX-Operation model. The aim is to provide techno-economic assessments of configuration optimisations of households' energy systems, in order to support decision-making on technology adoption at the residential level. Despite the fact that the model primarily responds to societal trends for 2030, which means it provides more flexible integrating technology recommendations when a household already owns a 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. This project can be used to guiding decisions on the use of clean energy and energy technologies at the household level, and encouraging households to engage in energy conservation practices and investments.

1.3 Research gaps and questions

Regarding the transition to renewable energy sources, there has been a lot of study and advocacy in academy. The infrastructure has been shifted with the support of policy makers, the transformation is reaching its maturity, it is time to motivate households to actively engage in adjusting their home energy systems.

Empirical results suggest that households' propensity to invest in clean energy technologies depends mainly on home ownership, income, social context and household energy conservation practices, in addition, environmental attitudes and beliefs, as manifest in energy conservation practices or membership in an environmental non-governmental organisation, also play a relevant role in technology adoption [1].

Is there any literature review to add?

This proposed thesis attempts to answer: how HCI can help households' investment in energy efficiency and renewables from a techno-economic perspective? As well as to develop a user-friendly software for this purpose.

The following research objectives will aid in achieving the goal:

- Investigating the data required by the FLEX-Operation model.
- Identifying the typical European household types and understanding their perceptions of the household energy system.
- Designing the web application with user-centred approaches.
- Using data visualisation techniques to ensure explainability of the recommendations.
- Developing the frontend and backend web application.
- Evaluating the explainability of the recommendations from users' perspectives and measuring the impact of the households‘ perceptions towards proposed solutions.
- Allowing long-term event tracking for design iteration.

Accordingly, three subquestions are raised:

1. What are the data required by the FLEX-Operation model from households?

2. What are the typical European household profiles?

3. How to offer trustworthy and user-friendly recommendations to European households from a techno-economic perspective?

1.4 Supervision and planning

The master thesis project is worth 30 Credits at Siegen University. This proposed project will discuss both research and application aspects related to the crucial topic of techno-economic assessment. To meet the design requirements, it is expected that scientific review, data analysis, user testing, and evaluating will be involved. Thus, the project is believed to be justified for those credits.

1.4.1 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.

1.4.2 Time planning

The following is the time allocation for the research objetives, which are scheduled to be completed in 26 weeks.

1	Investigating (...)
2	Identifying (...)
3	Designing (...)
4	Using data visualisation techniques (...)
5	Developing (...)
6	Evaluating (...)
7	Allowing long-term event tracking (...)

Table 1.1: Objectives

		1	**2**	**3**	**4**	**5**	**6**	**7**
	w1							
	w2							
Feb	w3							
	w4							
	w5							
	w6							
Mar	w7							
	w8							
	w9							
	w10							
	w11							
Apr	w12							
	w13							
	w14							
	w15							
May	w16							
	w17							
	w18							
	w19							
Jun	w20							
	w21							
	w22							
	w23							
Jul	w24							
	w25							
	w26							

Table 1.2: Time planning

Chapter 2

Methodology

Introductory lines...

2.1 Design case studies

Pre-study, design, approriation.

2.2 Grounded design

A method to create concepts out of profound empirical analysis. Reduce the gap between theory and practice.

Chapter 3

Dataset

Introductory lines...

3.1 Review

3.1.1 Pecan street

The dataport by Pecan street collected high-resolution, appliance-level electricity use data from approximately 1,000 houses and apartments in the U.S. [16].

3.2 Input data by FLEX-Operation model

In order to accurately anticipate household's energy costs, the FLEX-Operation model takes a set of variables into account, and they can be divided into following 15 categories:

- behaviour profile,
- battery,
- behaviour,
- boiler,
- building,
- energy price,
- heating element,
- hot water tank,
- PV,
- region,
- space cooling technology,
- space heating tank,
- vehicle,

- energy price,
- region weather.

Furthermore, the specific data required within each category is shown in table 3.1.

Category	Data
Behaviour profile	id_hour, people_at_home_profile_1, hot_water_demand_profile_1, appliance_electricity_demand_profile_1, vehicle_at_home_profile_1, vehicle_distance_profile_1.
Battery	ID_Battery, capacity, capacity_unit, charge_efficiency, charge_power_max, charge_power_max_unit, discharge_efficiency, discharge_power_max, discharge_power_max_unit.
Behaviour	ID_Behavior, id_people_at_home_profile, target_temperature_at_home_max, target_temperature_at_home_min, target_temperature_not_at_home_max, target_temperature_not_at_home_min, shading_solar_reduction_rate, shading_threshold_temperature, temperature_unit, id_hot_water_demand_profile, hot_water_demand_annual, hot_water_demand_unit, id_appliance_electricity_demand_profile, appliance_electricity_demand_annual, appliance_electricity_demand_unit, id_vehicle_at_home_profile, id_vehicle_distance_profile.
Boiler	ID_Boiler, type, power_max, power_max_unit, carnot_efficiency_factor.
Building	ID_Building, type, construction_period_start, construction_period_end, person_num, Af, Hop, Htr_w, Hve, CM_factor, Am_factor, internal_gains, effective_window_area_west_east, effective_window_area_south, effective_window_area_north, grid_power_max, supply_temperature.
Energy price	ID_EnergyPrice, id_electricity, id_electricity_feed_in, id_gases, price_unit.
Heating element	ID_HeatingElement, power, power_unit, efficiency.
Hot water tank	ID_HotWaterTank, size, size_unit, surface_area, surface_area_unit, loss, loss_unit, temperature_start, temperature_max, temperature_min, temperature_surrounding, temperature_unit.
PV	ID_PV, size, size_unit.
Region	ID_Region, code, year, norm_outside_temperature.
	Continued on next page

Table 3.1 – continued from previous page

Category	Data
Space cooling technology	ID_SpaceCoolingTechnology, efficiency, power, power_unit.
Space heating tank	ID_SpaceHeatingTank, size, size_unit, surface_area, surface_area_unit, loss, loss_unit, temperature_start, temperature_max, temperature_min, temperature_surrounding, temperature_unit.
Vehicle	ID_Vehicle, type, capacity, capacity_unit, consumption_rate, consumption_rate_unit, charge_efficiency, charge_power_max, charge_power_max_unit, discharge_efficiency, discharge_power_max, discharge_power_max_unit, charge_bidirectional.
Energy price	Region, year, id_hour, electricity_1, electricity_2, electricity_feed_in_1, gases_1.
Region weather	region, year, id_hour, pv_generation, pv_generation_unit, temperature, temperature_unit, radiation_south, radiation_east, radiation_west, radiation_north, radiation_unit.

Table 3.1: Input data required by FLEX-Operation

Appendices

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