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Functional Requirements and Recommendations for AI-based Sustainable Energy Solutions

Maximilian Lowin [1], Cristina Mihale-Wilson [2]

Abstract: SMEs contribute to energy conservation by innovating smart services across domains. This article supports the design and implementation of AI-based products and services for sustainable energy solutions by uniting insights from research and practice. Specifically, it presents an iterative approach to document and refine appropriate functional requirements from the literature and three expert focus groups. The set of requirements presented can help SMEs to allocate their development resources efficiently by indicating those functions that are a must or rather optional. Besides, to bolster SME initiatives for AI-based sustainable energy solutions, this article articulates several recommendations for implementing the most important requirements into practice.

Keywords: AI-based Services, Functional Requirements, Sustainable Energy Consumption, Sustainable Heating

1 Introduction

Increased energy costs affect almost two-thirds of small and medium-sized enterprises (SMEs) and are a burden for half of them [Kf22]. Likewise, SMEs are essential in reducing energy and carbon emissions as they account for more than half of all industrial energy use [FH20]. Reducing energy consumption is a crucial strategy to minimize operational costs and to contribute to the environment. In this vein, SMEs can either implement green strategies for optimizing their existing business processes or create new business models that support other organizations in *sustainable* energy consumption.

The Rio Conference in 1992 played a pivotal role in shaping an understanding of the meaning of the term *sustainability* by launching several high-level convention processes, especially regarding climate change, biodiversity, and desertification, to counteract global environmental issues [Sc07]. The implication of such conventions can burden SMEs, e.g., by dealing with increased costs [Kf22] or being obliged to implement specific legal requirements such as reporting requirements [SS15]. However, sustainability does not necessarily mean burdening SMEs; instead, it can be a competitive advantage if they reinvent their strategies to foster sustainability [HK21]. Indeed, information technology and innovation can be driving forces for SMEs in the global competition, and identifying

[1] Goethe University Frankfurt, Information Systems and Information Management, Frankfurt am Main, lowin@wiwi.uni-frankfurt.de, https://orcid.org/0000-0003-0467-059X
[2] Goethe University Frankfurt, Information Systems and Information Management, Frankfurt am Main, mihale-wilson@wiwi.uni-frankfurt.de, https://orcid.org/0000-0002-9725-0078

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opportunities for new technologies is a condition for the successful adoption of SMEs [Pr19]. For instance, SMEs can develop new smart services to help various application domains consume more energy sustainably. Relevant areas of energy consumption optimization are, among others, industrial and residential heating, traffic and transportation, power consumption, and waste management.

A promising emergent application domain is sustainable heating, which aims to reduce the heating energy consumption of a building and decrease the associated environmental impacts, e.g., by implementing energy conservation measures or using renewable energy sources [LT20]. However, such energy-related optimizations typically induce specific trade-offs when impacting the environment of human users [Ba15]. In the case of sustainable heating, lower energy consumption potentially affects the level of comfort of inhabitants of a building [Ba15]. Therefore, it is imperative to collect a wide range of requirements before implementing a smart service for sustainable energy consumption and to include the perspectives of various stakeholders that such a service would affect. This paper aims to pave the way for SMEs that are typically operating in the area of tension between limited resources for AI implementation and the development of new and innovative products and services by addressing the question: *What are the most important functional requirements of AI-based services for sustainable energy consumption?* As we argue in the next section, we focus on functional requirements due to their importance in the development process of AI-based services. We investigate the research question in the smart living domain but intent to provide open, domain-independent recommendations.

2 Making a Case for the Importance of Functional Requirements

Common to the design and development of new solutions, before starting the design and development process, companies need a thorough understanding of the requirements for the products and services they are about to develop. Thorough requirement engineering ensures that the outcome aligns with user's needs and expectations and represents foundational knowledge that is essential to ensure that the product or service is competitive and effective [Be14]. Additionally, through thorough knowledge about requirements in the early stages of the design and development process, organizations can avoid or mitigate risks associated with the solution implementation. Thus, thorough requirements engineering in early stages reduces costs and efforts in later development stages, such as testing or corrective development steps [St18a]. This is also valid for the development of effective AI-based services for sustainable energy consumption, where it is equally indispensable to understand the application domain, potential users, and their requirements. Such user and domain requirements can be of various natures. Literature often distinguishes between functional and non-functional requirements. While functional requirements specify *what* the system should do (i.e., describe the tasks and services the system should feature) [MCN92], non-functional requirements specify *how* the system performs its functions (e.g., by defining legal, quality, and performance metrics). [CD09].

Thereby, some requirements are highly domain-dependent, while others are domain-agnostic. For illustration purposes, let us consider the legal and functional requirements of a sustainable heating implementation: while a sustainable heating system in the residential area has different legal requirements than in an office complex, the functional requirements remain in both cases the same—i.e., optimize the energy used for heating.

While all types of requirements constitute important puzzle pieces when designing and developing AI-based services and products, in this work, we focus on functional requirements only, i.e. those, that contain explicit functionalities (*what* the product or service should do). We do so based on the conviction that the functional requirements will influence various architectural and technological features of the future product or service. We argue that functional requirements are linked to *efficiency and effectiveness* of the system [Ar16], but also the *effective resource allocation* within the providers' organization. After all, functional requirements ensures that resources—development time, and computational power—are aligned with the complexity nascent from the functional requirements. While many stakeholders would like to choose the latest cutting-edge AI technology to develop a certain product or service, such choices often turn out to be an 'overkill' that imply not only higher development efforts but also higher risks because best practices, boundaries, and other essential implementation pitfalls are yet to be discovered and documented. The functional requirements define the complexity and capabilities needed from the AI models [Bo09]. Hence, by aligning the functional complexity of the system with the AI models needed, organizations can manage to significantly cut down on development expenses and mitigate risks.

Notably, the above-stated arguments are not meant to present an exhaustive elaboration of the matter, they aim to highlight the importance of functional requirements when designing and developing AI-based products and services. Yet, after establishing the significance of functional requirements for implementing AI-based services, the next question that arises is: *what are the most crucial functional requirements for implementing an AI-based system for sustainable energy consumption?* Prior literature presents a plethora of requirements (albeit not all of them are functional requirements) in relation to the development of such systems. In this work we distill the numerous requirements proposed by prior literature and insights from various practice applications into a set of functional requirements essential to the successful development of AI-based systems for sustainable energy consumption. Additionally, to further pave the way for SMEs to design and implement such systems we also offer concrete implementation recommendations that we derived in an iterative research methodology comprising a literature review and three focus groups. The next section explains our research methodology in more detail.

3 Research Methodology

Our research approach was iterative and started with a literature review that allowed us to craft an initial set of requirements. We conducted a literature review using the Google

Scholar search engine and several keywords connected to energy consumption in multiple contexts, e.g., "sustainable heating," "energy efficiency requirements," or "smart building." From the resulting papers, we manually extracted all requirements. Since most requirements were non-functional (e.g., technical or belonging to business models), we filtered these requirements, and keeping only functional requirements. Then, to better structure the insights presented by prior literature, we classified each requirement into one or more categories. We constructed the categories using a bottom-up approach by grouping similar requirements, naming these groups and iteratively refining the categorization. This approach resulted in an initial set of functional requirements. To further refine our set of functional requirements and identify complementary or obsolete requirements, we conducted three expert focus groups. In the first group, we presented our initial pool of requirements to experts and asked them to refine these. The expert groups consisted of individuals working for academia and private sector companies. The research institutes mainly focus on smart service engineering and artificial intelligence (AI). The practice partners (mainly SMEs) consisted of various industries like housing companies, smart living products and service providers, and heating experts.

We organized the first focus group with a modified version of the nominal group technique. This technique ensured an early integration of essential stakeholders in the generation process [DVG75] and the preparation of the participants (i.e., the familiarity with the results of the literature review) before the focus group session [Fo89]. After the first focus group session, we refined the initial requirements by adding new requirements, deleting unnecessary requirements, or altering existing requirements better to suit the overarching goal of sustainable energy consumption. Criteria for adding new requirements were novel insights from the industry partners that occurred in earlier projects and fit to the domain of AI-based sustainable energy solutions. Contrarily, we deemed requirements as unnecessary if they are too close to other requirements or if they were non-functional and we could not find an adequate functional counterpart. Likewise, we restructured the categories and assigned the requirements to the categories. Subsequently, we organized a second focus group session to validate our changes with the stakeholders and further refine the requirements. Experts ranked the refined requirements and prioritized them in accordance with their importance. To this end, each expert rated the requirements individually on a scale between 1 (very important) and 4 (rather unimportant). Based on these individual ratings, we created an average importance score that we used as input for the last focus group session, where we determined the final set of requirements. Fig. 1 summarizes the methodology and serves as an outline of the structure of the next section, which presents the results of the requirement aggregation process.

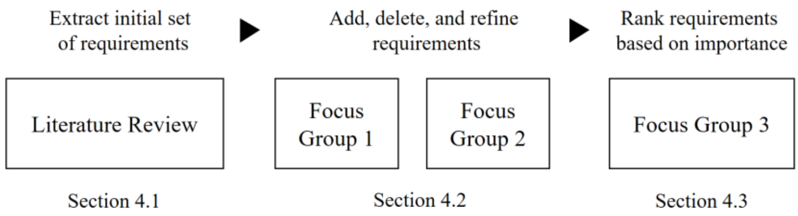

Fig. 1: Summary of Methodology

4 Results

4.1 Literature Review

Our literature review resulted in 23 publications, ranging from scientific papers to press releases. Seven of them mainly concentrate on applications of energy reduction in heating, air conditioning, and ventilation. Two papers focus on electrical energy consumption. The remaining papers consider energy consumption as a multidimensional construct consisting of various kinds of energy consumption.

From the original 23 publications we documented 143 requirements spanning 15 different categories, ranging from *adaptability* over *data privacy* to *finance*. To reduce complexity and distill the insights provided by prior literature; while allowing a productive workflow in the focus sessions, we filtered all non-functional requirements from the functional ones. This refinement resulted in 113 functional requirements spanning ten categories, all containing explicit features or requirements that we can later refine into specific functionalities. Tab. 1 shows the reduced set of categories, the number of requirements, and one exemplary requirement for each category.

Category	**Number of Items**	**Exemplary Requirement**
Adaptability	13	Automatic adaptation to resident activities [PBH08]
Optimization	21	Reduction of peak consumption [Ji18a, KP17]
User–System Integration	10	Explain decisions and functionality to users to reduce user intervention [St18b]
Visualization	7	Different views: daily, weekly, monthly, and yearly consumption [Gw20]
Control & Transparency	3	Locus of control [Gu21]

Category	Number of Items	Exemplary Requirement
User Experience & Adoption	14	Quantification of savings [Gr21]
Information	25	A system must inform users of the automatic decisions it makes, including an explanation of why this is being done [St18b]
Energy Analyses	13	Recommendations should consider CO2 price [RSS15]
Hardware	2	Interoperability [Gr21]
Service	5	Establish predictive maintenance to allow an energy-efficient operation of infrastructure [LRW22]

Tab. 1: Initial Set of Functional Requirement Categories and Examples

4.2 Refinement after the First Two Focus Groups

The two first focus sessions allowed us to sharpen the requirements from the literature and adapt them according to the industry's actual needs. For instance, we split the category *optimization* into two sub-categories: *optimization method* and *optimization target*. Besides, we merged other categories and removed too general categories (e.g., the category *hardware*).

Besides the changes in categories, we merged similar requirements, removed unnecessary requirements for our setting, and added additional requirements not part of the initial set of requirements obtained from the literature. For instance, one requirement stated that the system must know what the inhabitants are currently doing [PBH08]. Since this requirement is relatively non-specific, we refined it into the absence and presence of inhabitants and the concretization of how many inhabitants are at home. Another requirement stated that users should compare consumption information with a neighbor [Gr21]. While we initially limited our comparison to a concrete neighbor, European privacy regulations prohibit such implementations. Consequently, we needed to alter this requirement to comply with the European regulation. Furthermore, we added additional requirements put forward by the practice partners (e.g., the need for personnel training).

The refinement process resulted in 47 functional requirements spanning seven categories: *adaptability*, *optimization target*, *optimization method*, *energy analysis and forecast*, *consumption visualization*, *information*, and *context dependency*. While the category *Adaptability* seems to be non-functional, we focus on the functional aspects within the category, i.e. how the system should adapt in case of changes in market structure (e.g., energy price changes) [RSS15] or changes in their users' heating preferences [AS22]. After all, depending on individuals' activity level, age or health condition the perceived comfort at a certain level of temperature can vary significantly. The *optimization target* refers to the overall goal of the system—i.e., whether the system should focus on optimizing the consumption within one sole unit or in the entire building [GNJ19, Ji18a, KP17, ZSP13]—while the *optimization method* relates to the specific techniques and algorithms used to achieve this goal [Gu21, Gr21, Gw20, Ji18a, KP17, LRW22]. The *energy analysis and forecast* category focuses on accuracy, transparency and other features related to energy prediction [Ba15]. Further, the functional requirements could appertain to *consumption visualization* (which focuses on how information is communicated) [KP17], or the *information category* which entails requirements about what data (information) should be displayed by such systems [Gr21]. Ultimately, the *context dependency* category entails requirements on the degree to which the system should adapt to the current user or overall context [Ji18a, KP17].

4.3 Final Prioritization

In the pre-final focus group participants were asked to rate the requirements according to their relative importance. Ultimately, in the concluding focus group, we discussed individual prioritization to finalize the functional requirements for sustainable energy consumption services. The participants ranked 22 of the 47 requirements as very important or important. Table 2 lists the most important and important requirements grouped by the seven categories mentioned above.

Category	**Functional requirement, only rated as very important (*) or important (x)**	
Adaptability	*	Adaptability in accordance to heating demand
	*	Adaptability to desired thermal comfort (apartment, room) and user needs: comfort, user information, health & well-being
	*	Adaptability to outside temperature and weather conditions
	*	Adaptability to dynamic changes in user preferences
	x	Adaptation to resident activities and habits
Optimization target	*	Reduction of energy consumption
	*	Central system optimization
	x	Reduce the overall demand of buildings, building systems
	x	Monitoring: Transparency of when and where an interaction occurs between building technology and humans, to detect errors and optimization potentials in the system
Optimization methods	*	Consideration of building properties, such as thermal storage properties
	x	Considering human behavior (habits): Ventilation, presence, absence, interaction with the system
Energy analysis and forecast	x	High accuracy of energy analyses and forecasts
	x	Transparency and comprehensibility of energy analysis and forecasts and their presentation

Category		Functional requirement, only rated as very important (*) or important (x)
	x	Reliability of energy analysis and forecasts
	x	Customizable heating energy analysis and forecasts
Consumption visualization	x	User interface with the ability to create schedules, setpoints, and display important information
	x	Plausible billing values (in monetary units), e.g., weather-adjusted
Information	*	Explanation of the benefits / quantification of savings through the use of the system
	*	Users should receive tips for behavioral optimization
	x	Live feedback helps to identify savings potential and meet the actual needs of all users—not just a few opinion leaders—reducing complaints
	x	Heat transparency, including cost display and forecasts, e.g., on users' smartphones
	x	Information on energy-efficient heating only for those who want it (the majority do not wish to be actively informed)
Context dependency	x	The system must know where the residents are located (motion awareness)
	x	Consideration of user profiles and that savings potentials differ depending on whether the user are heavy energy consumers (retirees, individuals working in home office) or low-level consumers (working individuals)

Tab. 2: Results—most important functional requirements

5 Discussion

In summary, the presented results reveal not only the most essential functional requirements, but also which requirement categories are–in relation to each other–more important. Therefore, under limited resources for the design and implementation of AI-based product and services, SMEs should aim at addressing the most important categories of requirements first. In this respect, the results reveal that the *adaptability of the system* is deemed particularly important. Remarkably, four adaptability requirements are rated as very important [Gu21]: adapting to dynamic preference changes, to external temperature and weather conditions, to desired heating comfort (apartment, room), and to user needs like comfort, information, health, and well-being, as well as adapting to heating demand [RSS15]. While adaptability is typically a non-functional requirement, the different needs here mark important input features for AI systems. The next important requirement categories involve *optimization targets* and *information*, with information being slightly more critical. The intelligent system should offer users tips for behavior optimization and explain the benefits and savings from using the system at hand [Gu21]. For instance, language models can generate context-dependent tips. Additionally, providing energy-efficient heating information only to those who want it is essential, as most do not want unsolicited information [KP17]. Transparency in heating costs, forecasts on tenant smartphones, and live feedback to uncover savings potential and meet all users' needs (not just a few opinion leaders) are also important [Ji18a]. For *optimization targets*, reducing energy consumption and central system optimization are essential [Gu21]. Reducing overall building demand and monitoring to create transparency [KP17], identifying interactions between building technology and humans to detect errors and optimization potential is also necessary [GNJ19]. Determining these targets beforehand helps AI developers in the model creation. Other key requirement categories include *optimization methods* and *context dependency*, followed by *energy analysis and forecast*. In the sustainable heating context, considering building characteristics, such as heat storage capacity [Ji18b], and human behavior (ventilation, presence, absence) is crucial [AS22]. AI algorithms should incorporate this information, requiring that such data is available. For context dependency, recognizing user ventilation behavior (how often, when, and how) and detecting occupant locations (motion awareness) are particularly important. Savings potentials vary with usage intensity, which must be considered in comparisons [KP17]. In contrast, *consumption visualization* for the user seem to be less critical.

Based on these insights we derive the following *recommendations [R]* that can serve as guidelines for SMEs' future implementations of AI-based services for sustainable energy consumption: *[R1]* Starting with the dynamic nature of energy consumption patterns, smart service *systems should be able to adapt according to changes in the preferences of users and to changes in the usage context* (e.g., weather conditions). This recommendation is not only necessary from an ecological perspective but also crucial for user acceptance and trust in the technology. User acceptance is linked to personal experiences with the comfort of using such a service and satisfaction. Thus, a service should not only respond accordingly to routines but also to unexpected changes. User behaviors and preferences can be heterogeneous and context-dependent; therefore, a smart service cannot be a one-size-fits-all solution. *[R2]* Besides, *users of smart services should get enough information about the system status and enough control of the system.* They should know such a system's ecological and economic benefits to shape their expectations and increase their satisfaction. However, the availability of information should be flexible, as not every user needs the same information in the same granularity. Users should understand how a system works and should not need to specify anything manually. An inclusive smart service allows every kind of user to benefit from such a service independently of their age or technological affinity. However, they should always be able to overwrite rules or make changes to the configuration. *[R3]* Beyond the pure provision of information, *users require informational cues that enable them to engage in more sustainable energy consumption behaviors.* These cues need to be personalized due to the heterogeneity of individual preferences. *[R4]* In addition to the input and configuration of such a sustainable service system, *the system should provide a bidirectional live feedback channel for monitoring specific goals, progress, and potential changes in user* *preferences*. The bidirectional communication helps users understand and optimize their energy consumption behavior. This approach is also called human-in-the-loop, which enables humans and machines to work together and increase overall efficiency. *[R5]* Furthermore, *a sustainable energy system needs to consider human behavior and the characteristics of the respective environment.* For instance, a sustainable heating implementation should include characteristics of the building (insulation, thermal inertia, type of heating) and current and future weather. *[R6]* Finally, *any implementation of sustainable energy services must integrate use-case-specific characteristics*. While this paper aims to aggregate rather general requirements that SMEs need to incorporate into their service design independently of the respective type of energy and application domain, they must be aware of the context-specific requirements that go beyond such a general setting. For instance, in sustainable heating, SMEs must consider that heating is a process that typically lasts approximately half a year and repeats itself yearly. Consequently, users can learn a particular behavior over one heating period but forget such behavior in the next heating period. Of course, there are many more peculiarities also in further application domains, where a deeper dive into the respective domain is necessary.

These recommendations and the list of the most important functional requirements seek to pave the way for SMEs designing and implementing new AI-based products and services for more sustainable energy consumption. They serve as an important starting point in distilling insights from research to support SMEs. Nevertheless, these insights are not meant to be considered utterly in isolation from other types of requirements. As stated previously, functional requirements are indeed crucial for various reasons, but SMEs should always remember that functional requirements represent only one part of the development 'puzzle'. Technical, legal, user experience, and further non-functional requirements also play significant roles when developing innovative AI-based services. Therefore, future research should combine our insights with the most important requirements from these other categories. Similarly, while our set of requirements is intentionally general, future research should investigate the appropriateness of these general requirements in application domains other than the one presented in our study. By pursuing these research paths, scholars can foster effective knowledge transfer that helps SMEs implement their innovative ideas with less risk and greater success.

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