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Summary of WP Student Team

Developing a low-code Application: The Use Case EnMo

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A Work Project, presented as part of the requirements for the Award of a Master's degree in Business Analytics from the Nova School of Business and Economics.

Challenges and Opportunities of low-code Platforms for Software Development

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Abstract

The current energy and climate crisis emphasize the energy-efficiency knowledge gap as a pressing problem. This is addressed in the report and the mobile application called EnMo, which was developed as part of this field lab. Topics regarding gamification, big data analytics, and low-code development were investigated. The findings provide the foundation for developing the app and its mission as a solution to the problem. EnMo incentivizes users to reduce their household energy consumption, by collecting user information and providing educational and gamified content. Thus, EnMo enables consumers to change their behavior and reduce their energy-efficiency knowledge gap.

This exposition discusses the challenges and opportunity of low-code platforms for software development specifically. While speedy development, low maintenance and cost as well as low transparency and customization were filtered out as advantages of low-code, potential vendor lock-ins, black box issues and the fear of replacing software developers might present pitfalls of the technology.

Keywords: Low-Code, Product Development, Mobile Application, Gamification, Innovation, Sustainability, Energy Efficiency, Household Energy Consumption Data, Big Data Analysis

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I. Introduction

This exposition was created in the context of a field lab as part of a master's thesis in Business Analytics at the NOVA School of Business and Economics. The goal was to provide a practical approach to apply business and digital skills to develop a new digital product that helps solve an environmental or social challenge with impact. The result is a mobile app called EnMo and this written report. The developed application can be accessed by scanning the QR code on the right. It is important to note that at the current moment the app is not yet fully complete but represents a working minimum viable product (MVP) to showcase the approach and solution.

Figure 1
EnMo Access QR Code

EnMo sets out to be an energy efficiency mobile app for private households to record, understand and reduce the users' energy consumption in an easy and fun way. Its ultimate goal is to facilitate the following: *save energy, money, and the planet*. It stems from the need to provide relief considering the climate and energy crisis with a contemporary digital approach. The survey-based app collects information from users regarding their energy consumption behavior. In turn, personalized challenges, tips and tricks are proposed to the user based on their survey answers to incentivize them to change their behavior and become more energy efficient.

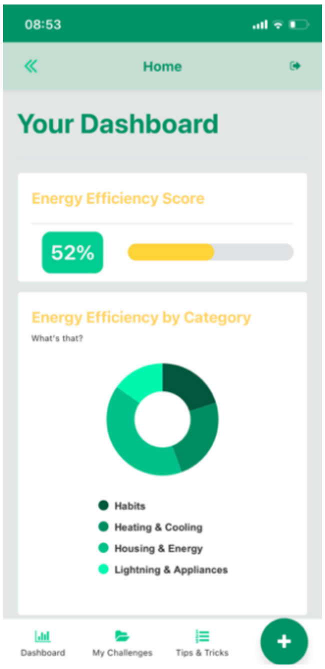

Figure 2 Screenshot Dashboard

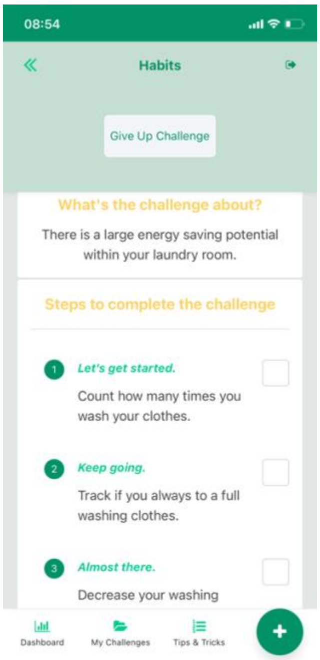

Figure 3 Screenshot Challenges

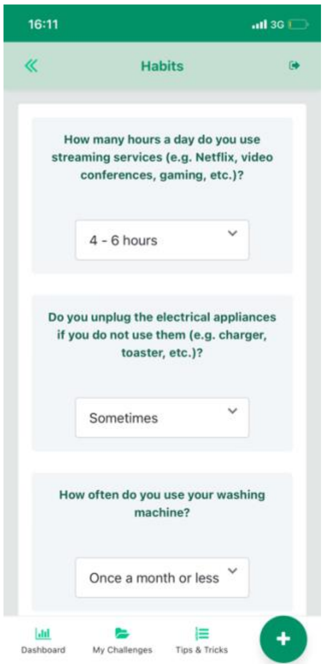

Figure 4 Screenshot Survey

The app is the practical embodiment of three separate research efforts that contribute to the context and objective of EnMo´s development. Those parts have been individual contributions by the team members:

- “Gamification for Sustainability and Data Analytics“ by Hanna Rotering,
- “The Value of Big Data for Sustainability and the Energy Sector“ by Clara Börner
- “Opportunities & Challenges of Low-Code Platforms for Software Development” by Leonie Mostbeck

Together they constitute the first part of this report. It is followed by the common part, “Developing a low-code Application: The Use Case of EnMo” written jointly by all team members describing the development and composition of the EnMo solution.

II. Opportunities & Challenges of Low-Code Platforms for Software Development

In today's world, digital is a must. To keep up with the ever-changing market requirements and lack of skilled talent, low-code has been on the rise (Frank, Maier, and Bock 2021). Low-code makes it possible to build digital products like software or applications much faster with so-called citizen development (non-IT-trained persons developing software) (OutSystems 2022c). With the help of platforms offering a graphical user interface and a higher level of abstraction, low-code makes it easier to develop software than traditional computer programming (Talesra and G. S. 2021). According to Gartner (Wong et al. 2021), 70% of all applications created by organizations will be developed with low-code technologies by 2025, up from less than 25% in 2020. Given these developments, this research part will analyze both the opportunities and challenges that software development with low-code platforms (henceforth, LCP) might entail through an extensive literature review. To set the scene, crucial concepts such as product and software development, as well as the different development methods, will be discussed. After differentiating low-code from no-code, the central part will be dedicated to the various features and benefits of LCP while also taking into account potential shortcomings. This paper will also touch upon the landscape of LCP providers before taking a closer look at OutSystems, with which, as part of the field lab related to this research part, an MVP of a mobile app was developed, which shall exemplify the opportunities and challenges mentioned now.

1. Definitions and Concepts

While product and software development are often used interchangeably, they are not the same for one apparent reason: the goal of product development is a physical, tangible good that shall be sold to a customer, while for software it is an intangible product that does not need to be manufactured (Nager 2021). The software itself consists of instructions made of lines of codes, also known as programs, that tell a computer what to do (Sommerville 2011). Applications are then specific pieces of software that shall help a user to carry out different tasks (IBM 2022). If a program now runs on a mobile device, it is commonly known as a mobile application or just an app. Although software and application can sometimes mean the same thing, software can consist of several applications but not the other way around e.g. Microsoft Office suite is a software with several applications like Word or PowerPoint (Smith 2022). The process through which those different types of software come about is called software development and can be carried out by various methods.

1.1. Different software development methods

Generally speaking, the goal of following a particular software development method is to have guidelines and a framework that shall simplify all stages of the software process and streamline the development team (Sommerville 2011). The traditional waterfall approach is molded to the functioning of big corporations with their regular audits and shareholder reports (Jančovičová and Skotnica 2018). It is a plan-driven process where one cascades from one phase to another. After defining the requirements as a first step, the next phase is system and software design, followed by two testing phases: implementation and unit testing and integration and system testing. The final step is the operation and maintenance of the software (Sommerville 2011). The next phase shall not be entered until the previous one has reached its goals, resulting in a rigid process. Although it is still quite popular because of its simplicity and ease of use, it can become costly and time-consuming (Leffingwell 2010). "All the time could be spent designing and documenting the software, while the quality of the program itself was poor, deadlines were missed and budgets went bigger than initially expected"(Virta 2018). Thus, the agile development approach was born from a reaction to this in the 1990s (Jančovičová and Skotnica 2018).

The main distinction is that the development process is divided into short cycles. At the same time, there is a constant exchange between the development team and the customer or user (Visavacheevinanan 2022). This means that the software is built incrementally and iteratively. Agile development follows four principles which are: working software over comprehensive documentation; individuals and interactions over processes and tools responding; to change over following a plan; and lastly, customer collaboration over contract negotiation (Leffingwell 2010). Further, the development cycles are also known as sprints, where each moves through all life-cycle stages again: planning, development, testing, delivery, and assessment. It is necessary to note that agile is an approach followed by various methodologies (Abrahamsson, Oza, and Siponen 2010). The most popular is Scrum, where the team is guided by self-management, transparency, and iteration in very short sprints. However, all agile methodologies offer quick adaption to changes, customization, and minimal planning and expenditures upfront (Carter 2022).

Apart from that, agile can be reconciled with the waterfall method (or others), meaning there can be mixed forms as well as more software development methods like DevOps or Rapid App Development (Visavacheevinanan 2022). Discussing them more in detail is beyond the scope of this piece, though it is important to note that they all have in common the need for a software developer who knows how to write code and program the application (Vikebø, Sydvold, and Osmundsen 2019). As they need to provide clients with reliable, high-quality software while under continual pressure to shorten delivery times, they need to be highly skilled in what they do. Thus, software engineers are not only in high demand but also expensive in addition to the already high costs when there is a need to change the software in the traditional developing process (Frank, Maier, and Bock 2021). This is where low-code development can come in and tackle some of these issues.

2. Low-code

2.1. Low-code development

Revell (2017) describes low-code development as “a way to design and develop software fast and with minimal hand-coding, a quick setup and deployment, for systems of engagement”. By using low-code platforms, working Proof of Concepts can be developed swiftly, allowing all types of organizations to experiment with the technology quickly (Vikebø, Sydvold, and

Osmundsen 2019). In this way, low-code development circumvents the shortage of conventional developers by reducing the learning curve and involving citizen developers who might not have much coding knowledge (Goswami 2021). It is a relatively new concept with the term "low-code" being first by Forrester in 2014 to describe pre-built components and visual rule-based development tools that speed up application deployment (Richerson and Rymer 2014). Thus, low-code development consists at its core of and is dependent on low-code platforms.

2.2. Low-code platforms

Although other notions such as low-code application platforms or low-code development platforms are also found in the literature (Bock and Frank 2021), for simplicity, the term low-code platforms (LCP) is henceforth used. Regardless of their terminology, there is indeed a consensus that LCPs “are products and/or cloud services for application development that employ visual, declarative techniques instead of programming and are available to customers at low or no cost in money and training time to begin” (Rymer 2017). The visual is a graphical user interface (GUI) that allows the user to choose a virtual object and move it to the desired position through drag-and-drop (Feldman 2013), while the declarative technique achieves the same outcomes as standard coding by offering click-and-select of prewritten components that essentially give the computer the goal and let it determine how to get there (Virta 2018). Hence, it can be said that LCPs originate from fourth-generation programming languages (4GL) that are also aimed at reducing the time thinking about the syntax of the code and embracing the functionality and aesthetics of the application. LCPs initially emerged as simple auto code generation tools but have grown since then into corporate-level scalable platforms handling the entire app delivery life-cycle (Frank, Maier, and Bock 2021).

This is made possible through three main components of any low-code platform: an application modeler and IDE (Integrated Development Environment), server-side services like API and data integration, and an application life-cycle manager (Talesra and G. S. 2021). The application modeler consists of a GUI and an IDE widgets, toolboxes, connectors, and more allow the user to develop the desired application with all necessary workflows, authorization schemes, or logic flows (Waszkowski 2019). The next layer then builds on the one hand the backbone of the app where data can be stored, structured, or retrieved when needed, and on the other, makes sense of the application model from the previous step through a set of compilers or code generators (Talesra and G. S. 2021). Here applications can connect to external services or databases through APIs that enable diverse data to be merged and processed uniformly (Gartner 2021). In addition, unique business logic flows or customized APIs can be integrated through manual coding. Finally, the application life-cycle manager assists in producing, debugging, deploying, and maintaining the application, which can either run on-premise or on a cloud depending on the platform (Talesra and G. S. 2021).

2.2.1. Low-code vs. no-code

At this point, discussing the difference between low-code and no-code platforms might be helpful. While both come in handy when enabling citizen developers to build digital software products, no-code platforms are restricted to back-end programs that were explicitly designed for them since they lack scripting languages. In turn, they do not require any understanding of code or syntax, meaning they can reach an even broader user base (Elshan, Dickhaut, and Ebel 2022). So what then is exactly the appeal of low-code platforms? This question will be answered in the following by examining the distinct features and related opportunities of LCPs.

3. Features and Opportunities

The first and most mentioned opportunity LCPs can offer is speed. It is so essential to software development that software expert Terhorst-North (2013) even stated that “everything else is detail.“ When a development team can minimize their lead time, they can build more applications in less time resulting in greater productivity (Talesra and G. S. 2021). One key aspect that makes this possible is the modularity and debugging features many low-code platforms provide. Using pre-compiled modules that are already programmed effectively and tested for faults can significantly reduce the time and resources spent on testing and debugging (Goswami 2021). For example, mobile compatibility, offline support, and responsive design, while native to LCPs, are hard to establish through traditional programming. Also, the visual GUI makes requirements analysis much more efficient by enabling the quick creation of Proof of Concepts that are easy to understand for clients (Virta 2018). It allows following agile software development methods for real-time customer feedback by validating features and functionalities quickly through low-cost prototypes. This goes hand in hand with the easy maintenance and security settings LCPs provide (Talesra and G. S. 2021). Role-based access control functionalities contribute to the straightforward erection of user permissions by an administrator without any coding involved. Changes may be done with no concern for performance effects because of LCP's centralized environments and application life-cycle manager.

Another crucial advantage of using LCPs is that with increased speed and simple servicing comes decreased costs. Developers are expensive not only to hire but also to pay per hour. LCPs reduce the number of software engineers required, the hours needed to complete a project, and thus the wages to be paid (Rymer 2017). Moreover, by turning business professionals into citizen developers, LCPs strengthen the bond between business and IT teams (Jančovičová and Skotnica 2018). According to a study that conducted semi-structured interviews in SMEs, low-code allows both sides to speak a common "language", which can break down the silos that often exist within an organization (Talesra and G. S. 2021).

However, not only enterprise-wide but also cross-platform accessibility and compatibility is an attractive feature of LCP. Platform APIs are in most cases compatible with major open-source frameworks like React or AngularJS (Virta 2018). Also, LCP applications can be accessed and run on all platforms or devices, not only making them easier to integrate with other systems but also creating a smoother customer experience (Vikebø, Sydvold, and Osmundsen 2019). All in all, the features mentioned above can lead to increased digitalization and cheaper innovation in organizations through the quick automation of business processes with rapid development times the potential to compensate for the lack of software developers and software integration possibilities (Waszkowski 2019). Nevertheless, some concerns need to be considered.

4. Challenges and Possible Pitfalls

One fundamental challenge of LCPs is a third-party dependency which sometimes even poses an implementation barrier. For example, the code of generated applications is not made visible by most providers to the customer, leading to a black box that can only be interpreted to some extent (Elshan, Dickhaut, and Ebel 2022). Further, the customer is completely reliant on the provider of the LCP when it comes to schedules of software updates or security issues. This ultimately provides customers with significant concerns about lock-ins with vendors (Talesra and G. S. 2021).

Moreover, one is also dependent on the tool's available building blocks, resulting in limited customization possibilities. Existing modules may not be able to bring about a required feature, limiting the scope of application and complexity of LCPs (Lichtenthäler et al. 2022). Because of the confined options, LCP applications are also very similar in terms of UI (user interface) and are often spotted easily by a trained eye. Making the UI appealing and singular may be more difficult than with tailored solutions since one must follow the platform's logic (Elshan, Dickhaut, and Ebel 2022). Thus, there will always have to be manual coding for custom algorithms or advanced logic flows. It is a myth that LCPs eliminate the need for any hand-coding or professional developer as code is just hidden from the end user (Virta 2018). Hence, the term *low*-code and not *no*-code platform. Declarative creations require the exact conversion, compilation, and execution steps as regular programming (Virta 2018). This is subject to debate, as some believe that because of that LCPs can indeed solve complex business cases (Waszkowski 2019), while others argue that they still pose a black box mentioned above that does not give complete control over their inner workings and thus shall not host any critical services (Ideses 2017).

Either way, it is clear that there is a possible pitfall or preconception that LCPs could replace the work of professional software developers. This becomes clear with the considerable resistance that Elshan et. al. (2022) noticed in their investigation. They found out that some companies are hesitant to implement LCPs because they are seen as new technology threatening jobs through automation and digitization (Elshan, Dickhaut, and Ebel 2022). Nevertheless, a study of online developer communities by Luo et al. (2021) showed that ¾ of IT specialists consider low or no code crucial to rapid application development, and more than half of them even expect their usage to increase in the future. Thus, it is believed to be more likely that either way, LCPs will get a place in the developer community and the business landscape.

5. General Landscape and Market of low-code Platforms

This tendency also becomes apparent when looking at the low-code technology market, which is said to reach $29 billion in revenue by 2025. In particular the LCP market are expected to grow tremendously with a CAGR of 26,4% according to Gartner (2021). In addition, there has been thriving competition between numerous LCP vendors, with Mendix, Microsoft PowerApps, and OutSystems being the leaders in the field, according to Gartner's Magic Quadrant. Notably, Appian and Oracle are challengers in the field, while Creat.io and QuickBase are amongst other niche players (Gartner 2021). As discussing all players is beyond reach, only OutSystems will be examined in more detail as this supports the understanding of the use case EnMo to follow (see chapter *III. Developing a low-code Application: the Use Case EnMo*) of this work project).

5.1. OutSystems

OutSystems is a low-code platform that supports the development of both mobile and web applications on the cloud, on-premise, or hybrid (Elshan, Dickhaut, and Ebel 2022). The user can build the data model, business logic, workflow process, and UI through a visual drag-and-drop environment that can be complemented with custom hand-written code. OutSystems facilitates a develop once and deploy anywhere feature through which deployment requires only a single click and no prior expertise (Talesra and G. S. 2021). Moreover, according to Gartner (2021), it offers "robust security, multi-experience development and AI-augmented development capabilities," which renders prompt application development.

Addtionally, OutSystems offers the possibility to differentiate between dynamic entities like typical tables that are used to store information and static entities that are not changed very often, automatically allowing for improved performance. Some entities are even generated automatically, and changes in the database are updated across the application without causing errors, taking off work from the developer. A locally installed client software called Service Studio constitutes its development system that covers autocomplete, guidelines, and tooltips for the whole application development life-cycle (Vikebø, Sydvold, and Osmundsen 2019).

5.1.1. Service Studio

Service Studio is then divided into four layers: *Processes*, *Interface*, *Logic*, and *Data*. *Processes* presents an optional layer, which enables the user to automate business flows and consists of processes and timers but was not used in the case study (OutSystems 2022d). The *interface* allows the creation of individual screens for the user journey, and the design of the user interface can be adapted. The *logic* is a layer where through the use of flowcharts, actions and exceptions thereof are defined, which can also be integrated with external systems and APIs. Also, here access can be managed and granted by assigning roles to the users that determine their capabilities (Vikebø, Sydvold, and Osmundsen 2019). Eventually, the *data* layer consists of different entities (like tables) stored on a server that account through their relations for the data model. In addition, there are in-memory data or site properties (Vikebø, Sydvold, and Osmundsen 2019; OutSystems 2022d), which together with the data layer build the backbone of the application built in Service Studio.

The back end enables the generation of workflows and business rules. In Service Studio actions can be defined that easily fetch data from the database with an aggregate to show data on the screen. Through input and local variables, it is simple to manage user interaction and pass data between screens. Buttons or Links also help with navigation from one screen to another without coding. Although there are many templates and pre-built screens available to build the design and feel of the application, the UI can be extended in Service Studio with custom CSS to get a unique look (Vikebø, Sydvold, and Osmundsen 2019).

6. Conclusion

Although LCPs are a fairly new phenomenon, they come with a plethora of benefits as we have seen above. They accelerate software development, lower costs and simplify maintenance. Easy use, flexible features, and cross-platform capabilities make them highly versatile. Especially in combination with agile development methods, it leads to speedy development, as the use case of EnMo will demonstrate. Also, in organizations, LCPs can bring about new opportunities by increasing the link between IT and business departments and empowering employees to digitize.

Nevertheless, despite all benefits, there are also some downsides. There is the risk of third-party dependency or vendor lock-ins, as sometimes the code of the generated applications is hidden from the creator. Moreover, due to LCP's modular and declarative setup, there might need to be more room for customization of the applications, which could also lead to similar and distinguishable low-code UI. However, this can be remedied by extending the visual components with manual code, for example. This, in turn, shows that there is still the need for coding and hence developers, counteracting the common fear that LCPs will make software engineers redundant. Designing an application well and more complex requires some familiarity with best practices from software development indeed.

In conclusion, low-code platforms seem to have more opportunities than challenges, and those remaining can be mostly redressed. For developers, LCPs are an opportunity to increase the output and productivity of their teams. For business professionals, they are a possibility to become citizen developers and build simple applications and automation on their own. And finally, for organizations, LCPs are a chance to bring new value to the business faster.

III. Developing a low-code Application: the Use Case EnMo

With the use case EnMo, the development of a low-code application will be discussed in the following chapter. For doing so, the problem the application addresses is explained, external benchmarking is conducted, and the app's solution is introduced upon this. Then, the product development, the data model, and the application analysis are examined, and limitations and outlooks are presented.

1. Problem

Today's world is complex. Accordingly, the problem solved by EnMo reflects this complexity. More precisely, the aspects of climate change, the energy crisis, and an energy consumption knowledge gap were identified as the main drivers and roots of the approached problem of high energy consumption and inefficient energy behavior in private households.

1.1. Climate Change

Climate change because of global warming is a pressing problem affecting ecologies, societies, and economies globally. There are multiple factors leading to rising temperatures and global warming by releasing greenhouse gas emissions (GHG emissions) into the planet's atmosphere (NASA 2022). Energy is one of the main drivers of today's climate change making up almost 75% of global GHG emissions worldwide (Ritchie 2020). Breaking down this figure to energy use in buildings results in 17.5% of global GHG emissions, with residential buildings accounting for almost 11% of emissions globally.

Nevertheless, figures vary between different geographies. In the United States, the second largest emitter worldwide (World Population Review, n.d.), household energy consumption demonstrates even 25% of total emissions (Yanes 2022). However, less emitting countries are mainly and more severely affected by climate change's consequences, leading to significant inequality (Althor, Watson, and Fuller 2016). Thus, household energy consumption constitutes an important area to consider when tackling global warming and climate change, especially in developed countries emitting the largest share of greenhouse gas emissions. Moreover, it represents a sector where people can act, which is not solely dependent on public policymakers or other factors that could not be influenced individually (Climate Policy Hub, 2022.).

1.2. Energy crisis

The world is currently experiencing a global energy crisis. Thus, saving energy and becoming more energy efficient has never been more relevant than it is right now. This applies not only to the environmental perspective but also to the economic as well as political perspective.

But energy crises are not a problem that just occurred in the last years but have a long history with peaking gas and oil prices during the OPEC oil embargo of 1970 or the Western energy crisis in the 2000s with its peak during the financial crisis of 2008 (National Museum of American History n.d.; Misachi 2017). But what is happening during this current energy crisis that is being experienced globally, and why is it different than before?

Since the summer of 2020, natural gas and oil prices have risen, reaching their all-time peaks in Europe and other parts of the world (Nagle and Temaj 2022). After the first Covid lockdown, industries started working again at full speed and demanded more energy which initiated the crisis. Especially after Russia invaded Ukraine, prices went to the top, and the war is often seen as the trigger point of the current energy crisis. There are countries more affected than others based on their dependency on Russia’s gas supply. Germany, for instance, has bought more than half of its oil supply from Russia. Thus, it makes a difference in how reliant countries are on the Russian gas supply or how much energy is already coming from renewables. Nevertheless, all countries face the consequences of the current energy crisis and the urge to become more energy efficient is growing (United Nations 2022). Furthermore, the issue is more pressing than ever before. The global population is growing, with energy demands increasing exponentially simultaneously, further intensifying the problem (Gordon and Weber 2021). Consequently, consumers deal with steeply rising prices and insecurity of energy supply in many areas, including their private households.

1.3. Energy consumption knowledge gap

Individuals consuming energy in their private households play an essential role in understanding the problem of increasing energy costs and the urgent need to act against global warming (Rahmani et al. 2020). Nevertheless, for private consumers, it is not always transparent and understandable how their behavior, actions, and living circumstances are reflected in their energy consumption (Solà et al. 2021). Thus, many consumers are unaware of how their household energy consumption is distributed (Morganti et al. 2017). Despite having a transparent breakdown of how one's energy consumption is distributed, consumers lack the environmental awareness and knowledge to act upon it (Żywiołek, Rosak-Szyrocka, and Mrowiec 2021). Research supports that individuals lack knowledge about how specific incentives and strategies could decrease their electricity consumption (Lesic et al. 2018).

2. Benchmarking

To help mitigate climate change and get oversight over their energy consumption and costs as stated before, there has been a rise in a variety of programs and products for consumers (Beck, Chitalia, and Rai 2019). Research has shown that people often do not know which actions they should take to effectively reduce the amount of electricity they use in their household. Thus, this "energy-efficiency knowledge gap" (Steg 2008) is commonly tackled in two ways: On the one hand, there are apps that deal with energy usage indirectly such as sustainability or CO2 footprint trackers. On the other hand, some solutions offer concrete measurements of household electricity through smart meters or home monitoring systems for consumers. In the following, it will be explained that while both present a step in the right direction, they are lacking substantial tools to lastingly increase household energy efficiency.

2.1. Other sustainability and CO2 tracking apps

Apps that measure individual consumption and report the emissions created can help customers regulate and minimize their carbon footprint. Although there have been some improvements, many people are still clueless of the impact their everyday consumption has on the environment, tough existing studies in the field are painting a positive picture of gamified apps in the battle against climate change (Douglas and Brauer 2021). They calculate the carbon footprint of the user by accounting inter alia for transport, diet, purchase, household consumption as well as energy. For example, an app called "Klima" promotes strategies to reduce offset and engage others in more sustainable behavior (Climate Labs GmbH 2022). The personal carbon footprint is assessed using survey data of the user, and then science-based options for emission reduction or offsetting are offered. While traction of the app is high with being live in 18 countries (Shieber 2020), the app asks the users for only limited details that contribute to a small portion of their overall carbon footprint and is especially lacking depth in the energy related area (Murray 2021). Only nine questions are being posed related to electricity consumption or related behavior. And this, although residential energy consumption amounts to a fifth of CO2 emissions (Goldstein, Gounaridis, and Newell 2020).

The sustainable living-focused app JouleBug approaches consumer behavior modification from a different angle: By using a points-and-badges system, it allows users to compete with friends, family, and other users to save money, conserve energy, and decrease waste (Joulebug 2021). While according to gamification and behavioral design experts, the quantification of a user's positive behavior is especially well made and leads to tangible results (Gossan 2002), one can easily take from the app´s content that there is no focus on energy usage on its own. However, it is fostered that in light of the current energy crisis, a greater sensibility and urgency is needed to address energy usage in households specifically.

2.2. Other energy tracking apps

In this regard, first and foremost smart meters that measure and report household electricity consumption come to mind, which have been rolled out in large numbers despite data privacy concerns (McKenna, Richardson, and Thomson 2012). Consumers first need to have insights into their electricity usage before they can act and change their consumption and those products can offer accurate electricity data per room or device (Geelen et al. 2019). Apps for smartphones and tablets offer an inexpensive and straightforward design alternative to specialized in-home displays for providing energy feedback. For examples, with the App and the sub-meter from "Smappee" users can manage their energy flows in addition to receiving a variety of data e.g. expenditure predictions of utilities, standby energy usage of equipment or appliance level consumption are presented quite clearly and visually with graphs(Smappee 2022). However, this can become rather technical for a non-tech-savvy user as well as capital extensive as setting up the monitoring devices costs over 250€.

Another option that is free of charge is the app "Energy Cost Calculator". It enables the user to find out how much an appliance is costing by inputting its wattage and how long and frequently the device has been used. The app then calculates the cost/usage by day/month or year (energy saving trust 2019). Although, this can enable the consumer to make better educated judgments about purchases and how to utilize the appliances in their home more effectively, it is a tedious and time-consuming process to gather the information for all appliance and the output might not be so easily to understand in terms of KWh. Nevertheless, a study from the Netherlands shows that smart meters and related applications can indeed raise the users´ energy awareness, and with even more information regarding the users personal living situation and household, those apps are thought to become more useful and productive (Geelen et al. 2019). Especially, a more gamified approach that engages the customer through educational content and specific calls to action can be considered as an effective method in reaching energy savings in households (Tolkamp et al. 2018).

3. Solution

In response to the compound problems and the conducted benchmarking, a market gap was identified, resulting in the ideation and creation of EnMo as a solution. EnMo is a mobile application for private consumers to record and understand their household energy consumption in the first step. Subsequently, EnMo provides functionalities and incentives for its users to reduce their energy consumption and become more energy efficient. Ultimately, the goal is that the users will save energy at home, save money, and save the planet following a gamified approach.

3.1. EnMo's mission

EnMo aims to provide its users with an increased understanding of how energy efficient their household behavior is based on their habits and lifestyle. With this understanding created, EnMo intends to tackle the lack of transparency and awareness about private energy consumption. EnMo wants to generate consciousness and supports this thought provocation with scientific background and knowledge. Thus, the users will be additionally educated on energy-efficiency-related topics.

As an overarching mission, EnMo wants to incentive its user to take climate action and reduce their energy consumption by minimizing the energy-efficiency knowledge gap of its users.

Consequently, the long-term mission is to decrease the users' energy consumption, which reduces their greenhouse gas emissions and ultimately fights climate change.

3.2. EnMo's approach

To pursue the introduced goals, EnMo strives for the approach of (1) a mobile application, (2) focused on the demand side of energy consumption, (3) addressing private households, and (4) using the method of gamification.

3.2.1. Mobile application

EnMo will be rolled out as a mobile application to follow the consumer-centric approach most efficiently. The increasing trend of smartphone usage within today's population strongly accelerates the prevalence of mobile apps (Li et al. 2020). Moreover, research suggests that mobile applications enforce consumer engagement, which EnMo aims for (Tarute, Nikou, and Gatautis 2017). Especially within the context of climate change, it has been shown that mobile applications are beneficial for spreading awareness about climate change-related topics to ultimately make the user adapt their actions towards a more sustainable behavior (Chakravarty 2017). Furthermore, using mobile applications can positively influence the user's behavior and help achieve the goal of energy efficiency (Brauer et al. 2016).

3.2.2. Demand side solution

As the highest emitting sector globally (Ritchie 2020), the energy sector presents various approaches to reducing emissions. For instance, the energy produced through fossil fuels could be substituted by renewable energy sources. Nevertheless, this measurement would need to follow national or global policymakers and is dependent on governmental decision-making. Moreover, high costs and technological constraints slow the transition toward clean energy (International Energy Agency 2020). Even though such measurements could create a significant and long-term impact on reducing emissions, progress is often too slow and needs to meet the desired target (Hogue 2020).

Hence, EnMo decided to focus its solution on the demand side of energy consumption instead of the supply side. Thus, people demanding energy from suppliers will be the targeted users of the application, and the focus will be on reducing energy and using already existing energy more efficiently.

3.2.3. Private households

Everybody demands energy nowadays. This includes industries and individuals in private households alike. Although, energy use in the industry represents an impactful approach by accounting for a quarter of global emissions (Ritchie 2020), EnMo decided to address private consumers and their household energy consumption instead because households' behavior is often neglected. The focus is often set on companies and policymakers and this despite the fact that households in developed countries account for nearly one-quarter of total energy consumption (Streimikiene and Volochovic 2011). With regards to this, individuals can even reduce their carbon emissions by up to 900kg CO_2 annually by changing energy household behavior (United Nations n.d.). EnMo tackles this by beginning with the most miniature gear wheel in this complex construct, the private consumers.

Addressing the user means reducing their private household energy consumption. EnMo's target group is in developed countries because of their high household energy consumption and thus high reduction possibilities (Pérez-Lombard, Ortiz, and Pout 2008). Further, consumers aged 16 - 35 are mainly targeted based on their tech affinity and increased willingness to take climate action (Farber 2020; Jaska, Werenowska, and Balińska 2022).

3.2.4. Gamification

EnMo's mission is to create awareness, spread knowledge and consequently get the users to change their habits and lifestyle to become more energy efficient. EnMo's research (see chapter ***Error! Reference source not found.***) and further research suggests different strategies to change user behavior within mobile apps, such as feedback, incentives, or goal setting (Conroy, Yang, and Maher 2014). Considering the most efficient techniques, EnMo focused on gamification (Hamari, Koivisto, and Sarsa 2014). Moreover, that focus on the gamification approach is supported by research underlining increased user engagement (Bitrián, Buil, and Catalán 2021), and applicability in the context of sustainability to promote and collect relevant data for more sustainability behavior (Douglas and Brauer 2021).

3.4. EnMo's content

Based on its approach of targeting private households to reduce their energy consumption with a gamified mobile app, EnMo provides various functionalities and content. Furthermore, EnMo aims to collect user data that can be leveraged for future analyses and usage, which further influences the app's structure and contents (see section *4.3.1. Content Development*).

3.4.1. Survey

One main component of the app is the survey, whose goal is to understand the users and collect valuable user data, which can be used to calculate analytical results. The user must answer a survey with 25 questions in the four categories of *(1) housing & energy, (2) heating & cooling, (3) lighting & appliances,* and (4) *habits*. A personal energy efficiency score is calculated based on the user's answers. Each survey question is weighted based on its impact on energy efficiency and potential to reduce energy consumption. The answers to each question have different points ranging from 0 to 10, also benchmarked based on the impact of each option on energy efficiency.

3.4.2. Dashboard and Energy Efficiency Score

To quantify the user’s energy consumption behavior, users will get an “energy efficiency score” derived from the survey. The score is calculated in relation to the optimal energy-efficient user, a user with a total score. Since EnMo aims to close the knowledge gap of energy consumption of its users and promote insights into their energy efficiency, the results will be visualized within a comprehensive dashboard. For the best understanding, the dashboard will have various functionalities, i.e., filter by category.

3.4.3. Tips and Tricks

To follow the approach of addressing the knowledge and awareness gap of energy efficiency, EnMo’s component of tips &and tricks will serve as a knowledge library. This is motivated by the belief that a basic understanding and awareness are necessary to form new habits and change behaviors (Petersen, Petersen, and Ahcin 2020). Thus, the tips &and tricks component provides essential explanations and recommendations covering all energy consumption categories.

3.4.4. Challenges

To integrate the gamification approach, EnMo includes challenges as a core component of the app. By actively providing initiatives to take part in challenges, the aim is to change the user’s behavior and habits. Moreover, knowledge and awareness should be created and spread through the challenges. EnMo allows its user to see which challenges are most relevant based on how much they would influence the user’s energy efficiency score. Furthermore, the user can track the challenge process in a separate dashboard. Once a challenge is completed, the user can update the survey, and its score will be adjusted accordingly.

3.5. EnMo’s User Journey

A user journey typically describes the steps users take to achieve their goals while using an app or visiting a website (Experience UX n.d.). From the product development side, the main objective is that users reach their goals as easily and quickly as possible.

For EnMo, two main user journeys are significantly relevant at the current stage of development, (1) the activation user journey and (2) the commitment user journey.

3.5.1. Activation

This user journey of *activation* describes the path taken by a user that is entirely new to the app. Thus, the user first needs to understand the app's purpose and content, which describes this stage's primary goal. For this, the pre-registration screen is included, which gives an introduction and description of EnMo. Another crucial part of the activation phase is completing the initial survey. This is done by guiding the user through four screens representing the survey questions of each category. After the survey, the user gets notified that they have completed the survey and now have full functionalities of the app represented in the post-registration screen. The *activation user journey* may be marked as complete once the user finished the survey by answering all the questions.

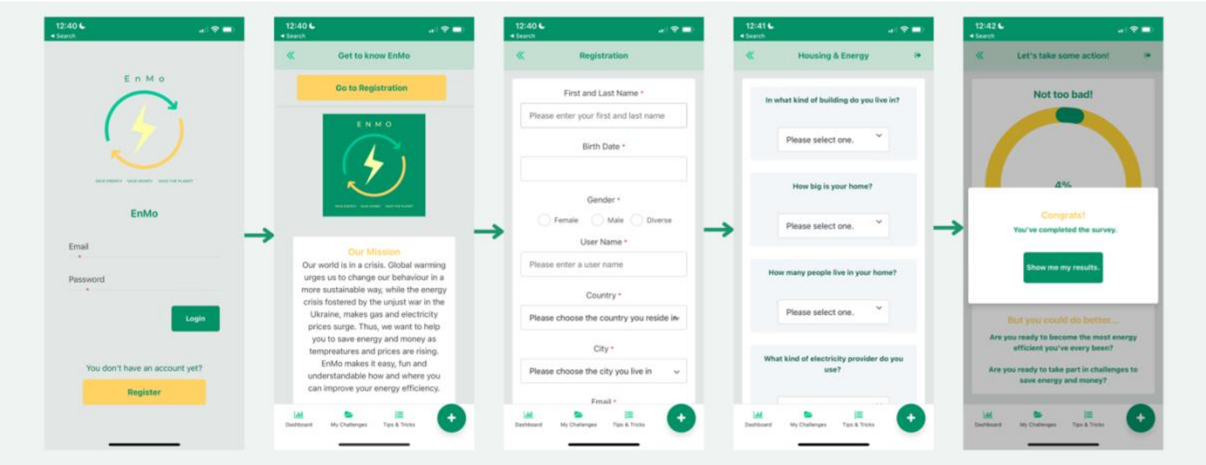

Figure 5 User Journey Activation

3.5.2. Commitment

This second user journey represents the core user journey for already registered users and can be described as *commitment* user journey. The goal for this stage is to keep the users highly engaged with the app. This means they use the app's full range of functionalities and resources. For EnMo, these can be classified into dashboard, challenges, and tips and tricks.

Firstly, the user interacts with the dashboard by checking the energy efficiency score obtained. Secondly, challenges are actively sourced and compared and further tracked and monitored after deciding to take them on (see Appendix B). The tips and tricks library is also actively used by reading recommendations in specific categories.

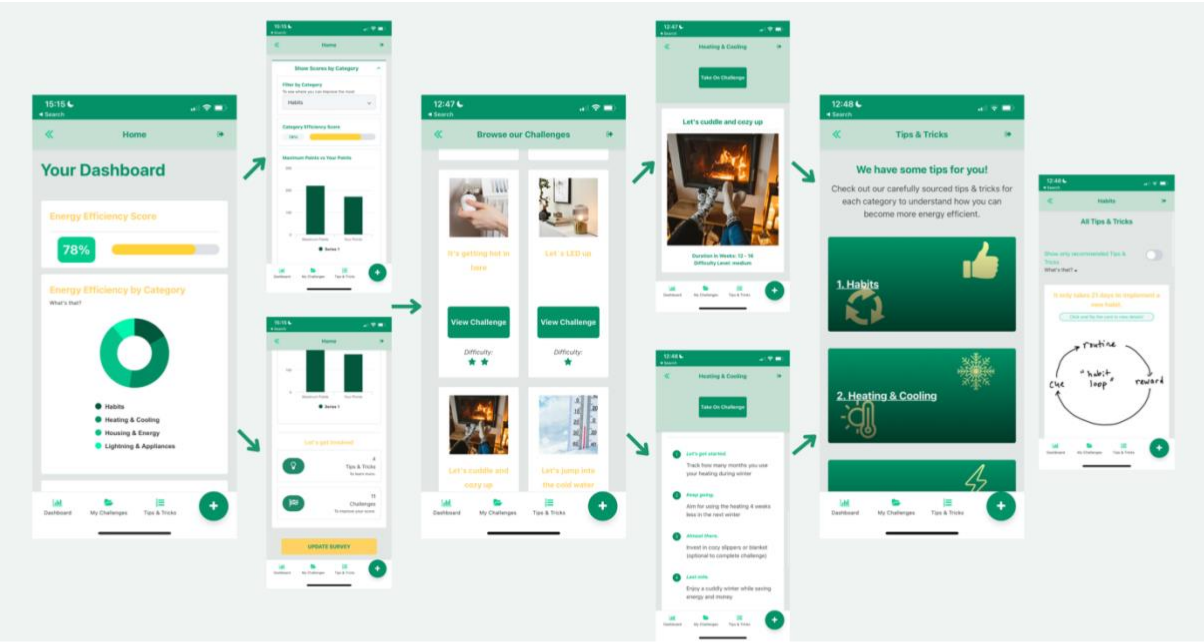

Figure 6 User Journey Commitment

4. Product Development

After having introduced EnMo and the problems the app solves, the following chapter will describe how it came about. It can be said that EnMo, as an intangible product, was built following a software development approach. Software development is "concerned with all aspects of software production from the early stages of system specification through to maintaining the system after it has gone into use." (Sommerville 2011, 9:7) The software itself is made up of programs, or lines of code that serve as instructions for a computer. Applications are therefore specialized bits of software that will assist a user in doing certain activities (Nager 2021). A program is now generally referred to as a mobile application or simply an app if it runs on a mobile device. The key challenge in application development is the need to deliver high quality with increasingly complex requirements within a short time frame (Dehlinger and Dixon 2011). This was also the case for developing EnMo. Thus, the development process relied on different tools and frameworks that provided not only a remedy for those issues but also entailed advantages as discussed in the following.

4.1. Framework & Tools

4.1.1. Agile Development

Because it simplifies the application development process, the EnMo team followed broadly an agile approach (Carter 2022). While there are many different methodologies within agile development, all of the have in common that the software is built in short cycles and piece by piece. Each sprint moves through the whole application development life-cycle again: planning, development, testing, delivery, and assessment (Abrahamsson, Oza, and Siponen 2010). Up until the current point of development, the team had a working MVP at all times which features were built in accordance with the sprint set-up and the four agile principles. They are: working software over comprehensive documentation, individuals, and interactions over processes and tools, responding to change over following a plan, and lastly, customer collaboration over contract negotiation (Abrahamsson, Oza, and Siponen 2010). In this way, it is possible to work fast and flexibly with minimal planning and maximal customization.

4.1.2. Project Management - Trello

For the overall management of the project, the team refers to Trello – a popular collaboration tool that allows any type of project to be divided into boards. There one can track tasks, divide different workflows, or add checklists (Trello 2022). The team uses three different boards during the development. One for general admin tasks like open to-dos and questions for each sprint. Another board helps to organize the user stories of the different screens so that the requirements for each screen of EnMo. Another Trello board is then used to coordinate the written part of the project.

4.1.3. Low-Code Development Platform - OutSystems

The application is modeled with low-code development, which enables the quick design and creation of software with little manual coding, fast setup and deployment, and simple servicing (Waszkowski 2019). It is made possible through low-code platforms (LCPs) like OutSystems. LCPs use a GUI (graphical user interface) and declarative techniques so that pre-compiled components can be used through drag-and-drop in a modular way (Talesra and G. S. 2021). As exemplified by Figure 8 below, the building blocks define business logic or workflows as well as UI/UX and thus, low-code platforms are capable of building the front-end, back-end, and database.

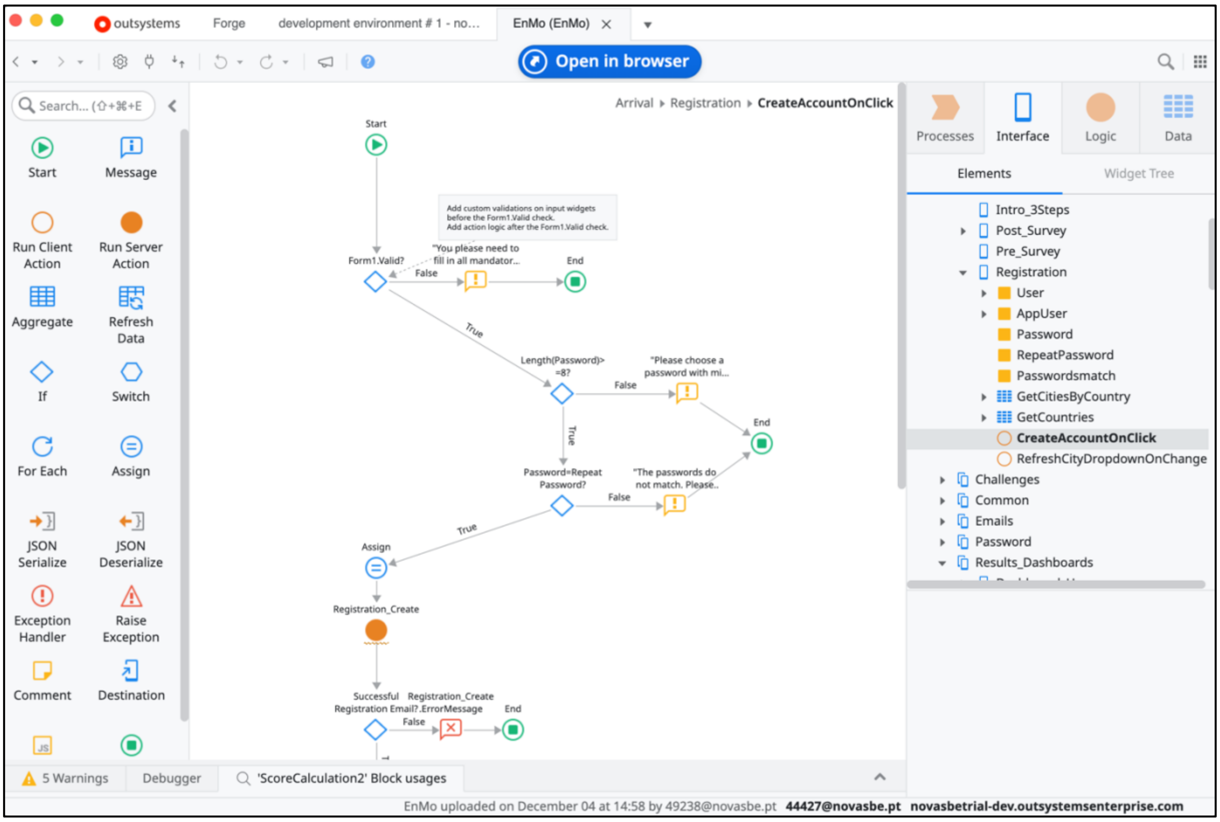

Figure 7 OutSystems Interface - creating a logic flow for a client action

Additionally, an application life-cycle manager helps in the development, troubleshooting, deployment, and maintenance (Martins et al. 2020). For a closer look at the opportunities and challenges of low-code platforms for software development please refer to the individual research part above.

4.2. Research and Training

The first step in the creation process of EnMO was the research and training phase. The ever-present climate crisis and newly emerged energy crisis initiated the first research into the energy sector as demonstrated in the problem section. Research then quickly uncovered the energy-efficiency-knowledge gap (Steg 2008) so that it became clear that there is an educational task to be done (Stibe, Krüger, and Behne 2022). When looking into ways to address that, the lack of digital solutions that help conserve energy surfaced. Thus, mobile application development methods were investigated (Smith 2022), resulting in a clear need for quick and agile development due to the time constraints of this project (Carter 2022). For this, the low-code platform became quickly apparent as the desired tool (Frank, Maier, and Bock 2021). Before writing this thesis, the EnMo team had no experience with mobile application development, which is why several online trainings on OutSystems were successfully completed. The shared background in business analytics and data science was considered helpful for quickly becoming a reactive low-code software developer.

More research went into determining how to best engage the user. It soon became clear that a gamified approach in mobile apps can result in more traffic and increased user engagement (Balińska, Jaska, and Werenowska 2021). As stated prior in the section about gamification, competing with other users or their own points motivates users to use the app even more (Bitrián, Buil, and Catalán 2021). However, not only gamification but also well-designed UI / UX can render more commitment from the user toward the app and help build a strong brand (Amelia 2022). As Markovate (2022) advocates, designing the interface in a user-friendly manner can help create a mesmerizing app experience so that people like using it. All in all, all the findings from this investigation and initial training phase were put into practice in the development phase.

4.3. Development

Overall, as stated before, EnMo is developed with an agile low-code approach, so the development happened in quick sprints. At every step of the way, the goal is to have a working MVP which leads to continuous iterations between content and software development. The application is then constructed incrementally by adding one feature or module at a time. First, the registration process was constructed. Then it was made possible to fill in the survey. Afterward, a score and overview dashboard was shown, and ultimately, the challenges and tips and tricks were integrated into the application. This results in the status quo: a fully functional application after only 8-10 weeks. The next section will first shed light on the content creation and then the software development consequentially, though in reality, it is an alternating process.

4.3.1. Content Development

The first and foremost part that had to be created in order for EnMo to come about was the survey as a way of measuring energy efficiency levels as well as behavioral progress as the desired goal. Other research like the ones from Groot et al. (2008a) or Uitdenbogerd (2007) also investigated the demand-side of energy consumption and household characteristics that influence it. They have also made use of questionnaires in order to gather this consumption information, which is why it was decided to model EnMo as well based on a survey. Moreover, other CO2 tracking apps (see benchmarking part) have also used similar structures with surveys in their setup. It became apparent that a concise and clearly divided questionnaire format would work best (Lindberg 2021). This then translated into the establishment of manageable 25 questions divided into four main categories: *(1) housing & energy, (2) heating & cooling, (3) lighting & appliances*, and (4) *habits*. . They were chosen because they have been commonly uncovered by EuroStat (2022) or the US Energy Information Administration (2022) as the main areas of waste of energy in households.

The next question was then how to measure the answers given in the survey. The initial idea was to get a numerical value as well as a monetary value. Gneezy et al. (2011) have shown that monetary incentives make the encouraged behavior more attractive by giving people additional motivation to rethink their actions. Hence, each answer should have not only been given the accurate electricity consumption in kwH but also, through a connected API, the accurate tariff price of the corresponding amount of energy usage. As a first MVP, however, a benchmarking model was used to obtain an energy efficiency score more swiftly and this approach helps to achieve continuous progress tracking (Doxey 2020; Dattakumar and Jagadeesh 2003). For that, each question was given weight (a number out of 10) with 10 meaning having the most influence on the energy usage of the user. The answers could also range from 0 to 10 with 10 being the greenest, most energy-efficient option. By multiplying the weight with the best possible answer option (10), one could at best generate 1310 points through the 25 questions. The user´s energy efficiency score is then how they compare to this benchmark energy-efficient user in total or per category. The questions and answers were collected in a spreadsheet and bootstrapped as entities in the data model in OutSystems. For further details, please refer to Appendix A.

Similar to the survey questionnaire, also the challenges were collected in a spreadsheet so that they can be easily integrated with OutSystems. As accomplishing them should have an impact on the user score, they were all connected to a survey question. Each challenge represents specific actionable instructions that should make behavioral change more agreeable. Additionally, the field lab team felt the need that also general insight into topics surrounding energy consumption and habit creation could be an excellent complement to the precise tasks of of the challenges (Stibe, Krüger, and Behne 2022). This concept is embodied by the tips and tricks section of EnMo. Each tip provides the framework for one or more challenges by setting the scene, giving the status quo of current research, or overarching guidelines. To exemplify, one of the tips and tricks informs the user how the way they wash and dry their clothes correlates with their energy consumption. In relation to that two different challenges exists: one focuses on the changing time of washing clothes to off-peak with regards to electricity price peaks, and the other urges the user to minimize the use of the highly energy-intensive tumble dryers (Flamer 2021). Specifically, the creation process of the tables can be found in the data model chapter.

4.3.2. UI Development

As stated before, the design of the app is crucial for the user experience and brand recognition (Markovate 2022). The layout and look of EnMo´s interface could only be customized to a certain extent due to the fact that the app was designed with an aforementioned low-code platform that by design leverages pre-built elements. Nonetheless, in the design of the interface different sizes, thicknesses and fonts were used for highlighting and to create a unique visual appearance (Stepanov 2021). In addition, every color has its own meaning and emotions attached to it, affecting moods and perception as a response of an individual. Studies have highlighted that more than half of the product assessments are done solely based on colors and that colors affect 85% of purchasing decisions (Canva 2022). Thus, EnMo´s brand colors were carefully chosen in accordance with color theory. A mix of warm, cold, and neutral colors was chosen to capture the variety of aspects EnMo tries to tackle and because each color evokes its own reaction. Beige was chosen as a neutral base to balance out the two other colors. Yellow is commonly known as a symbol of energy and optimism, resonating with the positive outlook and electricity as the core subject of the app. Green is known to have a calming effect because of its association with nature. It also has a notorious double meaning as on the one side it conveys sustainability and "being green", while on the other green is also often attributed to wealth, money, and growth (Chapman 2021). Both were seen fit for representing EnMo trying to save energy, money, and the planet, and were thus used in the UI design of the app. This was done with a color theme and by extending the low-code possibilities of OutSystems with CSS style classes that visualize different types of headings, text, and buttons.

4.3.3. Software Development

The software development for EnMo in OutSystems' Service Studio can be structured into three streams defined by the layers Service Studio provides – database development, interface development, and logic development. Please refer to section *5.1.1. Service Studio* about low-code platforms for more details on Service Studio and OutSystems.

The first stream in software development for EnMo consists of the data model's design, constituting the application's base. EnMo's database is comprised of, on the one hand, static content created by the EnMo team and, on the other hand, dynamic content stemming from user input. Please refer to the next section *5. Data Model*. The data model was implemented in OutSystems' Service Studio *Data* layer by creating adequate entities and attribute structures for the dynamic content and importing the static content.

Once the data model is implemented, the second and third stream of the software development in OutSystems Service Studio consists of developing the application's screens within the *interface* layer and implementing client and server actions within the *interface* and the *logic* layers. Client-side actions refer to user-visible content and actions, while server-side actions relate to actions hidden from the user, also called back-end, used for example, to browse, store and modify data (OutSystems 2021b; 2021a). Overall, the development of the interfaces and the logic elements is of iterative structure: it starts with a first rough design of the screen by inserting the basic visual widgets. Data aggregates then complement this to fetch necessary data from the database and assign it to the widgets as required. Furthermore, local variables and input parameters are defined, which are used to store local data and pass data between screens. In the next step, client actions are created. Finally, server-side actions are implemented to enable back-end logic - if necessary. This is repeated and improved, until the required functionalities work and in later development stage to improve user design and experience.

EnMo's interfaces are structured into six sections and accordingly divided into six different thematic folders within ServiceStudio: *User_Activation*, *General*, *Survey*, *Results_Dashboard*, *TipsTricks*, and *Challenges.*

- The development phase started within the *User_Activation* section, which contains the screens welcoming the user, explaining the EnMo solution, and leading the user through the registration process up to the beginning of the survey. During registration, the user demographic data is stored within the database.
- In a second cycle, the *General* section was created with the interface elements and the logic to first display info about EnMo's solution as well as a profile screen to display and modify the user information.
- The third cycle was made up of the development of the *Survey* section, which contains the elements and logic for the user giving answers to the survey questions and storing those in the database as well as computing and saving the user energy efficiency scores resulting from these answers.
- In a fourth cycle, the *Results_Dashboard* section was implemented, containing the screen and the logic for visualizing the user's energy efficiency scores.
- Within the fifth cycle, the interface elements and logic within the *TipsTricks* section were realized: the overview display of all tips and tricks, as well as the display of only the relevant ones for the user - computed by filtering for those tips and tricks for which related question the user does not have the best score yet. It also contains the elements for detailed view of each tip and trick.
- In the sixth cycle, the *Challenges* section was developed, which encloses the interface elements for visualization of all challenges, as well as, similar to the *TipsTricks* section, a filtered view for only relevant challenges and, finally, the detailed challenge interface element.

It is important to note that through the interconnection of elements across the different folders, the development of the interface widgets, as well as the client and server logic connected to them, is performed in iterative cycles: for example, after the completion of the basic version of the *Challenges* folder within the sixth cycle, a new logic element was built within the *TipsTricks* folder which was first developed within the fifth cycle, to display the relevant challenge within each tip and trick.

4.4. Testing

Testing is a step of evaluation that validates if prior defined requirements are met by the product or software (Jamil et al. 2016). Within the context of product development, testing the product is a significant step that is often carried out towards the product release and is usually performed at different stages within the process, as research suggests (Tahera, Eckert, and Earl 2015). Depending on the product development process, testing is also carried out differently.

Following an agile approach for the development of EnMo, the goal is to have multiple testing cycles. Moreover, pursuing the user-centric approach and having user feedback regularly yields many benefits. Thus, possible challenges can be detected early in the development process and errors might be adapted or avoided. Also, the development direction can be pivoted, if necessary, at an early point of the process.

4.4.1. Testing Methods

EnMo's product testing will be analyzed from the perspectives of testing a mobile application as well as testing a minimum viable product. In both contexts, usability testing is crucial (Cheng 2016; Ma et al. 2012). Existing methods differ between quantitative, i.e., surveys or questionnaires, and qualitative approaches, i.e., laboratory testing or field testing. Depending on the results one wants to achieve with the testing, the methods can be used separately, or a mixed approach can be chosen (Maramba, Chatterjee, and Newman 2019). Since the development process of EnMo is still at an early stage, feedback that can be collected rather quickly and includes detailed information is preferred and will lead to more insights. Thus, the qualitative usability testing approach is chosen for the first two testing cycles.

4.4.2. Usability testing

Usability testing is a qualitative approach in which the app users and their behavior is observed while testing the application by voicing their thoughts on completing a given task (Kaikkonen et al. 2005). One definition of usability is given in ISO 9241-11 by describing usability as ‘‘the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use’’ (Jokela et al. 2006). By applying usability testing, EnMo aims to understand its users’ way of thinking while using the application with the goal of app improvement. Based on research, the number of users is relevant for user testing. Prior research supposed that five users are enough to get reliable and significant results (Bevan et al. 2003). Nevertheless, there is some evidence that increasing the numbers for usability testing leads to more errors detected (Faulkner 2003).

4.4.3. Testing process

EnMo’s usability testing is conducted with five users in the first testing cycle and 15 users in the second testing cycle. Regarding the method of usability testing, laboratory testing is selected by observing the test users in a home environment.

Testing cycle 1

The approach during the first testing cycle was straightforward. The EnMo team and two additional users were asked to test the app without a particular scenario. During that, the test users described their actions while using the app and provided verbal feedback after the testing. The main goal of this testing cycle was to get an initial understanding of the core functionalities and to comprehend if something crucial was missing in the development.

Testing cycle 2

The second testing cycle expanded the testing capabilities. Thus, 15 participants used the app within a home environment while being observed. Within the testing, test users were given a set scenario. Therefore, it was assumed that the user was new to the app. Moreover, the app was tested on its three main functionalities by proposing three tasks. The three tasks were 1) *You want to find out what your energy efficiency score is for the category “housing & energy,”* 2) *You want to take on two challenges, you complete one of them and then want to check your challenges completion process* and 3) *You want to find one tip and trick article that is relevant for your score.*

Further, the test users were observed to detect if they spend significantly more time at certain screens, actions, or tasks to detect possible pitfalls or unclarity of the app.

Generally, the testing phase is an iterative process. The testing method and results described in this chapter are the recent testing cycle at the current development point. Nevertheless, additional testing methods will be deployed in the future as the app development continues. EnMo plans to include more quantitative testing methods once the app is developed further. Furthermore, feedback retrieved in early testing cycles can also influence the determination of user requirements, whereas the input from later cycles is more suitable for evaluation purposes (Jokela et al. 2006). Moreover, the number of users participating in the testing will increase for more reliable feedback results.

4.4.4. Testing results

The first two testing cycles resulted in valuable insights and user feedback for EnMo's development. First, it became clear that during the registration process – the *activation user journey* – the pre-registration screen is essential for the user's understanding but that the survey takes some time to complete. Following the proposed challenge, test users completed the tasks on the dashboard easily and quickly by filtering the dashboard by category. The tips and tricks task also seemed easy for most test users to assemble. The most difficulties were observed while test users completed the task regarding the challenges. Two main points became visible that disrupted their flow in using the app. First, many test users were unsure which challenges to take on. Secondly, the task of tracking their process regarding challenge completion was not intuitive for many test users.

4.5. Adaptation & Deployment

Based on the conducted testing, two main changes were implemented into the consequent development sprint, next to general improvements and development. First, the challenges library structure was adapted to filter challenges and tips and tricks by relevance. Thus, with a switch button, users can now only see the challenges or tips and tricks that can influence their score. Secondly, an additional dashboard for their challenge process was implemented. Hence, users can now track their active and complete challenges. Furthermore, when they enter a challenge-specific screen, their challenge process is also visible to them.

5. Data Model

As with any other mobile app, it is necessary to create a database where all the data can be stored and organized so that it can be accessed when needed. As the goal is to create an interactive and customizable application for the user, it is needed to provide not only static content (meaning content is pre-generated for everyone) but also dynamic content (meaning content is personalized to the individual user of the app). Thus, the database must store user-related information, enable data transformation and allow customization of content. The typical approach in web development for this consists then of a backend server and corresponding database to maintain dynamic applications (Ferreira 2021b). Databases are typically sorted and arranged in a particular logic so that it functions smoothly. They enable the collection of user information, user interactions with the app and all other exchanges of information (Menezes 2022).

The data is organized in OutSystems in a so-called relational database which means that information is stored in a table similar to rows and columns in a spreadsheet and certain data points are connected to each other through a key (Harrington 2016, Kemper and Eickler 2015). In OutSystems such tables are called entities. “When an Entity is created, an attribute called Id is automatically added as Entity Identifier. By default, it is of data type Long Integer and its value is automatically calculated in sequence (an AutoNumber in OutSystems)” (OutSystems 2022). The Entity Identifier is what is commonly known as the primary key, which is used to uniquely label each table record. They are also dynamic, signifying that their entries can be changed during runtime with CRUD actions (create, read, update, and delete). Contrary, Static entities hold data that does not change often and is frequently reused, building a set of named values (OutSystems 2022) that are useful for ensuring data persistence and performance (Arede 2019).

5.1. Static Data

The survey through which the user shares information necessary to calculate their energy efficiency score, lies at the core of EnMo. This was an important point of consideration when designing and constructing the data model in OutSystems. For a full picture of EnMo´s data model, please refer to Figure 9 below. This was eventually translated to three entities in the backend. One table contains all the questions (*Question*) and another all the answers (*Answer*). They are connected with a One-to-Many relationship as one question can contain several answers. Hence, the primary key of the *Question* (= *Id*) represents the foreign key (= *QuestionId*) in the *Answer* table. A foreign key is an Attribute in an entity in OutSystems whose values correspond to the values of the primary key in another entity. The *Question* also has a foreign key, *CategoryId*, referring to the static entity *Category*. The categories were constructed as a static entity as they can only take four values – *Housing & Energy*, *Heating & Cooling*, *Lighting & Appliances*, and H*abits* - and will be used a lot in the application to group together interactions and information that are related.

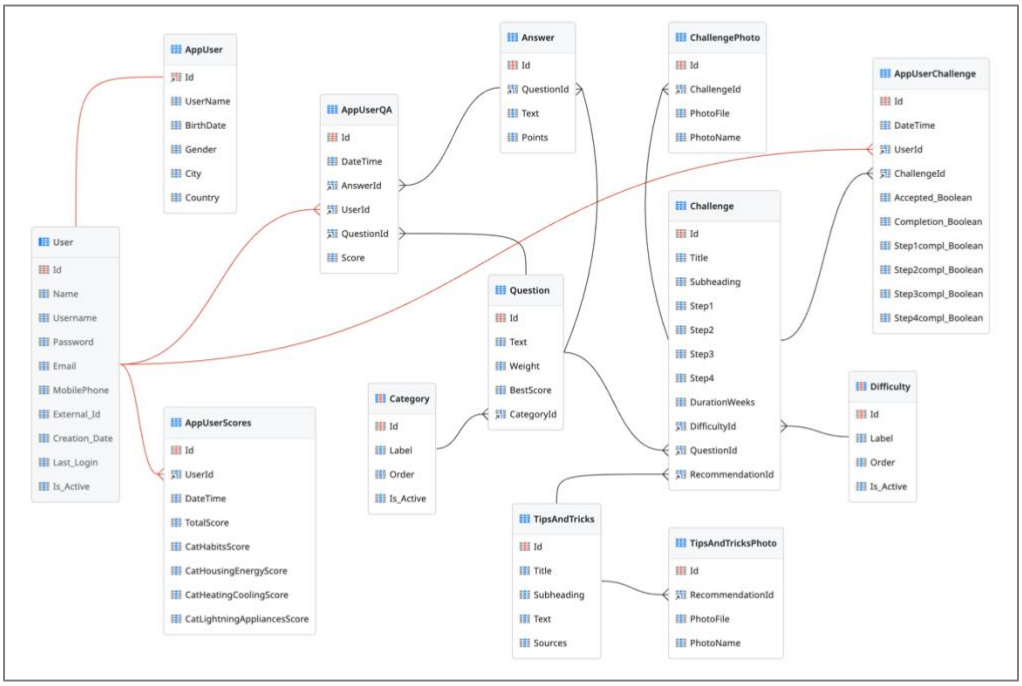

Figure 8 Entity Diagram of EnMo in OutSystems

Another pillar constitutes the challenges and tips and tricks that are shown to the users, that should motivate them to change their behavior towards and educate them about energy efficiency. Each entry in the *Challenge* table consists of *Title*, *Subheading*, up to four steps (*Step1*, *Step2*, …) and the duration (*DurationWeeks*) needed to complete this challenge as well as three foreign keys. One of them refers to the static entity *Difficulty* that stores the 3 different levels of difficulty possible to fulfill the challenges, namely *low*, *medium* and *high*. *Challenge* is also connected to *Question* with a One-to-One relationship, as the user can increase their points of one question by finishing the exact corresponding challenge. In turn, there is a Many-To-One relationship of *TipsAndTricks* and *Challenge*, which represents the third and last foreign key in the *Challenge* entity. This means that there can be several challenges that belong to the same tip and trick..

Furthermore, to improve the design of the app, photos were added to the challenges and tips and tricks. For best practices purposes, the images were not stored in the main entity but in a side entity with a foreign key of the main entity (e.g. *ChallengeId* or *TipsAndTricksId*). This improves the performance when it is only wanted to retrieve the main data. While the survey with questions and answers and the tips and tricks with challenges form the backbone of EnMo, the users and their data also had to be linked to the model for user data analysis purposes as well as in order to provide a dynamic and personalized experience (Ferreira 2021).

5.2. Dynamic Data

The dynamically created user data can be structured into three sections: first, personal user data; second, survey and score data; and third, challenges data. To begin with, the first pillar will be considered - personal user data. This consists of two entities: on the one hand, the default system *User* entity and, on the other hand, the *AppUser* entity. The *User* entity is a system entity which stores information on the user such as name, email address, or last datetime of login. Through the Users API, one can use multiple pre-built functionalities allowing to execute actions on the *User* system entity entries, such as encrypting the password (OutSystems 2022a; 2022b).

In addition to that, there is the *AppUser* entity, whose purpose is to store additional personal data not contained in the *User* entity. The *AppUser* table is linked to the *User* table through the attribute *Id*, which is at the same time its primary key and a foreign key referring to the primary attribute *Id* of the *User* entity. The attribute *Username* contains data for the app's practicability and user experience, while the attributes *Birthdate*, *Gender*, *City*, and *Country* store demographic information on the user, which is, on the one hand, relevant to know what type of users are using the application, and on the other hand, helpful for user energy consumption behavior analysis. The user behavioral data analysis is very interesting because it has been shown that user behavior is at least as important as the technology itself in a household's energy use (Gram-Hanssen 2011). Finally, the *CountryCity* entity is an additional table constituted by a static database extracted from the basic version of SimpleMaps, which is used as a base for the user input of the *Country* and *City* attributes (Pareto Software LLC 2022). Those data points are gathered during the users' registration process. Moreover, the user can modify the data points of the email address as well as the country and city of residence within the profile section of the app.

Survey answers given by the user constitutes the second pillar of the dynamic data and the energy efficiency scores are computed based on these answers. As a base, there is the *AppUserQA* entity. Each entry of this entity is related to the *Question*, the *Answer, and* the *User* entity through the three foreign keys *QuestionId*, *AnswerId*, and *UserId*. The data is gathered when the user first answers or afterward updates the answers to the survey questions. A unique index was created to only store the current answer given by the user, which requires the combination of *QuestionId* and *UserId* to be unique. Accordingly, when the user updates its answer for a previously answered question, the *AnswerId* and the *Datetime* attributes of that entry get updated. Moreover, the *Datetime* and the *Score* are stored within the *AppUserQA* entity, whereby the score represents the computation, multiplication, of the respective question's weight and the respective answer's points.

This leads to the *AppUserScores* entity containing the users' energy efficiency score data over time. Each entry consists of the foreign key *UserId* relating the entry to the *User* entity. Furthermore, it contains the *Totalscore* attribute, which stores the overall user score, as well as an attribute for each category score - *CatHabitsScore*, *CatHousingEnergyScore*, *CatHeatingCoolingScore*, and *CatLightingAppliancesScore*. All these attributes are computed based on the *Score* attribute in the *AppUserQA* entity. They are complemented by the *Datetime* attribute, which stores the point in time of the entry creation. The user's scores are computed during usage of the app when the user either first answers the survey questions or updates a response to a survey question. When users update an answer and improve or deteriorate their score accordingly, a new entry is created in the entity with the new score data.

Last of all, the third pillar of dynamic user data is composed of user challenge data. This represents data related to users and the challenges they took on, they completed, as well as the steps they fulfilled to accomplish the challenge. To summarize, it stores all user actions related to challenges over time and is created when users interact with the challenges in the app.

It consists of the *AppUserChallenge* entity, which is related to the *User* and the *Challenge* entities through its foreign keys *UserId* and *ChallengeId*. Additionally, it has the attributes *Accepted_Boolean* and *Completed_Boolean*, which represent the status of acceptance and completion of the challenge, as well as four attributes reflecting the individual steps necessary to complete the challenge – *Step1compl_Boolean*, *Step2compl_Boolean*, *Step3compl_Boolean* and *Step4compl_Boolean*.

Through the *Datetime* attribute, the entry creation date and time is stored. Again, similar to the *AppUserScores* entity, each time a user either takes on or gives up a challenge or completes or revokes the completion of a challenge, as well as accomplishes individual steps, a new entry is created in the *AppUserChallenge* entity. Please view Appendix A for a complete overview of all entities and their attributes.

6. Data Analysis

As described above in section *5. Data Model*, user created data is collected in three areas: firstly, demographic info on the app users, stored in the *AppUser* entity, which is produced during user registration. Secondly, user energy consumption behavior and score data are collected through the survey and stored in the *AppUserQA* and the *AppUserScores* entities. Thirdly, data regarding user's development and change in energy use behavior, based on updates of survey answers as well as the completion of challenges, is reflected in the *AppUserChallenge* entity. EnMo plans for the future to conduct data analysis of these collected data points.

6.1. Demographic Data

Within the demographic data, the following data points relating to the users are collected and valuable for analysis: gender, birth date, city and country of residence (*Gender*, *BirthDate*, *City* and *Country* attributes of the *AppUser* entity). Those data points have two areas of interest: Firstly, concerning the type of user making use of the app and analysis of the target audience. This information is beneficial with regard to the marketing of EnMo as it allows to make data-based analyses and marketing decisions. It will help verify whether the target demographic was chosen correctly. Moreover, it will allow to improve the targeting of the potential audience and further adapt EnMo to its target group's unique habits (Guo et al. 2019; Bencsik, Machova, and Zsigmond 2018). Finally, it can be used to offer a more personalized approach to engagement and hence to improve the user experience of EnMo's users with the final aim of successfully spreading the positive impact of energy consumption reduction (Anshari et al. 2019; Fernández-Rovira et al. 2021). Secondly, the demographic data can be used to create demographic user profiles, which can then be related to energy consumption behavior, as described in the following part.

6.2. Behavioral Data

In the user energy consumption behavior data area, the ensuing information is relevant: each user's answers to the survey questions (*DateTime*, *AnswerId*, *QuestionId*, *UserId* and *Datetime* attributes of the *AppUserQA* table), which again translate into energy efficiency scores per category and in total. Those are stored in the *AppUserScores* entity (*DateTime*, *UserId*, *TotalScore*, *CatHousingEnergyScore*, *CatHeatingCoolingScore* and *CatLightingAppliancesScore*). The collected data allows to further complement the demographic user profile analysis with behavioral data and to create behavioral user profiles.

A method to perform the user profile creation is K-means clustering, a very sought-after unsupervised machine learning algorithm and, as explained in section ***Error! Reference source not found.***, as well an essential analytical method in gamification. It uses non-labeled data as input, and its output consists of classes or so-called clusters which are unknown and inferred by the model. Specifically, this means that it partitions n data points into k homogenous clusters by minimizing the sum of squared error across all clusters (Jin and Han 2017; Patil 2021; Jain 2010). Accordingly, users are assigned to their respective profile clusters and are segmented such that users with similar behavioral energy consumption patterns are grouped.

This allows verifying in the next step, for example, whether specific demographic groups display a relationship with energy consumption behavior. Previous research has shown that not only the energy efficiency of appliances but as well user behavior itself has a critical impact on how much energy is used and is at least as significant as technological effectiveness (Gram-Hanssen 2011). Moreover, it has been shown that user profiles exist with regard to energy load and timing of energy use, determined by population-based register data (Trotta 2020). In addition, it has been demonstrated that user groups defined by demographic factors such as education and marital status are related to differences in the group's energy consumption (Santin 2011; de Groot, Spiekman, and Opstelten 2008b). Accordingly, it would be very interesting to verify whether there is a link between EnMo's app users' demographic profiles and their energy consumption.

Finally, there are two sources of valuable data concerning user behavior change and energy consumption improvement. To begin with, intrinsic user change refers to changes in the energy efficiency scores value for each user, which can be found in the *AppUserScores* table, as well as the analysis of changing answer data of a user relative to each question, located in the *AppUserQA* entity. Moreover, in the light of externally incentivized behavior improvement, information is gathered in the form of what challenges are taken on by users, how long they take to complete each step, and whether they fulfill the challenge in the *AppUserChallenge* table (*DateTime*, *UserId*, *ChallengeId*, *Accepted_Boolean*, *Completion_Boolean*, *Step1compl_Boolean*, *Step2compl_Boolean*, *Step3compl_Boolean* and *Step4compl_Boolean* of the *AppUserChallenge* entity). As explained in section ***Error! Reference source not found.***, this data stemming from gamification elements is very valuable for data analytics. To start with, it can be analyzed what type of user takes on what kind of challenge, considering the category, difficulty, and duration of the specific challenge. Moreover, it can be inspected what type of user takes how long to fulfill the individual steps of the challenge completion. Finally, this can be complemented with findings on what types of users successfully complete which challenges and which challenges are less prone to be completed, also taking into account which completion steps are not accomplished.

These two sources of data, combined with the behavioral user profiles, can be used to build a multi-label classifier model which helps to predict the probability of users taking on and completing a challenge. In contrast to regular classification models, where there is only one label as output, a multi-label classifier model allows having multiple labels as output. To be machine-readable, the multi-label dataset would have to be transformed into a single-label dataset, making it easier to build a model as it is then machine-readable. The multilabel problem can be split into multiple unique single-class problems using a binary relevance technique. In context, it means that a user would represent the input, and the probability of for example, taking on or completing a specific challenge, would be predicted with the multilabel classifier model (Zhang et al. 2018; Nooney 2018).

All in all, it can be concluded that the three individual areas of user-created data are to be brought together and analyzed by firstly, creating demographic user profiles and, secondly, extending them with behavioral energy consumption data and creating user profiles based on demographic as well as behavioral characteristics. The final step involves connecting them with the development and improvement data by developing a recommender system, which provides users with a personalized proposition of tips and tricks, and challenges, that they are most likely to take on and implement. This represents a form of user nudging and would help to contribute to EnMo's overall goal of helping the users to reduce their overall energy use (Jesse and Jannach 2021).

7. Shortcomings & Outlook

So far, the MVP version of EnMo has been developed within this field lab project. This version includes collecting demographic user data and behavioral energy consumption data. Through energy efficiency score computation and visualization paired with the proposition of tips and tricks and challenges, EnMo aims to support and incentivize its users to reduce their household energy consumption. To begin with, the field lab team did not have the capacity so far to perform data analysis of the data collected so far. Thus, it is planned to analyze the data collected to detect interesting knowledge and improve the application accordingly. Please view section *6. Data Analysis* for further explanation. Furthermore, within the current version, the regular use of the app and users' returns are only incentivized by the challenges as well as tips and tricks. Thus, for the next development phase, there are three crucial features planned, aiming to increase user engagement with the overarching goal of improving the effectiveness in encouraging users to reduce their energy consumption: through (1) integration of energy prices, (2) visualization of real-time data based on smart meters and (3) the establishment of a social network among EnMo's users.

7.1. Integration of Energy Prices

First of all, it is planned to integrate electricity and heating prices in the next version of EnMo. Based on the user's indication of the location and the type of heating method, the last month's average wholesale price of the energy sources can be computed. This info is to be integrated into the challenges section, such that the user gets displayed for a challenge how much money can approximately be saved based on the past month's average wholesale price. To do so, the amount of electricity or heating energy saved will be computed with the past month's price. As mentioned in section ***Error! Reference source not found.***, according to both categories of research within the area of energy consumption behavior - the economic paradigm and the behavior-oriented paradigm – price can be an effective factor in influencing energy consumption behavior (Zhou and Yang 2016). Thus, displaying the potential cost savings in money units will increase the incentive to change behavior and reduce electricity consumption. The plan is to start with a German pilot for electricity price integration by using the data provided by the "Bundesnetzagentur" on wholesale electricity prices, which are available over an API and then to do user testing to see whether the feature is appreciated and has an additional positive effect on behavioral change of users (“SMARD | Marktdaten” n.d.). Further development cycles would then extend the price integration by including prices for different heating sources, such as oil and gas as well as for other countries as well.

7.2. Collection and Visualization of real-time Energy Consumption Data

In its current version, EnMo generates and collects user and behavioral data. For the next version, an important development step is to expand toward a third source of data: real-time consumption data stemming from smart meters and sensors. As shown in section ***Error! Reference source not found.***, there are multiple application possibilities for real-time consumption data, bringing significant improvement opportunities to the energy sector.

To begin with, EnMo would leverage it firstly by providing users visualizations of real-time usage, hence strengthening user awareness about their consumption. This will improve the value offered to the user as well as enhance the overall experience of the EnMo app: complementing the static display of the energy efficiency scores with real-time usage data will help to increase user engagement with the application and increase usage time, eventually improving the effectiveness in incentivizing the user to reduce energy consumption (Bonino, Corno, and de Russis 2012). Secondly, it can be used to provide personalized and tailored challenges – expanding the current version, which allows to filter for relevant challenges only based on the user’s survey answers - relying on the analysis of current consumption data, to reduce the amount of energy used (Dell’Isola et al. 2019)

Finally, the real-time consumption data could be used to refine the current version's consumption profiles based on the demographic user and energy consumption behavior data. This could then be transferred back to energy service providers, which could benefit from it in improved demand forecasting and optimized customer targeting by offering tailored services.

To be able to integrate smart meter data, EnMo could follow two strategies: Firstly, partnering up with energy service providers whose offers comprise smart meters and cooperating with them to offer their customers the EnMo solution, including real-time usage visualization. This could be tested in a pilot, to begin with for electricity measurement and in Germany, with a service provider such as *NEW Niederrhein Energie und Wasser GmbH*, which offers their customer a smart meter for real-time electricity measurement. While creating a dependency on the energy service provider, this strategy gives EnMo direct access to the energy service provider's customer base as users. It requires no additional effort from the users, as they already have the smart meters installed. Secondly, EnMo could develop a ready-to-buy recommendation and installation guide for smart meter solutions. This would allow EnMo to remain independent from energy service providers. At the same time, depending on whether EnMo takes care of the installation or whether it leaves it to the user, it represents a much greater operational effort for EnMo in the former case and a greater hurdle for users in the latter case, as they need to be willing to install the smart meter and to connect the communication module to the EnMo solution. This is a strategic development that must be further analyzed and elaborated on before deciding which path to follow.

7.3. Establish a Social Network

Another important feature EnMo aims to implement is a social network. In that network, users can see their ranking in comparison to other users. For this there are two possible ranking options: on the one side, the users could compare each other in terms of energy efficiency score. On the other side, a ranking relating to the number of completed challenges would be possible. Moreover, it is planned that users can jointly take on challenges with peers which makes it more fun and easier to implement. This approach is derived from EnMo's gamification approach of driving motivation and user engagement for behavioral change (see chapter **Error! Reference source not found.**). Here one potential issue arises: too much peer pressure could lead to negative feelings among the users or could even discourage them then from continuing using the app. It will be a crucial task of the EnMo team to put mechanisms in place that avert this and to gather data to analyze this subject.

IV. Conclusion

In summary, EnMo is a digital solution that tackles the energy-efficiency knowledge gap as a pressing problem underlined by the prevailing climate and energy crisis. The use of gamified elements such as challenges and feedback mechanisms are suitable methods to engage the users and motivate them to change their behavior, as uncovered in the section about gamification. EnMo is thus a playful means for individuals to reduce their energy consumption and bills - indispensable at the present price surge. The app collects information from users regarding their energy consumption through a survey. In turn, users receive their energy efficiency score based on their survey answers. This is complemented with customized challenges, as well as tips and tricks that incentivize them to change their behavior and become more energy efficient.

During the field lab, this mobile app was developed with the low-code platform Outsystems. The individual research on the opportunities and challenges of those platforms has shown that low-code enables citizen developers to create software applications with increased speed through their easy visual interface and flexible pre-built features. The resulting user data of the app as well as data of soon-added sensors can be leveraged in the energy and sustainability sector. As established in the part about the value of big data, they can present, combined with big data techniques, powerful tools to gather new insights and ways of reducing energy waste, crucial in the fight against climate change. All in all, EnMo presents a novel digital product that addresses environmental and social challenges by leveraging state-of-the-art development tools, gamification, and data analytics.

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Appendix

Appendix A: Overview of OutSystems Entities and Attributes

Entity	**Attribute**	**Special Type**
Answer	Id	Primary Key
	QuestionId	Foreign Key
	Text	
	Points	
AppUser	Id	Primary Key, Foreign Key
	UserName	
	BirthDate	
	Gender	
	City	
	Country	
AppUserChallenge	Id	Primary Key
	DateTime	
	UserId	Foreign Key
	ChallengeId	Foreign Key
	Accepted_Boolean	
	Completion_Boolean	
	Step1compl_Boolean	
	Step2compl_Boolean	
	Step3compl_Boolean	
	Step4compl_Boolean	
AppUserQA	Id	Primary Key
	DateTime	
	AnswerId	Foreign Key
	UserId	Foreign Key
	QuestionId	Foreign Key
	Score	
AppUserScores	Id	Primary Key
	UserId	Foreign Key
	DateTime	
	TotalScore	
	CatHabitsScore	
	CatHousingScore	
	CatHeatingCoolingScore	
	CatLightingAppliancesScore	
Category (Static)	HousingEnergy	Record
	HeatingCooling	Record
	LightingAppliances	Record
	Habits	Record
Challenge	Id	Primary Key
	Title	
	Subheading	
	Step1	

	Step2	
	Step3	
	Step4	
	DurationWeeks	
	DifficultyId	Foreign Key
	QuestionId	Foreign Key
	RecommendationId	Foreign Key
ChallengePhoto	Id	Primary Key
	ChallengeId	Foreign Key
	PhotoFile	
	PhotoName	
CountryCity	Id	Primary Key
	City	
	City_Ascii	
	Country	
	Admin_Name	
	Population	
Difficulty (Static)	Low	Record
	Medium	Record
	High	Record
Question	Id	Primary Key
	Text	
	Weight	
	BestScore	
	CategoryId	Foreign Key
TipsAndTricks	Id	Primary Key
	Title	
	Subheading	
	Text	
	Sources	
TipsAndTricksPhoto	Id	Primary Key
	RecommendationId	Foreign Key
	PhotoFile	
	PhotoName	
User (System Entity)	Id	Primary Key
	Name	
	UserName	
	Password	
	Email	
	MobilePhone	
	External_Id	
	Creation_Date	
	Last_Login	
	Is_Active	

Appendix B: Commitment User Journey Detailed