The ENaQ Energy Signal Light: Collaboration and innovation for the energy transition

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Abstract
In order to solve the grand societal challenges, achieve the Sustainable Development Goals (SDGs), or have a successful energy transition, innovations are essential. Furthermore, there is enough evidence that positively links innovation to sustainable development. However, an overview of the literature on the different understandings of innovation in relation to sustainable development shows that there is no agreement on a concept and many different conceptualizations (co)exist and are used at this intersection. In the transdisciplinary research project "ENaQ" the cornerstone is the development of innovations for an environmentally friendly neighborhood in Germany with a highly participatory approach. Hence, the concept of responsible research innovation in which all stakeholders are involved early on. The goal is to improve the possibilities of research and innovation benefiting society and preventing negative consequences. This goes in coherence with the ENaQ project, where participation is a fundamental element. However, other conceptualizations of innovation, for example, sustainability-driven, behavioral or social innovations, also apply, showing that some innovations will be a combination of these concepts. In this paper, we introduce one such innovation, the ENaQ Energy Signal Light. An innovation designed and developed within a participatory process with the aim to incentivize the use of green energy. A color light indicates when plenty of green energy is available, making it easier to visualize when is the best time to use energy-consuming household appliances such as a dishwasher or washing machine. In this paper, we will present the Energy Signal Light, and how it was developed within the ENaQ participation process. Furthermore, we have conducted a study to test the use and implications in behavior with three user groups, one using the Energy Signal Light itself, a second one using the digital version (in form of an App or website), and one control group. We will introduce preliminary results of the study.

1. Introduction
Green gas emissions, high energy consumption, environmental challenges, are all well know problems for which solutions are being design, developed and partly implemented. To achieve this, many countries, in both the global north and global south, are working towards an energy transition, expending the production of green energy. In this regards, innovation plays a pivotal role. However, innovation to solve these challenges needs to be responsible, take into consideration aspects of sustainability, social and behavior, as well, as consider different stakeholders. The literature presents different innovation concepts, and as we will see with our case, sometimes these concepts overlap in one single innovation. In this sense, we want to clarify the concepts of innovation that meet in the Energy Signal Lamp. The concept of

> Responsible research and innovation (RRI) is essentially an attempt to govern research and innovation in order to include all the stakeholders and the public in the early stages of research and

> development. The inclusion of different actors and the public is, in turn, meant to increase the possibilities to anticipate and discern how research and innovation can or may benefit society as well as prevent any negative consequences from happening. (Burget et al., 2017, p. 15)

This concept does not address sustainability directly and can only be interpreted as a benefit for society. On the other hand, the sustainability innovation concept clearly states the goal of human well-being, as well as, respect for natural resources. However, it does not take into consideration the inclusion of the stakeholders: "[T]he development of new products, processes, services and technologies that contribute to the development and well-being of human needs and institutions while respecting natural resources and regeneration capacities" (Tello & Yoon, 2008, p. 165). Finally, the concept of behavioral innovation is of great relevance in regards to our research. As Beretti, et al. (2013) explain "Well-crafted behavioral innovations can 'nudge' agents to make better choices and can therefore constitute powerful solutions to sustainability".

One particular area in which solutions for the energy transition are very relevant is in the households energy use. According to Steg et al. (2015) "fundamental changes needed to realize a sustainable energy transition, substantial modification of a wide range of household energy behavior is needed. These include (...) to match energy demand to available supply of (renewable) energy carriers". In our research, we noticed that one of the challenges in terms of households is to adapt the energy use according to the actual availability of green energy. We realized that there is a lot of misinformation or lack of about the energy system. To achieve this a visualization tool was developed within the ENaQ Project the "Energy Signal Lamp". The lamp's goal is exactly to provide users with timely information about the green energy available so they can change their behavior in their electricity usage. In this technical paper, we will explain the technological development of the lamp, as well as, the role that participation activities had in the iterative innovation process.

2. Hybrid Living Lab and the Project ENaQ

The Helleheide Living Lab is a neighborhood under construction in the city of Oldenburg in Germany and is the location of the ENaQ research project[1]. The city of Oldenburg following its smart city strategy (Damm et al., 2017) has allocated this space as living lab in order for different stakeholders to work together with citizens in looking for solutions to local challenges. ENaQ is the first of these research projects. The project's goal is to develop solutions for an energy friendly neighborhood using a participation process and active involvement of the residents. In this sense, the term living lab is understood as a hybrid concept of two main understandings. First, the real- world laboratories in which transformation and sustainability are in focus. In this respect ENaQ is looking to transform the use of resources and create spaces for the residents and other stakeholders to communicate and exchange ideas about values, sustainability and urban development. Second, living lab or sustainable living labs in which the development of products or services is in focus, here ENaQ is creating solutions for a more sustainable energy production and use, as well as solutions on the residential level for the citizens to improve their energy consumption (Brandt et al., 2021). The project includes 21 partners among which there are different research institutes including informatics or energy systems as research areas, universities, university of applied science, the city of Oldenburg, as well as industry partners, for example, an IT consultancy firm and software developer, a measurement and control technology producer, and the construction and housing company involved in the project.

1. See Brandt et al. (2021) for more information on the project's story, the understanding of living lab and participation.

There are important considerations to mention about this project, seeing that they have been advantages for the development of innovations and particularly the energy signal light.

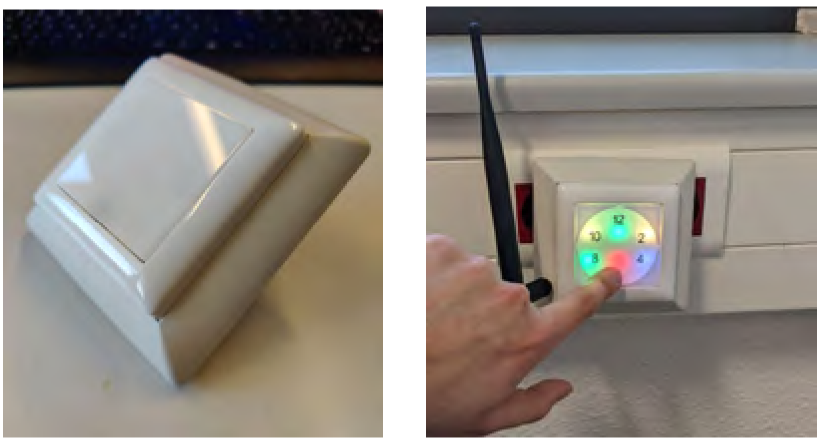
- All partners are aware of their active role in participation activities, this was always part of the project proposal and therefore all partners included time and resources for participation activities.
- There is funding for the development and testing of innovations.
- The combination of partners from different sectors, industry, research, and government, has also been beneficial, particularly since stakeholders such as the city and the construction and housing company are involved.
- Different partners brought together the necessary expertise for the development of the energy signal lamp.
- The participation process design, which will be further explained in section 3.2, also contributed to the development of the energy signal lamp.

3. The ENaQ Energy Signal Light: Resources and methods

This chapter describes the Energy Signal Light (ESL), from the first emergence of the idea, the further development using participation activities to the technical implementation.

The ESL is a small physical device (see Figure 1) that provides the user with a color based visualization of the energy mix and allows them to adapt their energy consumption to the times when more green energy is available. The ESL contains a microcontroller as a computing and control unit. Control of the ESLs is realized via a centrally run service application, which converts from ENTSO-E-provided energy mix data to control messages. These control messages contain color values for the six LEDs of the ESLs, which are sent to TTN-Servers, which forward these messages via LoRaWAN to the ESLs. The fact that the control messages contain only LED colors instead of e.g. time-series which are converted on the hardware devices allows a higher flexibility of changing e.g. the data source or display algorithm in the central backend service even while an ESL is already deployed. Additionally, this architecture enables the possibility of having the user choose the displayed data, e.g. choose between local or country-wide electricity mix or different prognosis lengths.

FIGURE 1. Left: Earlier version of the ESL including the housing, the light is turned off. Right: Later version of the ESL in the powered-on state and with an antenna for improved reception



This microcontroller controls the six LEDs on the front of the ESL. Each LED represents a time period, for example the LED on the top left of the picture with the number 10 stands for the time period from 9 to 11 o'clock. The other LEDs then represent the following two-hour long segments in a circular order, similar to an analog clock. The color of the LED symbolizes the share of green electricity in the total German electricity mix. Red stands for little green power (<25%), yellow for moderately green power (25-40%), light green for much green power (40-60%) and dark green for very much green power (over 60%). Finally, the color blue has a different function than displaying the power mix. It indicates the last past time interval. In the example in Figure 1, the past time interval was from 3 to 5 o'clock. This serves as an orientation for the user to quickly see which time interval we are currently in, namely clockwise directly after, in this example from 5-7 o'clock. The user should know whether the displayed time interval is in the AM or in the PM, therefore, it is not indicated in the ESL.

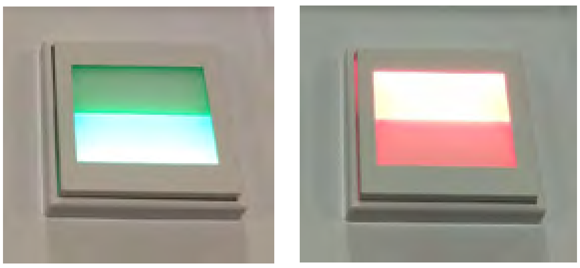
As a data source for the German electricity mix, we use the European data platform "ENTSO-E"[2]. This data platform is the best known and most widely used for information and data on electricity generation, transport and consumption in Europe. For our display we use the forecast of electricity generation, listed in different power plant types. The green power share is determined by the amount of energy of all green power plant types (solar, wind, hydro, biomass, etc.) divided by the sum of the total electricity generation including fossil and nuclear. The forecast for the next day is published on the data platform at around 7 pm.

3.1. The technical development

The ESL as first described in the above section is the current stand. Several versions of the ESL were developed and constructed over the course of the project. The first prototypes followed the same goal but looked somehow different. Thanks to the iterative approach and using participation activities described in detail in the next section, we were able to further develop the ESL improving it for a friendlier and more effective use. Based on the Design Thinking approach (Allio, 2014), we tested the prototype and developed it further using the gained feedback from the participation activities. We iterated through this loop several times, focusing on the usability.

In the first version, we tried to implement the core idea of the ESL: to indicate whether there is currently a lot or little renewable energy in the neighborhood. Therefore, this version had only two LEDs (top and bottom) and two different colors (red and green). Also it only showed the current value. The necessary data was transmitted to the ESL by means of a broker via WLAN. One of the first prototypes can be seen in figure 2.

FIGURE 2. Very early version of the ESL with only two LEDs



2. See https://transparency.entsoe.eu/dashboard/show

In the first iterations the test phase, with mainly partners from the research project (inward participation), help to uncover the following improvements:

- Prediction: we quickly realized that an instantaneous display is not suitable for everyday use. Only a few testers were willing to keep an eye on the ESL during the day and wait until the ESL displays a green light to do for example their laundry or turn on the dishwasher. A forecast of the next few hours would be particularly helpful, allowing users to adapt their washing and dishwashing cycles easily to the electricity mix and to integrate them into their daily routine. With the latest version, the fact that each LED represents a time interval of two hours has both advantages and disadvantages. One of the disadvantages is that the accuracy of the display is not very high. Within two hours, the green power percentage in a neighborhood can change significantly. However, if one looks at a larger reference level, such as the entire German electricity mix, the changes within two hours are smaller. We found that the green power share in Germany rarely changes by 20 percentage points within two hours. One of the advantages is that a large time span can be covered with the help of only six LEDs. Considering the blue LED for orientation, a forecast of the power mix of the next 10 hours is possible with five LEDs. Especially for electrical appliances with a longer operating time (such as washing machine, dryer and dishwasher) and for planning the switching on of these devices, a longer forecast is of decisive advantage.
- Finer resolution: two colors offer a low resolution. They only show whether there is currently a lot (e.g. >50%) or little (e.g. <50%) green power in the grid. A higher resolution with more colors gives the user more options and flexibility to customize their behavior. The four colors represent if there is a dark load (<25% green power) and the color is red, the user definitely does not want to do the laundry and prefers to wait. With a low green power share (25-40%), the user would wash their laundry only in urgent cases. With a higher green power share (40-60%), the user washes the laundry regularly. If the user is flexible on some days (e.g. home office), it is possible to only use the dark green electricity mix (>60%). A fine resolution of the electricity mix helps the user to better adapt their behavior to an optimal use of electricity based on the mix.
- Plug & play: the installation and setup of a microcontroller of the ESL into the local Wi-Fi can be associated with effort for the user and in addition to data-protection concerns. One of our main goals was to increase the user-friendliness of the ESL as much as possible. This includes a simple and fast installation. Therefore, for the next prototypes instead of using Wi-Fi we selected another wireless network: LoRaWAN (Long Range Wide Area Network). LoRaWAN offers a significantly higher range with a very limited volume of data. Since the amount of data in the ESL is quite small anyway, this disadvantage is of little concern for our prototype. Rather, communication via LoRaWAN opens up a decisive advantage. The communication runs via publicly installed LoRaWAN gateways, which are connected to the Internet. In our case, we decided for the publicly available "The Things Network" (TTN) LoRaWAN network, which is already widely deployed in Europe. Here it is possible to set the communication so that the ESL automatically connects to the nearest TTN-LoRaWAN gateway, receives and then displays data. Installation and setup is no longer necessary and therefore convenient for the user. A plug for the power supply allows further flexibility to freely choose the mounting location in the user's residency and to change it in case it becomes necessary. First feedback showed that some users favored the hallway because they often walked past it allowing them to have the ESL frequently in view. Other users preferred a place in the kitchen or utility room where their large electrical appliances were located. However, there are two drawbacks to the plug & play design that should be considered. First, the location requires a power outlet, which in some homes are sparsely available or already used for other electrical devices. Secondly, the mounting location needs a sufficiently good

LoRaWAN reception. Public LoRaWAN gateways are not available in all cities. Even if they are available, they should not be too far away. After further tests and feedback we opted to include an external antenna, increasing the reception of the ESL. In our experience, reception with an external antenna in urban areas was sufficient in most cases when the distance from the nearest gateway was less than one kilometer.

In collaboration with the research project "WärmeWendeNordWest" (WWNW), we have developed an ESL App to complement the ESL hardware. Initially conceived as an Android prototype, the app shares the same data source and objective. Its purpose is to display the percentage of renewable energy generation in Germany, assisting users in optimizing the usage of their large electrical appliances during periods of abundant wind and solar energy. The app's display design is modeled after an analog clock (see Figure 3).

FIGURE 3. First working version of the ESL app. Text at the top: "54% green energy in the grid." Below, a color scale is displayed to indicate the proportion of renewable energy represented by each color

The app development took place in the last phase seeing the need to make the ESL available and accessible to more users. When compared to the ESL hardware, the app presents several advantages as well as some drawbacks.

On the positive side, the app is more cost-effective, allowing for greater scalability. Additionally, it provides a longer forecast, encompassing the entire day, along with a comparison to the previous day. Furthermore, since many individuals carry their phones with them, they can conveniently and quickly access the app's display.

However, there are a few drawbacks to consider. Firstly, users need to physically retrieve their phones and open the app to access information about the power grid. Over time, some users may lose interest or simply forget about the app and its display. In contrast, the hardware ESL serves as a constant reminder of the current electricity mix as users encounter it during their daily routines, thus likely maintaining a more prominent presence in their perception.

The App is currently in further development based on the feedback and learnings from the evaluation study, and the advantages and drawbacks are being taken into consideration.

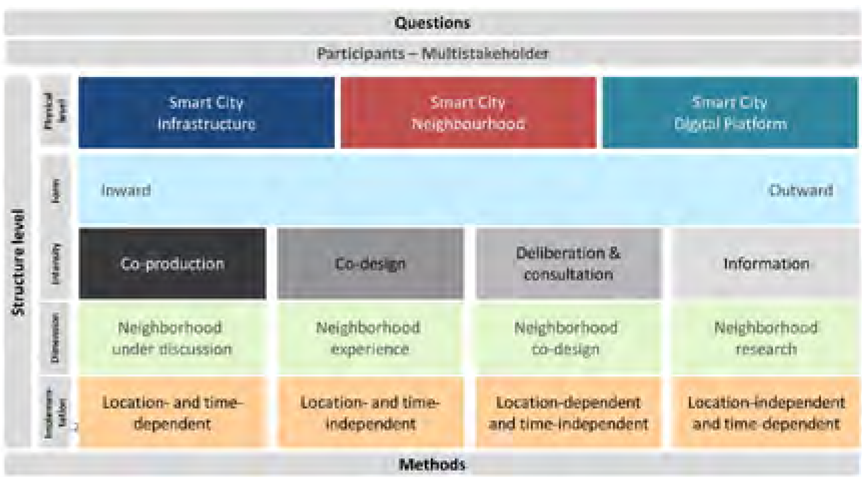
3.2. From the idea workshop to the evaluation study: the role of participation and co-creation in the innovation process

The Energy Signal Light is a clear example of an innovation developed within a participative and iterative innovation process, in which different forms, formats, intensities, dimensions of participation were used. As explained before the ENaQ Project has a clear focus on participation, and the participation activities were fundamental in the development of the ESL. The participation process design as can be seen in Fig. 4. is based on a multistakeholder approach, as explained, stakeholders from different sectors and backgrounds are part of the process. The two aspects of the participation process design we want to highlight in relation to the ESL are the form and intensity of participation[3].

As you can see in figure 4 the form is the only structure level in which there is no clear differentiation. This represents the flow that participation activities have in terms of form, going from the inward to outward. Inward participation activities are those in which only project partners take part, and the outcomes remain within the project. The outward participation activities are those in which only stakeholders that are not part of the project, except for the moderation or input, take part. The contributions are also used in the project but could also be used elsewhere. In between different stakeholder combinations are possible, in a form of hybrid participation, where there is not a fixed distribution of the amount of internal and external contributors, and varies depending on the question to be tackled in the activity.

The intensity of participation is closely related to the level of power given to the participants, from the information level, in which the participation is limited to receiving information and getting clarification about concepts. In the deliberation and consultation level the participants are asked to share their ideas and opinions, and although these may be taken into consideration and integrated there is no influence or decision power. In co-design participants still do not make decisions but are able to be part and actively design and shape solutions and results, not only verbally, as it is in the deliberation and consultation intensity. Finally, co-production the participants not only take part in design and forming, but also in the decision-making and implementation of the idea(s) (Brandt et al., 2021).

FIGURE 4. The ENaQ Participation Process Design



3. For a detail description of the entire process see Alcorta de Bronstein et al. (in publication).

In the design and development of the ESL different participation activities took place. At the starting phase the need of a visualization tool to improve the energy consumption was discussed in inward participation activities, for example, business model development workshops with project partners from energy sector, software development, research institutions, construction and housing company. Also in an early phase the question of visualization solutions was part of a university seminar, an outward participation activity, in which master students developed ideas. From this, different options emerged, and the decision for an ESL was made. The idea soon turned into a collaboration in which a group of project partners from industry and research worked together co-designing the ESL hardware and software. With first prototypes other participation activities took place, inward testing and feedback, and outward a second university se. minar as well as a in citizens workshops. These activities were crucial in terms of feedback, usability and improvement of the ESL.

3.3. The evaluation study

However the question remains, is the ESL actually going to help users to adapt their behavior and improve green energy usage? For this crucial question, one more participation activity was designed and implemented, an evaluation study. Before the study started, a pre-study with project partners took part. In this test, we reviewed all methods and tools to be used, collected feedback, discussed with the study team, and made the necessary improvements and adaptations. The study was conducted in the city of Oldenburg with three tester groups: group one, 13 participants, using the ESL in the hardware version, group two, 15 participants, using a virtual option (App or Website) and group three, 15 participants, was the control group. Using a Logbook (see Fig. 5) all participants had to track the use of the washing machine and dishwasher for a period of two weeks. This included date and time, duration of use, temperature, and person of the household that washed. Also, a comment area to clarify, for example, that the dishwasher on a particular day was often on because of a family gathering. They also had to indicate their electricity meter status at three points in time, the day before the study started, two weeks after, and at the end. After two weeks groups one and two receive their ESL, either hardware or the login information for the digital one. All three groups had to continue tracking the use of the two home appliances for four more weeks.

FIGURE 5. Logbooks from the ESL evaluation study

After the six weeks semi-structured online interviews were conducted with each participant, in order to look into changes in their routines, and also feedback about the usability and improvement of the ESL. The logbooks were also collected and all participants also had to fill in a questionnaire to collect socio-demographic data and measure their environmental awareness. The different methods used and data collected allow for a triangulation of the data and in this sense being able to achieve a deeper understanding of the results (Fielding, 2012).

4. Looking in to the future: pre-results and improvement

4.1. First observations of the evaluation study

Based on the interviews it was already possible to give intensive feedback to the App developers and discuss important aspects that the users noticed. For example, the children pf one of the participants in our evaluation study are color blind, therefore their feedback on this aspect was very important, but also inspire us to think about other disabilities that might affect the better use of the App. There were also additional noteworthy requirements in terms of design modifications and desired new features expressed by the participants, for example integrating the logbook. Some suggested making slight adjustments to the existing design to enhance usability and visual appeal. Moreover, there was a desire for the inclusion of new functionalities, such as push notifications, for example, when a self-defined threshold for the share of renewable energy is reached, or a widget for the ESL app.

Another frequently suggested improvement for both the hardware and app was to provide a more extended forecast. Many testers expressed the need for a forecast that spans beyond the current day, such as for the upcoming day or even two to three days ahead. They believed that having access to such a forecast would greatly assist them in effectively planning the usage of their major electrical appliances in their daily routines. For instance, if today's forecast indicates limited availability of renewable energy, but tomorrow's forecast predicts an extended period of abundant renewable energy, some participants would be willing to postpone their laundry tasks for a day. However, implementing this feature has proven to be challenging on multiple fronts. Firstly, the ENTSO-E data platform currently releases forecasts for the next day at approximately 7 p.m. of the current day. Moreover, obtaining longer-range forecasts from other organizations often comes with associated costs. Additionally, as the forecasts extend further into the future, their accuracy diminishes. On the other hand, the current hardware ESL display has limitations in terms of resolution, utilizing only six LEDs. Currently, each LED represents a time interval of two hours. To accommodate longer forecasts, the LEDs would need to represent more hours, such as four hours, resulting in a total forecast length of 20 hours. However, this would introduce a trade-off between representation and accuracy, as the renewable electricity mix is more likely to undergo changes within a four-hour timeframe compared to a two-hour one. One possible solution would be to incorporate more LEDs or explore alternative display technologies, but both options would require additional development of the hardware ESL, entailing extra costs and efforts. Additionally, this would increase the complexity of the information to display and thus lower the glanceability of the device. On the other hand, integrating a longer forecast into the ESL app itself would be a more feasible implementation.

A recurring request voiced by many participants in the study was the inclusion of local or regional energy data specific to their city or state. For instance, one participant aptly pointed out, "What good is it to know about high solar energy generation in Bavaria (a southern region of Germany), if I live in Oldenburg (located in the northern part of the country)?" This observation highlights an important aspect, as the distribution of renewable energy infrastructure in Germany is uneven. The southern regions boast a higher concentration of photovoltaic (PV) plants, whereas the windier north is home to a significant number of wind turbines. Due to insufficient grid transmission capacities between these regions, bottlenecks and redispatch measures occur frequently, which in turn can invert the supposed effect the ESL should have on energy consumption. Consequently, it becomes meaningful to provide a regional perspective and display of the electricity mix or other energy-related data. Some grid operators have already attempted to mitigate the need for redispatch measures by presenting regional energy data and highlighting network bottlenecks. Notably, the transmission system operator Transnet BW has developed the "StromGedacht"3[4] *(ElectricityThought)* app serving as a prominent example. However, obtaining the necessary information for regional display options becomes challenging without the support and provision of regional energy data by the grid operators.

4.2. Next steps in the ESL development

As seen in the description of the evaluation study, the amount of data collected, the integration and interpretation, will take some time. In this sense there are four next steps planned.

Firstly, an in-depth analysis of the qualitative data, encompassing all conducted interviews, is currently underway. This undertaking aims to uncover further and, most importantly, deeper insights into the beha-

4. Stromgedacht (ElectricityThought), see https://www.transnetbw.de/de/newsroom/presseinformationen/heute-schon-an-stromgedacht-stromampel-sprang-erstmals-auf-rot

vior patterns exhibited by the participants. The objective is to ascertain the extent to which the individuals have adjusted their usage practices in response to green energy generation.

Secondly, we intend to utilize the findings from the qualitative data analysis to derive additional recommendations for enhancing the hardware ESL. These recommendations will be integrated into the ongoing development of the ESL, which will be installed in all 124 residential units within the newly developed "Helleheide" neighborhood.

Thirdly, an evaluation of the quantitative data is planned. This evaluation encompasses the analysis of both questionnaires and logbooks. By examining the logbooks, we will be able to precisely determine the extent to which the participants' actual usage behavior has transformed during the test period. The primary aim here is to gauge the actual impact of the modified usage behavior on energy consumption. All data sources will then be integrated and analyzed for each participant.

Lastly, a more extensive and prolonged study is envisaged to take place directly within the Helleheide neighborhood. This study aims to investigate the long-term effects of the ESL on its residents. However, given that the current research project is concluding this year, this final step is contingent on whether a subsequent project can be conducted.

Overall, these planned steps seek to delve deeper into the participants' behavior, incorporate improvement suggestions into the ESL development, evaluate quantitative data, and pave the way for future research in the Helleheide community to assess the lasting impact of the ESL.

5. Conclusions and considerations for Latin America

In this paper we were able to bring some insights about the development of the ESL from the ENaQ project. A key aspect of this innovation process was the participation activities which took place in parallel with the iterative innovation process, allowing for timely improvements. The inward participation activities allowed firstly for the development of the ESL itself (coproduction and codesign), as well as, for a faster test and feedback. The outward participation activities brought new perspectives and aspects not always taken into account before, or confirmed others from the inward activities. In this sense, the innovation process went hand-in-hand with the participation process. The most complex participation activity was the evaluation study given the amount of time invested from the researchers group and the design and implementation, but also from the participants who worked on logbooks for six weeks. The pre-results show so far that the participants found the ESL useful, but found a need for further improvements, in both the hardware and the app versions. Therefore, this visualization tool, could achieve the goal and help users to improve their consumption of green energy.

In regards to Latin America given the growing investment in the production of more renewable and green energy (Cantatero, 2020), and the possibility that more energy might be produced but not timely used, tools like the ESL could also favor Latin America and other countries, to adapt their consumption to those time frames when there is more green energy. Depending on the countries energy system and tools in place for the energy transition, this adaptation of the consumption, could also contribute to using less energy storage tools. Finally, seeing the advantages of local residents and different stakeholders, development of innovations should also consider this approach, especially when behavioral change is seeked for, taking into consideration the human perspective for technological developments.

Acknowledgments and funding

The authors thank all the ENaQ and WWNW project partners involved in the development of the Energy Signal Light, the testers of the evaluation study for their valuable input and feedback, as well as participants from other participation activities in the innovation development. Finally, all the colleagues that worked and are part of the evaluation study. This research was funded by the Federal Ministry for Economic Affairs and Energy (BMWi) and the Federal Ministry of Education and Research (BMBF) of Germany in the project ENaQ (project number 03SBE111).

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