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charged

CleAnweb Gamified Energy Disaggregation

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Lessons Learnt

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1 Lessons Learnt

User Requirements Elicitation
Be thorough and as much detailed as possible. In the user requirements elicitation process, we conducted interviews with pilot users, a user survey for personality traits, energy consumption-related behavioural traits, energy-consumption habits and game preferences, and pre-pilot and post-pilot questionnaires for energy consumption behaviors, traits and intentions. Only thanks to this data analysis, we were able to mostly understand the pilot results, correlate the in-game behaviors to the energy-savings and accurately assess the effectiveness of the ChArGED solution to change energy-wasting behaviour at work.
Listen carefully to the pilot users. During the user requirements elicitation process, user requirements regarding the ChArGED gamified app were gathered and most importantly respected. It was recorded from the beginning that a certain number of users use iPhone and that they are not willing to use a second Android phone, just for the ChArGED game. Due to additional effort to port ChArGED app to iOS and limitations such as that NFC was not supported in iOS, focus was put on Android implementation. The iPhone users were provided with additional Android phone for the pilots, which eventually, did not result in their participation in the pilots.

User Engagement
Follow user in-game requirements. The game was a team competition in rounds and points were awarded based on challenge accomplishment according to the user requirements. This was highly appreciated by the pilot users, as they found the game entertaining and useful, yet non-intrusive. Moreover, most pilot users reported a high desire to continue using the ChArGED app after the pilot studies.
Be proactive in the game design. 12 different in-game challenges were designed, all linked to different user actions that reduce or time-shift energy consumption. The game pilots started with 3 challenges at two pilot sites and 2 months later 3 more challenges were added to the first site. The user interest significantly boosted after the addition of the new challenges at the first pilot site, while, at the second pilot site, keeping alive the people's interest was not easy. A better tactic would be to plan incremental enhancements to the game from the very beginning, such as new challenges, new tips, rewards, and add them progressively into the game to maintain high user engagement. In addition, the game architecture should be made in such a way that more challenges can be added seamlessly and configured by the user in order to address the specific requirement of a building and its players.
Analysis of the public sector requirements for energy savings
A detailed mapping of the appliances to be monitored should take place. Depending on whether or not the meters are installed per circuit, the mapping should include details of the circuits which are monitored and the data that are collected by them. The electrical plan will help. This facilitates the conclusions of the disaggregation of energy savings. In the case that meters are not installed per circuit (for purposes of cost reductions) the detailed mapping of the appliances in the working environments should be sufficiently described and adopted across all system components to allow the disaggregation of the energy savings to the users and the allocation of energy savings awards /points. The strategy should include the use of minimum number of sensors, in this way re-usability for new use-cases and challenges is ensured during all pilot stages. A tactic to investigate would be to develop a database of reusable appliance signatures to decrease the game commissioning phase.

Development approach

Agile development methodology: In Charged an Agile software development methodology throughout the development stages was followed. The lessons learned can be summed up in that the overall consensus was that it helped partners actually "see something that works" much earlier than usual in such projects. Even though we did not accomplish to adopt a pure agile development method due to many mostly external factors, the concept of small milestones and predefined and accepted "sprints" helped us utilize our development time and increased "peer pressure" among partner development teams. We recognize the difficulties of implementing the agile methodology in research project development but surely recommend to other teams to make the extra effort and follow it, since for us it proved to pay off in the long run.

Game configuration

- The gamified approach has great dynamic and potential while it is flexible in terms of adding features, configuring teams/users, designing new challenges etc.
- The goal of raising awareness was achieved by enhancing green consciousness and/or ensure adoption by the users.
- Enhancement of team building spirit and fair play is an important asset of the gamified approach and must be exploited to the maximum.
- Teams distribution is preferable according to the location per work room.
- New challenges are not only welcomed by users but also it supports the game dynamics, re-attracts interest in the game and is more straightforward as it requires less feedback and support.
- Continuous communication and feedback towards end-users increase engagement. Especially if it includes highlights from the leaderboards e.g. with team won last **month**/week, which user was more active overall etc.

Software Implementation

The value of SiteWhere and AWS SQS. There compatibility among IoT devices, renewable sources, meters and sensor devices remains an issue. Open Application Program Interface (API) is needed to allow Internet devices to be registered and web applications to be built seamlessly. SiteWhere and AWS SQS facilitated the unification of IOT implementation, while SQS facilitated collection of data measurements with little downtime. That meant that even if our severs went down, all messages were recovered.

Deployment of EE projects

The deployment process should begin with the detailed analysis of the legacy infrastructures and the providers as the public sector often outsources the network tasks and the access to it can become very time-consuming. The study should include the internet connection settings and limitations. Proxy configurations or other constraints are possible to be met during preparation of CharGED installation. For Raspberry or other gateway deployment, a cooperation with the relevant IT Department of the organization is obligatory for data transmission, since a common practice of cybersecurity bans the latter usually and prohibits access to the internal network.

Even when deploying the same hardware into the different pilots, there are differences in the setup of provided infrastructure and the relevant deployment of the use cases. These infrastructural

differences can be direct related to the IT and energy infrastructure, but also indirect related to the shape of the building as thick walls which cause disruptions in wireless communication.
The **management of the building** is a key enabler of the success of any project for EE which should "impose" and "motivate" the game adoption and people engagement.

The aspect of **dropping interest by the end users** in the EE activities should be continuously monitored and ways to re-attract interest should be provided

- by the people: In our experience the colleagues motivate each other and ensure engagement of each other. The key owner of the game and facilitators (those who will bring an EE in the organisation) have a key role to play for ensuring the continuous motivation and engagement. It is recommended to have an “energy champion” in the building who is the one to push the adoption of the game, keep getting new players and increase their involvement in the game.
- by the management: reattract interest was the reward, which has not been tested in ChARGED but has been considered.
- By the game providers: novel challenges were found to re-attract interest and motivate new people to get engaged.

Solar photovoltaic panel installation in public buildings: It is very difficult for a public entity to autonomously decide and authorize the installation of solar photovoltaic panels on their rooftop due to various reasons. Further to that, even if the entity has made their decision and authorized it, it is imperative to guide them - with the help of an expert installer - through all the steps that need to be taken (permissions from various authorities, permission from other sharing tenants and building owners, DSO permits etc.) In the case of Greece, it is much easier to install a self-consuming set of panels, than try to get the installation on the grid.
In addition, the Solar panel installation for large-scale buildings shall include and foresee costs for maintenance, grounding installation against strikes, insurance costs for the equipment and costs for special cleaning of the devices.

Identification of baseline and Energy Savings calculation
Allow a long time period to build a meaningful baseline to build a reliable energy saving model. While the IPMVP protocol is a well-known methodology to validate savings, a major lesson learned is that savings can only be fairly forecasted if there is a sufficient baseline of energy data that spans across the 4 seasons to understand the performance of the building across the year, especially since several aspects are influencing energy consumption, like seasonality, people presence/absence, appliances replacement, etc. In general, the longer the baseline is monitored the safer it is and the forecasting models more accurate. For the specific sector of office buildings which consumption differ greatly by the season, collecting energy data for an entire year is highly recommended to fairly construct a model to verify savings.

Similarly, this historical energy data must be dissected and made available for areas and building appliances if the saving verification are to be reported at area level, team level or appliance level.
The choice of independent variables with high correlation is key to accurately predict savings. On this regard, a lesson learned is that for buildings where the energy is dominated by appliances for occupants such as heating, cooling ventilation, lighting, computers, etc the independent variables to always consider are always operating hours, heating and cooling degree days, solar radiations and public holidays or other days with reduced building occupancy.

The potential analysis of the wastages at the baseline will help to get a target for the challenges and the estimation of the required equipment for each potential new building. Hence, the resulted payback period of the investment will be facilitated and the interest of customers will be attracted.

IoT cost-efficient hardware reliability and performance: The selected ultra-low-cost hardware performed very reliably and does actually constitute a viable alternative to the expensive "brand name" top tier smart building hardware. In particular, the z-wave smart plugs and sensors, as well as the combination of the low range Android smartphones with the NFC stickers, performed perfectly, thus constituting in our view a reliable cost-effective commercial solution. However, the specific BLE beacons (Estimote) did not provide an accurate proximity location (room level) within the building of the users for the specific use case as promised but did provide user presence in the building with a more open range configuration. BLE configuration can be resolved with diverse configurations to ensure coverage of a building e.g. diagonally as implemented in DAEM, since BLE's coverage is usually overlapping. A study at each site is easy to do. Finally, the Raspberry Pi single board micro-computer has proven to be the reliable micro-server of choice for hosting an edge IoT data logger smart building solution.
IoT devices are easily transferable, removed and/or mistaken from people lacking relevant knowledge, hence a small additional quantity of devices must be foreseen.
Installation of IoT devices should be accompanied with relevant information of the building users to ensure that they will remain monitored.
The knowledge of appliance consumption profile for disaggregation was useful for refining game challenges. For example, to identify the printer activity (ON/OFF) through its consumption profile a continuous data collection in very 20 second took place. A lesson learned is that in order to achieve this level of insights only specific meters can be used. Those meters should be able to report a set of parameters such as active power, reactive, harmonics etc. with high frequency such as sub-minute reporting.

Social Impact
Significant behavioural changes. A properly designed game intervention, such as the one of ChArGED, can achieve significant behavioural changes of the targeted user behaviours. For example, the users self-reported 2.44% (45.55% of the maximum attainable change) improvement for turning their PC off after work and 3.46% (40.49% of the maximum attainable change) improvement for turning off the lights after work. The estimated energy savings that correspond to these behavioural changes were 59.69% and 29.37% electricity reduction for PCs at DAEM and ICAEN respectively, and 96.73% and 15.9% electricity reduction for lighting at DAEM and ICAEN respectively.
Improved Behavioral Traits. Despite the fact that we targeted only specific energy-wasting behaviours were targeted with the designed intervention, all behavioural traits related to energy-consumption behaviour were significantly improved. Specifically, the self-reported energy-saving behaviour at work improved by 9.61% (30.22% of the maximum attainable), the intention to save energy improved by 2.82% (24.31% of the maximum attainable), the personal norms improved by 2.17% (25.41% of the maximum attainable), the energy awareness at work improved by 5.16% (22.9% of the maximum attainable) and the locus of control became more internal by 6.14% (10.64% of the maximum attainable), i.e., the users feel more empowered to save energy by their own actions. Moreover, habituation of the energy saving at work has improved by 7.15% (32.98% of the maximum attainable) and energy conscientiousness at work has improved by 6.05% (20.02%

of the maximum attainable). Finally, the positive behavioural changes were reportedly also transferred to other contexts, such as the user homes (4.12% improvement, 28.36% of the maximum attainable).

User Satisfaction and Continued Use. Pilot users at both sites, in the very large, enjoyed the ChArGED game app, i.e., 5.68/7 and 4.69/7 enjoyment in DAEM and ICAEN respectively. Also, they had a very positive attitude towards the objectives of ChArGED, i.e., 5.9/7 and 5.57/7 at DAEM and ICAEN respectively. They found the ChArGED app easy to use, playful, and that requires low effort. Moreover, the ChArGED app was reported to perform highly as expected by the users. Finally, the pilot users reported using the ChArGED app as a habit (5.92/7) and their intention for continued use (4.65/7).

Economic Impact

Effective and profitable energy-saving investment. The deployment of the ChArGED gamified solution was proved to be economically profitable for both sites. Specifically, DAEM achieved 956.88 € estimated annual energy cost savings and with a very short payback period of 3.45 years, while ICAEN achieved 777.85 € estimated annual energy cost savings and a payback period of 3.26 years. Note that these economic savings resulted by only targeting 2-3 specific behaviours, namely lights-off and PC-off when unused.

Keep infrastructure cost low. The estimated annualized cost savings by electricity curtailment due to behavioural changes are significant as fractions of the overall electricity cost, however, in absolute numbers, they are low, i.e., ~957 € and 778 € for DAEM and ICAEN respectively. Therefore, it is important that the infrastructure cost for a potential deployment is kept low, in order for the investment in a ChArGED-like intervention to pay off. For DAEM and ICAEN pilots sites, the consolidated infrastructure costs were 4200 € for 46 employees at DAEM and 2532 € for 29 employees at ICAEN.

Significant energy savings per capita. Significant monthly energy savings have been measured per employee, i.e., 11.95 KWh at DAEM and 22.16 KWh at ICAEN respectively, i.e., on the average 17.05 KWh. The threshold of 15KWh monthly energy savings per employee is the lowest bound for investing in a ChArGED-like intervention, while with 20KWh/month/employee with own capital for investment, the payoff period and the internal rate of return (IRR) have been calculated to be 5 years and 23.18% respectively.

2 Conclusions

The project has overall conducted various dissemination activities for the second year. Most of the relevant KPIs for the period have been achieved and some of them significantly overachieved. The project will continue to intensify these activities during the next year, especially since more results will be available that can be demonstrated.