User-friendly Visualization of Energy Flows in Smart Homes

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***Abstract*—The constantly increasing energy consumption requires to make people aware of energy and the trend towards the smart home makes it possible. Every manufacturer of so-called smart products uses its own application to display the data obtained. However, this makes it difficult for users to see a connection between individual devices. Even if people are using a smart home hub to collect data from multiple devices, the data is still separated in different charts or tables and hard to compare. To offer them more transparency in their smart home, an application was developed for electricians that want to offer their customers added value without great effort. This app makes the data of the devices available in a central location and provides an overview of the energy flow users can easily interpret.**

***Index Terms*—Smart home, energy monitor, energy flow.**

I. INTRODUCTION

Energy consumption has been rising for years and has more than doubled between 1990 and 2017 [1]. Despite significant improvements in energy efficiency, the electricity consumption in the European Union per household has increased by 2% per year from 2000 until 2010 [2]. Reasons for this are manifold and country-specific. They include more widespread use of electronic equipment like electric dryer and dishwasher that go along with a higher degree of basic comfort [2], more entertainment electronics like large tv sets [3], gaming PCs and video game consoles, as well as extensive use of air conditioning and cooling devices. Energy consumption of Information and Communication Technologies (ICT) and Consumer Electronics (CE) has risen considerably in recent years and now accounts for approximately 15% of global residential electricity consumption. Research further indicates that almost 41% of supplied power is wasted, e.g., through devices in standby or wrong room temperature [4].

The emergence of modern smart home devices plays an ambivalent role since these devices require additional power on the one hand, but also offer a certain benefit and potential for saving energy on the other hand [5]. These smart devices provide the user with a wide range of data. This includes both the user's energy consumption and energy generation through various devices. The available data of the individual networked devices are usually only displayed in a smartphone application of the respective manufacturer. As a result, you have to use several apps to get all the information. A disadvantage of this is that the data are separate from each other and a possible connection is difficult to recognize. In order to offer the user more transparency for its energy consumption or its energy production and the devices used, the data must be visible in a central location. Several studies show that this kind of feedback can change user behavior in a positive way [6]–[9]. This is especially important, since user behavior is a relevant factor besides the devices mentioned before [10] and people also have certain beliefs regarding energy consumptions and possible savings that are far away from the objective facts [11]. To overcome some of these problems, the Energy Flow Monitor (*EFM*) was developed, a smartphone application that visualizes data from different devices of different manufacturers centrally in one app. Modern households include a variety of energy consuming and also generating devices like heat pumps, solar heating, photovoltaic collectors. Therefore, it is increasingly hard for users to keep track of their interplay. Is the dryer running while PhotoVoltaic (PV) collectors are providing electricity, or is it using expensive power from the national grid? *EFM* can show interactions like this to the user in an understandable manner. As a result, the user becomes more aware of how some devices are connected and where there is potential for energy saving.

The remaining paper is organized as follows. First, related work is presented and deficiencies of existing solutions are highlighted. This leads to the goal of our research, which is presented in section three. A short excursion to technical aspects of the developed app is discussed in section four, before our solution to the challenge is presented in section five. We conclude the paper with a discussion of limitations an outlook to future work and a conclusion.

II. RELATED WORK

The consumption of energy is abstract, invisible, and untouchable - unlike most other consumable goods [12]. Therefore, home energy usage often goes unnoticed. The only means of judging their household energy usage is often a monthly (or bi-monthly) bill (ibid.). In Germany, it is even worse, since many people only get yearly bills.
Although there is both great potential and great interest in stimulating behavioral change with energy monitoring tools, we still know little about how to design, situate, and integrate them to help people make good decisions to safe energy

[13]. “Current applications often require too much effort and management from occupants and are not integrated well with the set of information tools people already use” (ibid). Bartram et al. propose a combination of Web application to display on the PC, mobile app with a subset of the features of the Web app (see Figure 1) and an ambient display in the kitchen to positively influence the occupants.

THIS WEEK'S ACTIVITY
NET-ZERO: + 22 kWh
BEST GAIN: SUN. (+5 kWh)
WORST LOSS: THURS. (- 3 kWh)

THIS WEEK'S ACTIVITY
NET-ZERO: – 5 kWh
BEST GAIN: MON. (+10 kWh)
WORST LOSS: FRI. (–20 kWh)

Fig. 1. Screenshot of the mobile app from Bartram et al. [13].

Existing studies paint a diverging picture of the impact of energy monitoring solutions on energy savings. [14] found no differences in energy consumption for one device and only insignificant differences (12%) for the other device. However, this could be due to their limited study size since 12% would be significant for a larger sample based on the measures used in the paper. The amount is also in line with findings in [15] that report 10% savings. [16] found that initially, energy monitors led to nearly 8% savings, but after four month, no difference could be observed anymore. However, in large meta-studies it was shown that feedback systems are effective in supporting energy saving behavior and resulted in about 10% savings [12], although individual study results differed between 5% and 15%.

One problem of most existing solutions is that they do either display only the overall consumption or integrate the consumption of individual devices using plug adapters, as e.g., [17] do. This excludes devices without a plug like oven, water heaters, PV collectors and heat pumps. Some of the latter devices come with monitoring apps on their own, but as stated before, an integrative view is missing. [18] claim that they can monitor individual devices like refrigerator, washing machine, dishwasher and dryer in addition to furnace and water heater based on the home’s circuit breaker box (see Figure 2). However, this seems not plausible since usually there are only few fuses per house and only high power devices like the water heater and oven have a dedicated fuse, whereas refrigerator, washing machine and dishwasher share a fuse with other devices in the kitchen or cellar.

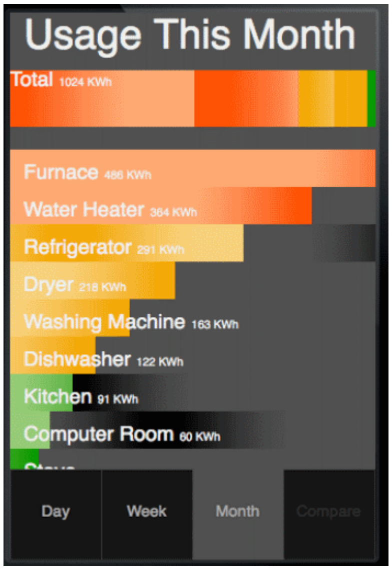


Fig. 2. Concept rendering of the *WattBot* application [18].

Feedback on energy consumption has a significant role in raising awareness. It can sensitize users to the extent that a reduction in consumption in the order of 10% is possible [6], [7]. One approach to communicate energy consumption to the user is by Fleisch et al. [19]. This system allows the user to monitor its energy consumption on a mobile phone and to compare devices with each other. The disadvantage of this solution is that one has to run its own web server, which may discourage some users from using it. There are also commercial solutions [20], which are installed on the electricity meter and offer the user a good overview of the electricity consumption, but there is no visualization how different devices are connected or the possibility to see the energy generation.

III. GOAL

In order to create more transparency for the user, an easy-to-understand overview of the main devices is important. These must not be scattered over several apps but integrated in one place. The resulting overview should provide the user with all important information and especially show the connection between the individual devices. The aim is to develop a mobile app that displays data of smart devices centrally and also provides an overview of the energy flow in a user-friendly way. This creates greater transparency and makes it easier for users to understand the energy consumption in their homes. User-friendly is used here in the sense that Trenner subsumes under ”how user-friendly is commonly understood” [21]. That means ”easy to use”, ”designed with the needs of users in mind” and ”to serve the non-expert or novice” (ibid.). Expert users are not considered in the first iteration.

The application should also be adaptable for companies without great effort by choosing systems that are as open as possible. Since there are two major smartphone platforms in

Germany that both have more than 25% market share and together provide for over 95% of the market [22], the mobile app should be available for both platforms.

IV. CROSS PLATFORM APP DEVELOPMENT

Given the task at hand, the decision is between developing two native apps or one cross platform app. Native apps offer some advantages. They have full access to all features of the device and the operating system. In addition, they usually provide better performance and smoother animations [23]. A native user interface uses the original widgets provided by the operating system, and will also be updated over time with operating system updates. On the other hand, one has to develop two separate applications, using different programming languages, development environments and paradigms. Offering the application natively on two platforms will multiply the effort by factor 1.3 [24] or even up to factor two [23].

Whether cross-plattform apps are a good alternative depends on the complexity and type of application [23]. A huge challenge is providing a consistent app behavior and still respecting the UI guidelines of the respective platform (ibid.), which is also important for the user experience, since users expect a certain degree of consistency across apps on their device. Cross platform applications can be developed with different approaches: Web, Hybrid, Interpreted, Cross-compiled and Model-driven approach [25]. Web apps run in the browser and are not installed using the platform's app store. Hybrid apps are developed with HTML, CSS and JavaScript like Web apps, but are packaged into platform-specific apps and run inside a Web view instead of the browser. They can use more native features through abstraction layers like *Phonegap/Cordova*. With interpreters like *Appcelerator Titanium*, developers can use a single language, which is than interpreted in a platform-specific container. It allows for native user interface components, but comes with performance degradation. Cross-compilers generate true native code out of a common codebase. *Xamarin* is probably the most popular example of this category. Model-driven development is a big trend, but it is not yet established in companies outside academia.

Having only web developers available that had no experience with *Android* nor *iOS* development, and the application being not too complex, a closer look at frameworks supporting the hybrid approach seemed sensible. This choice is also becoming more common since both performance and access to native features of hybrid apps has become better over the last years. [26] identified *Ionic* (hybrid) and *React Native* (cross-compiler) as innovative approaches and concluded that *Ionic* made development of interfaces and app flow easy through their component library, whereas *React Native* left more architectural choices to the developer. On the other hand, *React Native* mostly delivered un-styled and "not native-looking" interface components with the option of styling them to fit the app. *Ionic* provided a massive library of ready-made and pre-styled components making the development of standard native-looking interfaces easy (ibid.).

Recently, a new alternative became available, which is called progressive web apps [27]. Although they performed well in the comparison, we did not further consider them since they do not produce apps for *Android* and *iOS* app stores. Despite the fact that our own app does not make excessive use of native components, our choice was still *Ionic*, since other papers describe it as the "top choice among hybrid mobile app frameworks" [28]. The app presented here was therefore developed as a hybrid application using *Ionic*, *Angular* and *Apache Cordova* to increase its availability and to keep the programming effort as low as possible.

V. OWN SOLUTION

Froehlich found ten design dimensions when planning energy monitoring systems [12]: frequency, measurement unit, data granularity, push/pull, presentation medium, location, visual design, recommending action, comparison and social sharing. Our app displays current and historic energy consumption and flows with mostly a few seconds delay to recording. It uses kW as the measurement unit and displays data for PV collectors, heat pump, furnace and overall electricity consumption for a user-defined time interval (current, day, week, month). Additionally, it display the flow between national grid, heat pump, PV collectors and the electric devices in the house. Users have to actively query the data. There are no proactive push notifications currently. Information is displayed on mobile phones and therefore independent from the location of the monitored devices and even from anywhere on the world, as long as internet access is available. Visualization is not optimized for tablets given the dominance of smartphones and the comparatively small number of tablets in the market. We put much effort into the visual design, which consists of polished charts (see Figure 4) and our special energy flow visualization (see Figure 5). *EFM* does currently not recommend any actions, nor does it directly contain a social sharing functionality. Comparison with past data is easy, using the charts. Comparison with other households is not implemented.

Apache Cordova and *Ionic* were used for this application. Devices whose data can be displayed are a heat pump, PV collectors, heating, solar heating, thermal buffer, the total power consumption and energy accumulators. The data include the current consumption at the time of logging, the power gained or the temperature profile.

One important consideration for our solution was the ability to use it independently of the manufacturer of the heat pump or furnace. This gives electricians much more freedom in chosing the best solution for the customer, without thinking about the data connection. The latter is provided by sensors from a company called *Technische Alternative* [29]. They can be used in conjunction with all leading manufacturers. Despite the availability of a number of smart home hubs like OpenHAB (based on Eclipse Smart Home [30]), IP Symcon or others, including central heating systems, PV and water heaters is still a challenge for end users. Whereas lighting, blinds, temperature and other sensor data is usually available via standard protocols like Zigbee, Z-Wave or KNX, the listed devices usually do not provide an easy to use data interface. The Sensors by Technische Alternative can reduce this problem by providing energy data independent of the manufacturer and at affordable prices. A drawback is, that only certified electricians are allowed to install those sensors. This is much more effort compared to the usual plug-adapters that are merely plugged into the wall socket and the plug of the appliance is plugged into the adapter.

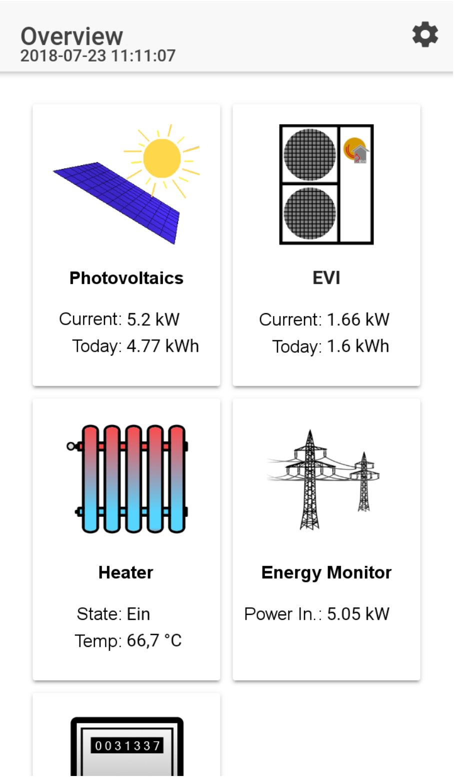
Avoiding the necessity to operate an own backend, a Mobile Backend as a Service (MBaaS) solution was desired [31] for retrieving the data via an Application Programming Interface (API). Fortunately, the *Technische Alternative* provides a web portal for accessing the data of its sensors in the field. In addition to the web interface for humans that is available for several years, they are offering an API for developers since spring 2018. We were granted early access to this API in order to develop EFM. Although this is not an MBaaS solution in a narrow sense, it provided all the necessary data. The company that provides the customer with this application therefore does not have to operate its own web server and thus has the advantage of offering the customer added value. In order to speed up visualization of data, it is stored in a local database on the phone after it was first retrieved from the backend. The database used for that is *SQLite*.

The great advantage of our application is that both the views of the individual devices and a combined view to illustrate the interaction of the devices are located in a central place. Hybrid cars were used as a basic idea and inspiration because they also display an energy flow, e.g., the interaction of the engine, its consumption and recuperation is displayed in a common view.

The app is divided into four views for energy and energy flow and the view of settings. Immediately after starting the app, the user sees the overview page with all connected devices (see Figure 3). The current value and energy of the current day is displayed for power generating or power consuming devices. For devices such as the heater, other data are displayed accordingly, such as whether the status of the heater and the current temperature. Each device is shown on an own tile on the main screen (see Figure 3). For users, that have less devices, only relevant tiles are displayed. The acronym EVI that can be found in Figure 3, is the abbreviation for the heat pump or our project partner.

If a device is selected in the overview by touching a tile, the detailed view for the respective device is shown (see Figure 4). In this detail view, you can see the energy production for the current course of the day, the current week, the current month and the current year.

In the overview of all devices, users will also find the tile “Energy Monitor”. If this is selected, a view is displayed showing the energy flow and thus the interaction in the house



Overview
2018-07-23 11:11:07

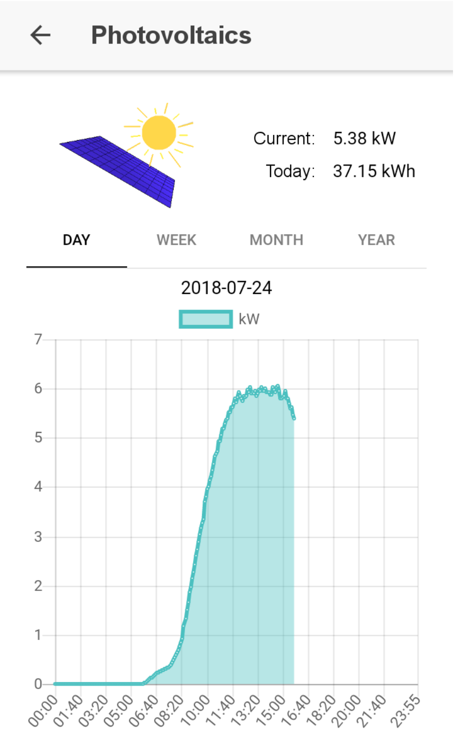
Photovoltaics
Current: 5.2 kW
Today: 4.77 kWh

EVI
Current: 1.66 kW
Today: 1.6 kWh

Heater
State: Ein
Temp: 66,7 °C

Energy Monitor
Power In.: 5.05 kW

Fig. 3. Example overview showing the connected devices with current values.



Photovoltaics

Current: 5.38 kW
Today: 37.15 kWh

2018-07-24

Fig. 4. The course of the current day can be seen in the detailed view.

(see Figure 5). If the user has a photovoltaic system, the current energy generation is displayed there. The total energy consumption and how it is divided into heat pump and other consumers can also be seen. If more energy is generated by the photovoltaic system than is consumed, it is fed into the national power grid and can also be seen in the energy monitor.

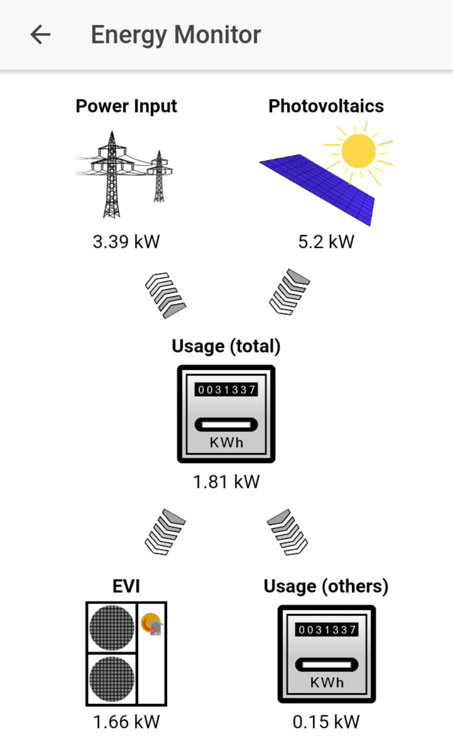
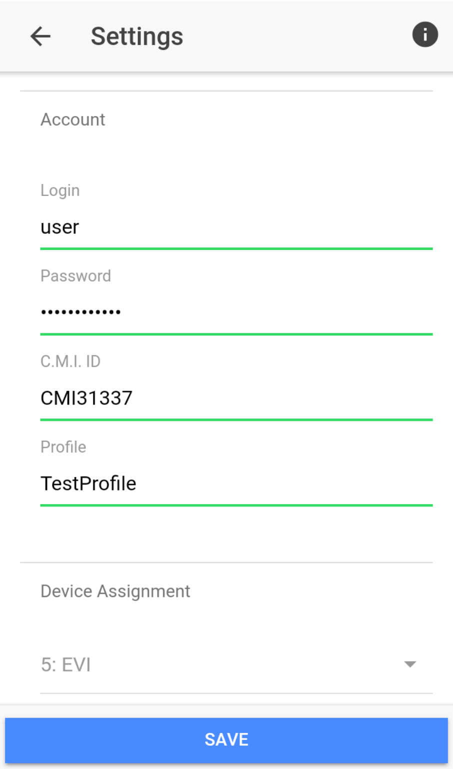


Fig. 5. The “Energie Monitor” shows the energy flow and the interrelationships of individual devices.

If the user has not yet set up the app, the settings are displayed directly at the first start (see Figure 6). The only information users are required to enter are username and password, which they know from their login to the Web portal of ”Technische Alternative” as well as the CMI ID and the name of the profile that can be easily found in the Web portal. The App comes with preconfigured mappings from the most common devices used by the project partner to the displayed variables so that there is no configuration effort here.

VI. LIMITATIONS & FUTURE WORK

The current app does not incorporate all of the aspects Froehlich suggests [12]. The envisioned target group is not known to be excessive users of social media. However, enabling the sharing of energy consumption with friends seems an interesting improvement. It would be even more valuable, but also much more complex to include recommendation for actions that are specific to the sensor readings of the household monitored. Those recommendations must be realizable and not trivial. Otherwise, users will reject them and get a bad impression of the app. Due to the limited amount of time to develop EFM, this aspect was not implemented yet. Once the app has a considerable amount of users, it would be also interesting to offer comparisons between different households. These comparisons only make sense for households that are sufficiently similar. Comparing a three person household with 120 square meters living space to another one with five inhabitants and 180 square meters is nonsense. Therefore, the app needs to collect meta data about the household in order to support such a feature. [32] found that users’ willingness to reduce their energy consumption can be increased from 25% to nearly 60% when appropriate comparison with peer groups is provided. However, the strict data protection rules of the European Union have to be taken into consideration, which might preclude the feedback with name and photo of other users that was used in the mentioned study. Finally, it should also be investigated whether the performance of the app can be further improved. We did not formal evaluation of the user-friendliness of the app, but initial feedback of a few test users was positive.



Account

Login: user

Password: •••••••••••

C.M.I. ID: CMI31337

Profile: TestProfile

Device Assignment

5: EVI

Fig. 6. The user has to enter its credentials, the corresponding identity of the device of the *Technische Alternative* [29], a created profile and the device assignment.

VII. CONCLUSION

This paper introduced *EFM*, a smartphone application that provides a central place for users to view data from their smart devices, especially power consumers and generators. It was developed as a hybrid app using *Ionic*, *Angular* and *Apache Cordova* and is able to run on *Android* and *iOS* devices. Thus, it is no longer necessary to use several different device- or manufacturer-specific apps to display device data. It collects data from different devices like heat pumps, PV collectors and furnace using sensors from *Technische Alternative*, independently of the manufacturer of those devices. Data is made available by *Technische Alternative* in both a web portal in human readable form and an API for consumption in own apps. Our app excels the web portal in providing an integrated view on energy flows between different devices, which is a significant benefit compared to single data of devices.

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REFERENCES

[1] Enerdata, “Global Energy Statistical Yearbook 2018.” [Online]. Available: https://yearbook.enerdata.net/electricity/electricity-domestic-consumption-data.html retrieved: September, 2018.

[2] A. De Almeida, P. Fonseca, B. Schlomann, and N. Feilberg, “Characterization of the household electricity consumption in the EU, potential energy savings and specific policy recommendations,” *Energy and Buildings*, vol. 43, no. 8, pp. 1884–1894, 2011.

[3] T. Crosbie, “Household energy consumption and consumer electronics: The case of television,” *Energy Policy*, vol. 36, no. 6, pp. 2191–2199, 2008.

[4] R. J. Meyers, E. D. Williams, and H. S. Matthews, “Scoping the potential of monitoring and control technologies to reduce energy use in homes,” *Energy and Buildings*, vol. 42, no. 5, pp. 563–569, 2010.

[5] A.-G. Paetz, E. Dütschke, and W. Fichtner, “Smart homes as a means to sustainable energy consumption: A study of consumer perceptions,” *Journal of consumer policy*, vol. 35, no. 1, pp. 23–41, 2012.

[6] S. Darby, “Making it obvious: designing feedback into energy consumption,” in *Energy efficiency in household appliances and lighting*. Springer, 2001, pp. 685–696.

[7] ——, “The effectiveness of feedback on energy consumption,” Environmental Change Institute, University of Oxford, Oxford, UK, A review for DEFRA of the literature on metering, billing and direct displays, 2006.

[8] T. Ueno, F. Sano, O. Saeki, and K. Tsuji, “Effectiveness of an energy-consumption information system on energy savings in residential houses based on monitored data,” *Applied Energy*, vol. 83, no. 2, pp. 166–183, 2006.

[9] W. Abrahamse, L. Steg, C. Vlek, and T. Rothengatter, “The effect of tailored information, goal setting, and tailored feedback on household energy use, energy-related behaviors, and behavioral antecedents,” *Journal of environmental psychology*, vol. 27, no. 4, pp. 265–276, 2007.

[10] K. Steemers and G. Y. Yun, “Household energy consumption: a study of the role of occupants,” *Building Research & Information*, vol. 37, no. 5, pp. 625–637, 2009.

[11] S. Z. Attari, M. L. DeKay, C. I. Davidson, and W. B. De Bruin, “Public perceptions of energy consumption and savings,” *Proceedings of the National Academy of sciences*, vol. 107, no. 37, pp. 16 054–16 059, 2010.

[12] J. Froehlich, “Promoting energy efficient behaviors in the home through feedback: The role of human-computer interaction,” in *Proceedings of the HCIC Workshop*, vol. 9, 2009, pp. 1–11.

[13] L. Bartram, J. Rodgers, and K. Muise, “Chasing the negawatt: visualization for sustainable living,” *IEEE Computer Graphics and Applications*, vol. 30, no. 3, pp. 8–14, 2010.

[14] M. A. Alahmad, P. G. Wheeler, A. Schwer, J. Eiden, and A. Brumbaugh, “A comparative study of three feedback devices for residential real-time energy monitoring,” *IEEE Transactions on Industrial Electronics*, vol. 59, no. 4, pp. 2002–2013, 2012.

[15] T. Ueno, R. Inada, O. Saeki, and K. Tsuji, “Effectiveness of displaying energy consumption data in residential houses. analysis on how the residents respond,” in *Proceedings of the European Council for an Energy-efficient Economy*, vol. 6, 2005, p. 19.

[16] S. S. Van Dam, C. A. Bakker, and J. D. M. Van Hal, “Home energy monitors: impact over the medium-term,” *Building Research & Information*, vol. 38, no. 5, pp. 458–469, 2010.

[17] A. Hashizume, T. Mizuno, and H. Mineno, “Energy monitoring system using sensor networks in residential houses,” in *Proceedings of the 26th International Conference on Advanced Information Networking and Applications Workshops*. IEEE, 2012, pp. 595–600.

[18] D. Petersen, J. Steele, and J. Wilkerson, “WattBot: a residential electricity monitoring and feedback system,” in *CHI’09 Extended Abstracts on Human Factors in Computing Systems*. ACM, 2009, pp. 2847–2852.

[19] M. Weiss, F. Mattern, T. Graml, T. Staake, and E. Fleisch, “Handy feedback: Connecting smart meters with mobile phones,” in *Proceedings of the 8th International Conference on Mobile and Ubiquitous Multimedia*. ACM, 2009, p. 15.

[20] “Blue Line Innovations Inc.” [Online]. Available: http://www.bluelineinnovations.com retrieved: September, 2018.

[21] L. Trenner, “How to win friends and influence people: definitions of user-friendliness in interactive computer systems,” *Journal of information science*, vol. 13, no. 2, pp. 99–107, 1987.

[22] Statista, “Mobile Operating Systems - Market Share Internet Usage in Germany until 2018.” [Online]. Available: https://de.statista.com/statistik/daten/studie/184332/umfrage/marktanteil-der-mobilen-betriebssysteme-in-deutschland-seit-2009/ retrieved: September, 2018.

[23] M. E. Joorabchi, A. Mesbah, and P. Kruchten, “Real challenges in mobile app development,” in *Empirical Software Engineering and Measurement, 2013 ACM/IEEE International Symposium on*. IEEE, 2013, pp. 15–24.

[24] F. Ramisch, “Study: App development costs 30,000 euro on average,” 2015. [Online]. Available: https://mobilbranche.de/2015/07/ibusiness-studie-die retrieved: September, 2018.

[25] M. Latif, Y. Lakhrissi, E. H. Nfaoui, and N. Es-Sbai, “Cross platform approach for mobile application development: A survey,” in *Proceedings of the International Conference on Information Technology for Organizations Development*. IEEE, 2016, pp. 1–5.

[26] T. Majchrzak and T.-M. Grønli, “Comprehensive analysis of innovative cross-platform app development frameworks,” in *Proceedings of the 50th Hawaii International Conference on System Sciences*, 2017.

[27] A. Biørn-Hansen, T. A. Majchrzak, and T.-M. Grønli, “Progressive web apps: The possible web-native unifier for mobile development,” in *Proceedings of the 13th International Conference on Web Information Systems and Technologies (WEBIST)*, 2017, pp. 344–351.

[28] M. Q. Huynh, P. Ghimire, and D. Truong, “Hybrid app approach: could it mark the end of native app domination?” *Issues in Informing Science and Information Technology*, vol. 14, pp. 049–065, 2017.

[29] “Technische Alternative.” [Online]. Available: https://www.ta.co.at/ retrieved: September, 2018.

[30] L. Smirek, G. Zimmermann, and M. Beigl, “Just a smart home or your smart home–a framework for personalized user interfaces based on eclipse smart home and universal remote console,” *Procedia Computer Science*, vol. 98, pp. 107–116, 2016.

[31] K. Lane, “Overview of the backend as a service (baas) space,” *API Evangelist*, 2015.

[32] M. Graffeo, I. Ritov, N. Bonini, and C. Hadjichristidis, “To make people save energy tell them what others do but also who they are: a preliminary study,” *Frontiers in psychology*, vol. 6, p. 1287, 2015.