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Department of the Environment,
Transport, Energy and Communication DETEC

Swiss Federal Office of Energy SFOE
Energy Research

Final report from 31.07.2018

Potential of Energy Aware Devices

and the IoT for a Smart Energy Management

Date: 31. July 2018

Place: Horw

Publisher:
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SFOE contract number: SI/501552-01

The author of this report bears the entire responsibility for the content and for the conclusions drawn therefrom.

Summary

The number of networked devices on the Internet of Things will continue to rise sharply. The computing power of the processors used in the devices is constantly increasing and increasingly enables more complex calculations to be carried out in the device. In the future it will also be conceivable to integrate machine learning algorithms, especially deep learning, into the devices.

Switzerland's Energy Strategy 2050 presents challenges in another area. The main points are lower energy consumption, more renewable energy sources and the phasing out of nuclear power. One of the consequences of implementing the energy strategy is that electrical energy in particular is more volatile than we are used to today. Solutions consist of smart energy management, so that the consumption of electrical energy is better matched to the supply.

One approach to smart energy management is that the detailed energy consumption of individual devices is known, and feedback and energy management systems are implemented on the basis of this information. The energy consumption of individual devices can be determined with sub-metering or load disaggregation algorithms. We follow another approach: Energy aware devices. Such devices know their own energy consumption and can communicate it to the outside world.

We expand the concept of energy awareness: In addition to the current energy consumption, the devices can also provide a forecast of their energy consumption for the next few hours and receive control commands from outside. We consider this a necessary extension to reap all the benefits of having Energy Aware devices. With this extended concept we analyse different scenarios in the living area and estimate the use of energy aware devices. In particular, we deal with the scenarios “Energy Saving”, “µ-Grid” and “Balancing Power”.

The "Energy Saving" scenario is about informing residents in detail and quickly about their energy consumption. This is done with the aim of motivating residents to behave sparingly. In the "µ-Grid" scenario, we consider energy management in a network of energy sources (e.g. solar systems) and consumers in a limited area. Such an area typically includes commercial and industrial buildings as well as apartments. And in the "Balancing Power" scenario we consider the possibility that households and their consumers can also provide balancing energy if a sufficiently large number of households are combined in a pool.

It turns out that predicting energy consumption is an important information for energy management systems, which can make more precise planning and optimization based on it. This applies to the two scenarios "µ-Grid" and "Balancing Power". These two scenarios also depend on the devices being able to receive control commands. Current consumption is required in all three scenarios.

To assess the economic benefits of energy awareness, the possibilities of energy aware devices are compared with other technologies that are suitable for determining the energy consumption of individual devices. In particular, this is the load disaggregation from a total current measurement. In general, the benefits of energy awareness should not be viewed in isolation. To estimate the benefit, the use of energy aware devices must be considered in the context of the respective scenario. We see a high benefit of energy awareness for "µ-Grid" and "Balancing Power" in the scenarios we are considering. The information provided by energy aware devices is important for the respective services in order to achieve the highest possible optimization of energy management. We consider the benefits for "Energy Saving" to be small. The fact that the individual devices provide their own energy consumption hardly influences the motivation to save energy.

For energy awareness to be successful, not only energy aware devices are needed. The devices must be networked so that a service provider can also use these devices for a specific scenario. In order for as many energy aware devices as possible to be connected for a service, the manufacturers of the

devices must be able to adhere to defined protocols. This is the only way to ensure manufacturer-independent compatibility.

Further work is necessary to specify and standardize such protocols and to create optimization algorithms for the respective scenarios. Challenges lie in the potentially high number of devices that can be distributed over a large area. In addition, the needs of customers must be taken into account. For providers of services based on energy aware devices, the challenge is to develop successful business models. Often the problem is to provide customers with a high enough incentive to be willing to participate in the service.

In order to exploit and demonstrate the potential of energy aware devices, we recommend initiating the measures mentioned in the previous section and carrying out further simulations, research projects and pilot tests.

Zusammenfassung

Die Zukunft bringt eine starke Zunahme vernetzter Geräte. Dabei wird kaum ein Bereich ausgeklammert, indem das Internet der Dinge keine Bedeutung erhält. Die Rechenleistung der in den Geräten verwendeten Prozessoren wird laufend höher und ermöglicht zunehmend, auch komplexere Berechnungen im Gerät vorzunehmen. So wird es künftig auch denkbar sein, Algorithmen des maschinellen Lernens, speziell des Deep Learnings, in die Geräte zu integrieren.

Herausforderungen in einem anderen Bereich stellt die Energiestrategie 2050 der Schweiz dar. Die wesentlichen Punkte sind ein geringerer Energieverbrauch, mehr erneuerbare Energiequellen und der Ausstieg aus der Atomkraft. Die Umsetzung der Energiestrategie hat unter anderem zur Folge, dass insbesondere elektrische Energie volatiler zur Verfügung steht, als wir das heute gewohnt sind. Lösungen bestehen in einem smarten Energiemanagement, so dass der Verbrauch von elektrischer Energie besser auf das Angebot abgestimmt ist.

Ein Ansatz smarten Energiemanagements besteht darin, dass von einzelnen Geräten der detaillierte Energieverbrauch bekannt ist und auf Basis dieser Information Feedback- und Energiemanagementsysteme realisiert werden. Der Energieverbrauch einzelner Geräte kann mit Sub-Metering oder mit Lastaufschlüsselungsalgorithmen bestimmt werden. Wir verfolgen einen weiteren Ansatz: Energy Aware Geräte. Solche Geräte kennen ihren eigenen Energieverbrauch und können diesen nach aussen kommunizieren.

Wir erweitern den Begriff der Energy Awareness: Neben dem aktuellen Energieverbrauch können die Geräte auch eine Vorhersage ihres Energieverbrauchs für die nächsten Stunden bereitstellen und von aussen Steuerkommandos empfangen. Dies erachten wir als notwendige Erweiterung, um die Vorteile von Energy Aware Geräten nutzen zu können. Mit diesem erweiterten Begriff analysieren wir verschiedene Szenarien im Wohnbereich und schätzen den Nutzen von Energy Aware Geräten ab. Insbesondere gehen wir auf die Szenarien «Energy Saving», «μ-Grid» und «Balancing Power» ein.

Beim Szenario «Energy Saving» geht es darum, dass die Bewohner detailliert und schnell über ihren Energieverbrauch informiert werden. Dies mit dem Ziel, die Bewohner zu sparsamen Verhalten zu motivieren. Im Szenario «μ-Grid» betrachten wir das Energiemanagement in einem Verbund von Energiequellen (z.B. Solaranlagen) und Verbrauchern in einem begrenzten Areal. Ein solches Areal umfasst typischerweise neben hier im Fokus stehenden Wohnungen auch Gewerbe und Industrie. Und im Szenario «Balancing Power» betrachten wir die Möglichkeit, dass auch Haushalte mit ihren Verbrauchern Regelenergie zur Verfügung stellen können, wenn eine genügend grosse Zahl von Haushalten in einem Pool zusammengefasst wird.

Es zeigt sich, dass die Vorhersage des Energieverbrauchs eine wichtige Information für Energiemanagementsysteme ist, welche darauf basierend eine präzisere Planung und Optimierung vornehmen können. Das betrifft die beiden Szenarien «µ-Grid» und «Balancing Power». Diese beiden Szenarien sind zudem darauf angewiesen, dass die Geräte auch Steuerkommandos empfangen können. Der aktuelle Verbrauch ist in allen drei Szenarien erforderlich.

Um den ökonomischen Nutzen von Energy Awareness abzuschätzen, vergleichen wir die Möglichkeiten von energy aware Geräten mit anderen Technologien, welche zur Bestimmung des Energieverbrauchs von einzelnen Geräten geeignet sind. Insbesondere ist das die Lastaufschlüsselung aus einer Gesamtstrommessung. Generell gilt, dass der Nutzen der Energy Awareness nicht isoliert betrachtet werden soll. Zur Abschätzung des Nutzens muss der Einsatz von Energy Aware Geräten im Kontext des jeweiligen Szenarios betrachtet werden. Bei den von uns betrachteten Szenarien sehen wir einen hohen Nutzen der Energy Awareness für «µ-Grid» und «Balancing Power». Die Informationen, welche energy aware Geräte bereitstellen, sind für die jeweiligen Dienste wichtig, um eine möglichst hohe Optimierung des Energiemanagements zu erreichen. Den Nutzen für «Energy Saving» stufen wir als gering ein. Dadurch dass die einzelnen Geräte ihren Energieverbrauch selber bereitstellen, wird die Motivation zum Energiesparen kaum beeinflusst.

Damit Energy Awareness sich durchsetzen kann, werden nicht nur energy aware Geräte benötigt. Die Geräte müssen vernetzt sein, damit ein Dienstleister diese Geräte auch für ein bestimmtes Szenario verwenden kann. Damit möglichst viele energy aware Geräte für einen Dienst zusammengeschlossen werden können, müssen die Hersteller der Geräte sich an definierte Protokolle halten können. Nur so kann eine herstellerübergreifende Kompatibilität gewährleistet werden.

Es sind weiter Arbeiten nötig, um solche Protokolle zu spezifizieren und standardisieren und um Optimierungsalgorithmen für die jeweiligen Szenarien zu erstellen. Herausforderungen bestehen in der potentiell hohen Anzahl von Geräten, welche über ein grosses Gebiet verteilt sein können. Ausserdem müssen die Bedürfnisse der Kunden berücksichtigt werden. Für Anbieter von auf energy aware Geräten basierenden Diensten besteht die Herausforderung darin, erfolgreiche Geschäftsmodelle zu entwickeln. Oft besteht dabei das Problem, den Kunden einen genügend hohen Anreiz zu bieten, damit sie zur Teilnahme an dem jeweiligen Dienst bereit sind.

Um das Potential von energy aware Geräten auszuschöpfen und aufzuzeigen, empfehlen wir, die im vorigen Abschnitt genannten Massnahmen zu initiieren und weitergehende Simulationen und Pilottests durchzuführen.

Résumée

Le nombre d'appareils en réseau sur l'Internet des objets continuera d'augmenter fortement. La puissance de calcul des processeurs utilisés dans les appareils est en constante augmentation et permet d'effectuer des calculs de plus en plus complexes dans l'appareil. A l'avenir, il sera également envisageable d'intégrer des algorithmes d'apprentissage machine, en particulier l'apprentissage profond, dans les appareils.

La stratégie énergétique 2050 de la Suisse présente des défis dans un autre domaine. Les principaux points sont la réduction de la consommation d'énergie, l'augmentation des sources d'énergie renouvelables et l'abandon progressif de l'énergie nucléaire. L'une des conséquences de la mise en œuvre de la stratégie énergétique est que l'énergie électrique en particulier est plus volatile que ce à quoi nous sommes habitués aujourd'hui. Les solutions consistent en une gestion intelligente de l'énergie, de sorte que la consommation d'énergie électrique est mieux adaptée à l'alimentation.

Une approche de la gestion intelligente de l'énergie est que la consommation d'énergie détaillée de chaque appareil est connue et que des systèmes de rétroaction et de gestion de l'énergie sont mis en œuvre sur la base de ces informations. La consommation d'énergie de chaque appareil peut être déterminée à l'aide d'algorithmes de sous-mesure ou de désagrégation de charge. Nous suivons une autre approche : Dispositifs sensibles à l'énergie (energy aware). Ces appareils connaissent leur propre consommation d'énergie et peuvent la communiquer au monde extérieur.

Nous élargissons le concept de sensibilisation à l'énergie : En plus de la consommation d'énergie actuelle, les appareils peuvent également fournir une prévision de leur consommation d'énergie pour les prochaines heures et recevoir des commandes de contrôle de l'extérieur. Nous considérons qu'il s'agit d'une extension nécessaire pour profiter de tous les avantages d'avoir des appareils sensibles à l'énergy. Avec ce terme prolongé, nous analysons différents scénarios dans la zone d'habitation et estimons l'utilisation d'appareils sensibles à l'énergie. En particulier, nous traitons les scénarios "Économie d'énergie", "μ-Grid" et "Balancing Power".

Le scénario "Économie d'énergie" consiste à informer les habitants en détail et rapidement sur leur consommation d'énergie. Ceci est fait dans le but de motiver les résidents à se comporter avec parcimonie. Dans le scénario "μ-Grid", nous considérons la gestion de l'énergie dans un réseau de sources d'énergie (par exemple les systèmes solaires) et de consommateurs dans une zone limitée. Une telle zone comprend généralement des bâtiments commerciaux et industriels ainsi que des appartements. Et dans le scénario "Balancing Power", nous considérons la possibilité que les ménages et leurs consommateurs puissent également fournir de l'énergie d'équilibrage si un nombre suffisamment important de ménages sont regroupés dans un pool.

Il s'avère que la prévision de la consommation d'énergie est une information importante pour les systèmes de gestion de l'énergie, qui peuvent faire une planification plus précise et l'optimisation basée sur elle. Ceci s'applique aux deux scénarios "μ-Grid" et "Balancing Power". Ces deux scénarios dépendent également de la capacité des appareils à recevoir des commandes de contrôle. La consommation de courant est nécessaire dans les trois scénarios.

Pour évaluer les avantages économiques de la sensibilisation à l'énergie, on compare les possibilités des appareils sensibles à l'énergie avec d'autres technologies qui conviennent pour déterminer la consommation d'énergie de chaque appareil. Il s'agit en particulier de la désagrégation de la charge à partir d'une mesure du courant total. En général, les avantages de la sensibilisation à l'énergie ne doivent pas être considérés isolément. Pour estimer l'avantage, l'utilisation d'appareils sensibles à l'énergie doit être considérée dans le contexte du scénario respectif. Dans les scénarios que nous envisageons, nous voyons un grand bénéfice de la sensibilisation à l'énergie pour le "μ-Grid" et le "Balancing Power". Les informations fournies par les appareils à consommation d'énergie sont importantes pour les services respectifs afin d'optimiser au maximum la gestion de l'énergie. Nous considérons que les avantages pour les "économies d'énergie" sont minimes. Le fait que les appareils individuels fournissent leur propre consommation d'énergie n'influence guère la motivation à économiser de l'énergie.

Pour que la sensibilisation à l'énergie soit un succès, il ne suffit pas de disposer d'appareils sensibles à l'énergie. Les appareils doivent être mis en réseau afin qu'un fournisseur de services puisse également utiliser ces appareils pour un scénario spécifique. Pour que le plus grand nombre possible d'appareils sensibles à l'énergie soient connectés pour un service, les fabricants des appareils doivent être en mesure d'adhérer à des protocoles définis. C'est la seule façon d'assurer la compatibilité indépendamment du fabricant.

D'autres travaux sont nécessaires pour spécifier and normaliser ces protocoles et pour créer des algorithmes d'optimisation pour les scénarios respectifs. Le défi réside dans le nombre potentiellement élevé d'appareils qui peuvent être distribués sur une grande surface. En outre, les besoins des clients doivent être pris en compte. Pour les fournisseurs de services basés sur des appareils sensibles à l'énergie, le défi consiste à développer des modèles d'affaires réussis. Souvent, le problème est de fournir aux clients un incitatif suffisamment élevé pour qu'ils soient prêts à participer au service.

Afin d'exploiter et de démontrer le potentiel des appareils économes en énergie, nous recommandons d'initier les mesures mentionnées dans la section précédente et de réaliser d'autres simulations, projets de recherche et essais pilotes.

Contents

List of abbreviations

4E	Energy Efficient End-User Equipment
API	Application programming interface
BMBF	German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung)
DSG	Data privacy law (Datenschutzgesetz)
DSGVO	General data protection regulation (Datenschutzgrundverordnung)
EA	Energy Aware
EMS	Energy Management System
EU	European Union
EV	Electrical vehicle
HSLU	Lucerne University of Applied Sciences and Arts
IEA	Internation Energy Agency
IoT	Internet of Things
ISP	Internet Service Provider
IT	Information Technology
LoRaWAN	Long range wide area network
NIALM	Non-intrusive appliance load monitoring
PLC	Power line communication
POF	Plastic optical fibre
SFOE	Swiss Federal Office of Energy
TSO	Transmission System Operator
UK	United Kingdom
WAN	Wide area network
WLAN	Wireless local area network

1 Introduction

The population of Switzerland voted for a new energy strategy that promotes renewable energy sources and increased energy efficiency as opposed to new nuclear power plants. To reach the envisioned goals and ensure that we will not be dependent on energy imports, Swiss energy has to be produced, stored and consumed smartly.

Extensive preparatory research has been done in studies targeting smart energy management using various mechanisms for load shifting, demand response, energy forecasting, load monitoring, decomposition and visualisation on different levels of abstraction. Looking at their conclusions, the experts more or less agree: The more detailed and the faster we know where the energy is produced and consumed, the better we can manage it.

In an ideal case, we have information on the type, the operational state and the energy consumption or production of each energy consuming or energy producing device at any point in time and in real-time. These insights have led to the concept of an “energy-aware” device [1], a device that knows and reports this information to a receiver or a chain of receivers able to use it to smartly manage energy. Approaches to identify loads non-intrusively by monitoring them from the “outside” seem promising for the moment [2] but are seen as an intermediate step on the way to the energy-aware device.

The vision of IoT aims at providing each electronic device (or even every-day object) with a communication interface and integrating them in a global information network. One of the most promising uses of the IoT is to monitor the physical world, or a specific domain, in real-time in order to control and optimize existing processes based on current data representing the real situation. Many stakeholders work together on mechanisms and standards in order to make this vision happen. A smart energy-aware device is merely an extension of an IoT-device and may not even involve new Hardware [1].

Of course, does the IoT pose other energy-related questions that would not be there without net-worked objects. An obvious one concerns the energy consumption of the new network nodes themselves and the needed infrastructure in comparison to the potential of the IoT to safe energy through its “smartness” [3]. However, if one assumes that the vision of the IoT will become a reality - as far as it is not already today - energy-awareness will be a prerequisite to manage and safe energy smartly.

This document is structured to reflect the methodology that was chosen in the project. In section 4.1 we analyse the stakeholders’ interests and needs. Here we focus on use cases relevant to energy aware devices in the field of feedback systems and smart energy management. This gives the basis to evaluate the utility of the solutions made available by making devices energy aware. To provide the basis for comparison to a potential new situation, in sections 4.2 to 4.4 we then make a survey of the relevant trends in technology and society, in relation with energy aware devices. The targeted fields comprise technology (e.g. e-mobility), social trends (e.g. sharing economy), technical trends (e.g. use of more renewable energy sources) as well as regulations and strategies from government’s side (e.g. switch off nuclear power stations in Switzerland). In section 5.1 we then develop the relevant use cases, which are relevant applications for the use of energy aware devices created by combining the interests and needs of stakeholders and future trends. In sections 5.2 we then combine the interests, needs and use cases to define the relevant Scenarios. Three of these are then selected to be analysed in more detail in sections 6.1 to 6.3. The analysis comprises the potential of energy aware devices in the respecting scenario, costs and benefits as well as the suitability of devices for the scenario. Based on the analysis, in sections 5.3 to 5.7, the Architecture and Requirements are developed that could form the basis for the solution. In Sections 7 and 8 we proposed solution, draw conclusions and provide suggestions for further work.

2 Context

2.1 Background

The most relevant work in relation to the proposed study was conducted by the IEA-4E resulting in a report with the name: “Energy Aware Devices – Study of Policy Opportunities“ [1]. We take the 4E-study as a basis to go more into detail with a special focus on energy- and technology-related concepts and without touching topics like policy considerations which were already addressed.

2.2 Motivation of the project

The 4E-study [1] focuses on a basic description of the concept of an energy-aware device and its applications, on existing initiatives e.g. of the ENERGY STAR programme addressing the topic and studies policy opportunities in this context.

Standards, policies and incentives for the stakeholders will play major roles as many challenges on the road to energy-aware networks are of non-technical nature. But also the architecture and the communication mechanisms for such a dynamic system, that still shall guarantee security of the energy supply, were not yet studied deeply. This study will look at the potential system architectures and implementation scenarios of such a network of energy-aware devices based on the communication mechanisms of the IoT as far as possible.

2.3 Goals

The goal of this study is to identify the challenges and sketch possible solution scenarios to grasp the complexity and get an overview of the energy-related potential of a smart, networked energy-awareness of devices in and outside the IoT. The results shall be taken to come up with further relevant questions and define the potential next steps to develop the topic further.

The study looks at the challenges and possible solution scenarios on a high abstraction layer to prepare more detailed studies. It shows the complexity and the potential value for an energy aware IoT and the milestones towards its realisation. The study focuses on the potential of energy aware and connected devices for a smart energy management in the residential area.

3 Approach and methodology

Using the information about stakeholders and knowing about their expectations and requirements for energy aware devices and findings about the future development, we developed use cases and scenarios related to a system of energy aware devices.

We then analysed which electrical devices are suitable for the respective scenarios and what the potential of a device is if it is converted into an energy aware device and used in different scenarios.

From use cases, scenarios and suitable energy aware devices we derived the important findings, listed open points and defined the next steps to implement a system of energy aware devices.

Stakeholders Interests and Needs
We determined stakeholders interests and needs by conducting a survey with open questions with the goal to identify relevant use cases. We focused on use cases for energy aware devices in the field of feedback systems and smart energy management.

In feedback systems energy aware devices can inform the user about their current electrical consumption in near real-time. Consumption data can be processed and presented to end-users as statistics through a graphical user interface.

If devices can communicate their current consumption and can give a forecast for energy consumption, a smart energy management can balance the flow of electrical energy for renewable energy sources in a more efficient way. Optimization of energy production and consumption can be just in residential homes but also within a community, village or the grid in large scale.

Trends in Technology and Society
We point out important developments in technology and society by bringing general trends in technology and society into relation to energy aware devices. The targeted fields comprise technology (e.g. e-mobility), social trends (e.g. sharing economy), technical trends (e.g. use of more renewable energy sources) as well as regulations and strategies from government's side (Swiss energy strategy 2050).

The Swiss energy strategy 2050 with the goal to obtain more energy from renewable sources, to use energy more efficient and finally switching off nuclear power plants are only three trends with an impact to systems and services built around energy aware devices. Such devices can support the stabilisation of the electrical network infrastructure and use as much renewable energy as possible by the time renewable energy is available.

Use Cases
We develop relevant applications for the use of energy aware devices by combining the interests and needs of stakeholders and future trends with our experience in smart energy management. Particularly, we consider that energy aware devices do not only provide their current energy consumption but also provide information about the internal state, a forecast of energy consumption and can be controlled remotely and therefore receive commands. The use cases form parts from which scenarios can be developed.

Scenarios
By summarizing stakeholders interests and needs, future trends and use cases we defined different scenarios and selected three of them that will be analysed in more detail. The analysis comprises the potential of energy aware devices in the respecting scenario, costs and benefits as well as the suitability of devices for the scenario.

Architecture and Requirements
We propose a network architecture for a system of connected energy aware devices by building on existing and widespread architectural elements capable to work with a huge number of devices. As one example, the internet as communication network for devices already exists.

We further depict requirements concerning data security, usability, connectivity to the internet and hardware and software interfaces.

Discussion, Conclusion and Outlook
We discuss and summarize the results of the scenarios analyses to depict the relevant findings of energy aware devices. In the outlook we show next steps that are necessary to ease the implementation of services basing on connected energy aware devices.

4 Investigations

4.1 Stakeholders

In this study we target smart energy management systems around connected energy aware devices and focus on the residential area. The stakeholders come from the fields of power generation and distribution as well as manufacturers, service providers, standardisation, government and consumers.

We have identified the following stakeholders:

- Power Utilities
- Transmission System Operators
- Service Providers
- Government / Regulator
- Consumer / End-user
- Prosumer
- Manufacturer
- Facility Management
- Smart Home System / Building Automation System Installer
- Smart Meter Manufacturer
- Standardization Groups
- Associations

To identify the interests and needs of the stakeholders we conducted a survey with open questions. The survey was sent to 136 persons and was answered by 18 persons (13%). We have complemented these answers with outcomes of discussions with customers and our experience in the field of smart energy management.

The interests and needs of the stakeholders are listed below. Further we have identified categories of stakeholders to show the variability in the stakeholder groups

4.1.1 Power Utilities

Interests

- Want to produce electrical energy only if needed. Current consumption data and consumption forecast of energy aware devices – especially those with huge consumption – can help utilities to plan their production.
- If real-time consumption data for shiftable loads are known and those devices can be switched off within short time periods, it can help to adapt the production and stabilize the network.
- Shiftable loads with huge consumption - like boilers, heat pumps, dishwasher, EV-charger – can help to stabilize and plan the production within short time limits if renewable and therefore often unplannable energy sources are used to produce our electrical energy.

Categories

- Large power plant operators
- Smaller and local operators

4.1.2 Transmission System Operators

Interests

- Provide a stable network during normal operation times but also in critical situations.
- Minimize power peaks on the network and try to shift loads into time spots during the day where the network capacity is only partly used (peak clipping).
- Get real-time consumption data and forecast data of shiftable loads to manage peak clipping.
- Remotely switch shiftable loads with renewable energy sources in large scale to manage the balance between production and consumption.
- Stabilize network in crisis situations by switching certain devices on/off and manage the balance between production and consumption.
- Avoid the extension of network infrastructure if peak situations can be minimized.

Categories

- Large network operators
- Local and smaller network operators

4.1.3 Service providers

Interests

- Provide services based on energy aware devices
- Get real-time consumption data and forecast data of relevant energy aware devices.
- Remotely balancing energy aware devices.
- Rely on standardized interfaces.

4.1.4 Government / Regulator

Interests

- Provide a stable infrastructure for citizens and the economy of Switzerland.
- Implement the Swiss Energy Strategy 2050 by improving efficiency of end devices, moving to renewable energy sources and switching off nuclear power stations.
- Support stakeholders with guidelines.

4.1.5 Consumer / End-user

Interests

- Simple installation (plug and play), no maintenance and no additional costs for energy aware devices.
- Get electrical power from stable and reliable electrical infrastructure.
- Dense network of charging infrastructure for EVs.
- Paying affordable prices for electrical energy.
- Get energy from renewable energy sources.

Categories

- Households / residential consumers
- Industrial and commercial consumers
- Customers that care about renewable energy sources
- Price oriented customers where the main focus is to buy cheap electrical energy

4.1.6 Prosumer

Interests

- Simple installation (plug and play), no maintenance and no additional costs for EA devices.
- Want to use as much as possible of their self-produced energy and therefore want to optimize consumption of devices installed in a house with the own production of energy (e.g. solar system).
- Wants a high degree of autonomy.
- Get electrical power from stable and reliable electrical infrastructure if additional energy is needed from the electrical network (e.g. during winter).
- If needed, get energy from renewable energy sources.
- Get an acceptable price from utilities for energy from own production supplied to the grid

Categories

- Households / residential prosumers / single-family houses where producer and consumer are the same.
- A community of prosumers (e.g. apartment house, residential area) where several consumer and producer share an electrical production system and are connected to the main electrical network if own production is not sufficient.
- Industrial and commercial prosumers.

4.1.7 Manufacturers

Interests

- The costs to upgrade a product to an energy aware device should be as low as possible. Since a lot of devices for the consumer market are produced in high volumes, costs for additional functionality are very price sensitive.
- If a product is energy aware it should have a functional advantage compared to devices that are not energy aware or products from competitors. This should increase the number of products sold and the margin.
- Energy aware products having a communication interface could not only transmit data about their energy consumption. They could also log errors and the way they are used in the field. Giving the manufacturer more information about the lifecycle of a product. Of course, end users must know and accept about data being sent to the manufacturer.
- Before devices can be upgraded with a communication interface and the energy awareness functionality is added, it must be clear how the interface to the energy aware infrastructure looks like. Standards must describe all hard- and software interfaces, data protocols, etc. This also applies to systems and services based on energy aware devices.

Categories

Concentrating on manufacturer of devices in the residential area, we see potentially the following categories of devices:

- manufacturers of white goods: washing machine, tumble dryer, dishwasher
- manufacturers of building technology: heat pump, warm water boiler, ventilation, air conditioning, home / building automation systems
- manufacturers of consumer electronics: smart-TV, audio system, game console, set top box, notebook
- manufacturer of network components: router, switch, WLAN access point, NAS
- software manufacturer: managing software needed for services based on energy aware devices

4.1.8 Facility Management

Interests

- Want to know which devices use how much energy at what time within buildings. Special interest is building technology.
- Want to optimize the operation and energy consumption of buildings. The final goal is to optimize the costs to operate buildings.
- If detailed information about energy consumption is available, further investments in renewable energy systems can be planned in an optimized way.

Categories

- Residential settlements are the main scope for this study.
- Office, commercial and industrial buildings are not within the focus of this study.

4.1.9 Smart Home System / Building Automation System Installer

Interests

- Want to install and maintain systems that support an optimized usage of energy. These systems should increase the consumption of locally produced energy and minimize energy costs.

Categories

- Smart home systems for residential settlements.
- Building control and management systems for office, commercial and industrial buildings (not in the scope of this study.

4.1.10 Smart Meter Manufacturer

Interests

- Want to sell metering technology to device manufacturers (energy measurement know-how, hardware chips).
- Want to sell additional metering infrastructure devices to utilities or end customers (e.g. data communication gateways).
- Can sell additional metering services to utilities or other stakeholders (e.g. data aggregation, data storage, data processing knowhow).

Categories

- Manufacturers of metering hardware.
- Companies providing additional metering services and data processing.

4.1.11 Standardization Groups

Interests

- Standards that are accepted worldwide providing interoperability between the different energy aware devices and data processing systems.
- Creating standards to keep installations and maintenance of energy aware devices simple and cheap.
- The standards should guarantee long term operation and compatibility of systems for energy aware devices.

Categories

- IT communication standards especially regarding the content for energy aware devices (accuracy, current consumption, forecast).
- IT security standards
- Data protocol standards
- Standards for electrical installation of energy aware devices

4.1.12 Associations

Interests

- Installations of energy aware IoT devices and additional hardware or services can generate new orders and business for association members.
- Creating and using widely accepted standards simplifies installations and maintenance of energy aware IoT devices.

Categories

- Associations for smart home installations
- Electrical installations
- Grid systems
- Telecommunication associations

4.2 Trends

For the future, we see the following trends related to our electrical energy supply and having an influence on the use of energy aware and remotely controllable IoT devices. The order of the following sections does not reflect their priority.

4.2.1 Energy strategy 2050 in Switzerland

Following the reactor disaster of Fukushima in 2011, the federal council and parliament decided on Switzerland's progressive withdrawal from nuclear energy production. This decision, together with further far-reaching changes in the international energy environment, requires an upgrading of the Swiss energy system. For this purpose, the Federal Council has developed the Energy Strategy 2050 [7] with the cornerstones increase of efficiency, increase of renewable energy sources and withdrawal from nuclear energy.

4.2.2 Networking of devices – Internet of things (IoT)

The increasing number of end devices connected to a local network or the internet enables the possibility, that these devices can inform the user, the utility, a community connected to a µ-grid, etc. about their state and energy consumption.

The forecast for the number of IoT devices used by 2020 differs massively [13]. But one can see that more and more household devices (e.g. washing machine, dishwasher, robot lawn mower / vacuum cleaner, coffee machine, etc.) on the market are equipped with a data communication interface. Today mostly the more expensive models are having a communication interface as an option, but in the future also cheaper models will have a data communication interface built in [14].

The Gartner Hype Cycle for emerging technologies [15] underlines the importance of IoT platforms for the future and sees the digitalisation as one of the three main trends.

4.2.3 Battery storage will become cheaper

The price of lithium-ion batteries for EVs has fallen from about 1000 USD/kWh in 2010 to around 200 USD/kWh in 2017. To be competitive with gasoline prices in the US, prices of battery packs for EV must fall between 125 – 150 USD/kWh. Analysts have forecast that this price parity can be achieved by 2020 [9].

In South Australia several projects using large-scale lithium-ion energy storage technologies to ensure electrical power supply have been started [10]. The battery will provide balancing services to the grid – rapid injections of supply and demand, and an ability to correct fluctuations in frequency through the ancillary services market. By 2017 the prices of lithium-ion batteries have dropped to a value, where a real business case begins to emerge for the commercial operation of grid batteries.

The installation of a battery storage together with a solar system at home tends to become increasingly lucrative due to rising energy prices, falling battery prices and falling payments for solar power from the utility companies. More than 50% of new solar systems installed in Germany in 2016 already included a battery [11].

4.2.4 Increase in electric mobility

Electrical vehicles (EVs) will partly replace the cars on the road today in the near future. The report from EBP [8] describes scenarios about the development of electric mobility for Switzerland. These scenarios see that by 2035 more than 50% of new cars sold in Switzerland will be EVs.

4.2.5 Cloud services

Cloud services today enable a ubiquitous access to shared pools of system resources and IT services. For end users today and even more in the future, cloud services will not be recognized as services that are running somewhere on a server farm connected to the internet. It is just normal to use them.

Since cloud platform are cheap to use (compared to run own hardware infrastructure), it would seem obvious to store data of energy aware devices on a cloud storage and analyse the energy consumption data using computer power of servers running on a cloud datacentre.

Concerns about data security and privacy are reasons, why companies or individuals renounce to use cloud services.

4.2.6 IT security

An unpleasant part of our digital world unfortunately is the aspect of cybercrime. Data theft of login credentials, credit card numbers, cryptojacking, etc. and blackmailing using ransomware or denial of service attacks – to name a few examples of the “business models” for cybercriminals – are common attacks today. These attacks can also threat critical infrastructure like energy supply systems or medical care. Especially if we are thinking about IoT devices which could be controlled remotely.

The Swiss “Reporting and analysis centre for information assurance” (MELANI) publishes semi-annual reports regarding the situation about IT security in Switzerland and internationally [16]. “HACKMAGEDDON” [17] reports statistics and trends about cyber-attacks. Apart from cybercrime – that is responsible for more than 80% of all attacks nowadays – other objects like cyber espionage or cyber warfare are used as motivation for attacks.

The daily press releases about surveillance, cyber-attacks and security flaws in soft- and hardware are making people sceptical about devices that capture personal data continuously and everywhere. Data protection laws like DSG 235.1 in Switzerland [18, p. 1] or DSGVO in Europe [19] shall protect citizens and companies from unauthorized gathering of data. To handle the data of energy aware devices we see that utilities – as an example – cannot collect personalized energy consumption data in large scale from all devices of their customers, if customers do not explicitly allow the utility to store and process these data.

4.2.7 Energy consumption per device decreases

Electrical appliances are becoming increasingly efficient. Although the total number of appliances in Switzerland has increased by more than 46% in the last thirteen years, their electricity consumption has fallen by 455 GWh per year (- 5.9%) over the same period [20]. This is shown by an analysis of the electrical appliances sold in Switzerland carried out on behalf of the Swiss Federal Office of Energy.

4.2.8 Growth of prosumers to maximize self-consumptions

According to a current study by the German Federal Ministry of Education and Research (BMBF), the number of prosumer households in Germany could rise to over 10 million by 2030, which could have a drastic impact on the energy market [34].

Other studies assume that the rate of self-consumed electricity by prosumers in Germany, Italy and the UK will increase to over 2.5 percent of total final electricity consumption by 2020, with more than 25 TWh of electricity being generated and consumed locally, which will increase the demand for smarter solar building solutions to balancing energy usage [35].

4.2.9 Liberalisation of the electricity market in Switzerland

The Swiss electricity market is to be opened up gradually [21]. Since 2009, large consumers (from 100'000 kWh per year) have been able to select their own electricity suppliers. In future, all end customers in Switzerland will have this option. The full opening of the electricity market will depend on developments in the energy strategy 2050, the market environment and the negotiations for an electricity agreement with the EU.

If customers can choose the electricity suppliers, it is possible that complex tariff models will be introduced to the market and replace the simple and often used two-tariff model today. If more energy is produced from unpredictable renewable energy sources, more flexible tariffs (e.g. energy consumption-related and with a 24 h forecast) might be introduced.

With an electricity market that is more open, having more renewable energy sources and a huge number of energy aware and remotely controllable devices, there is a chance that more companies will sell balancing energy [22] by integrating controllable devices into a network. Of course, end customers that finally offer to use their controllable devices (e.g. boiler, heat pump, dishwasher, battery) for balancing energy need to get a decent payback.

4.2.10 Machine Learning

Artificial intelligence and in particular machine learning algorithms can be used in IoT networks to predict the future power consumption of IoT devices and thus enable energy-efficient use [23]. In smart homes, self-learning algorithms can be used to optimize IoT devices for energy-efficient use [24]. There is also research on the extraction and annotation of sensor-based data for energy awareness so that the results can be better analysed with the help of algorithms and tools. [25].

In the past, numerous machine learning algorithms for data analysis of IoT devices have been developed. By 2020, the total number of devices with Internet access is estimated at 25 to 50 billion and it is becoming apparent that the evaluation of these big data can be handled particularly well with the help of machine learning technologies, which should also have improvements in the energy-efficient management of Energy Aware IoT devices [26].

4.2.11 Growth of subsidy-free renewable energy

Although a completely subsidy-free market for renewable energies is still a long way off, there is growing evidence that non-subsidized renewable energy systems is worthwhile.

For example, the UK is well on its way into a new era of subsidy-free renewable energy projects. Lower costs of wind and solar projects combined with advances in battery storage technology could make onshore wind and solar in the UK viable until 2025 without subsidies [27].

In the Netherlands, an offshore wind farm is currently being planned 22 km off the coast, which will go into operation in 2023 without state support. The plant will have 90 turbines with an output of up to 750 MW - enough to produce electricity for up to 2 million households [28].

In Southern Europe there has been a massive increase in subsidy-free solar energy projects in recent months. In Portugal, Spain, Italy and France, for example, more than 2.5 GW of subsidy-free solar energy capacity has been announced [29].

4.2.12 Global warming and climate change

Global warming is defined as the phenomenon of increasing average air temperature near the surface of the earth over the past one or two centuries [4]. Certain climate changes that have taken place since industrialisation can only be explained in terms of the increase in greenhouse gases and effects can also be seen in Switzerland [5].

To reduce the greenhouse gas emissions worldwide, a new climate agreement was passed at the climate conference in Paris at the end of 2015. Switzerland ratified the Paris Convention on 6 October 2017 [6]. For the objectives of the Paris Agreement to be achieved, Switzerland must also reduce its CO_2 emissions. For example, by replacing oil or gas heating systems or switching to electric vehicles.

4.2.13 Growing population

The worldwide population has been growing exponentially during the 19th and 20th century and this process is still going on, especially in third world countries [12]. A growing population means also an increasing amount of energy being used.

Together with a growing population one can see also demographic change in population. More and more elderly people will be using electrical devices. If these devices were energy aware and could communicate about their energy use and current state, one can think of use cases where these devices can support the life of this population group. As an example: if someone forgets to switch off the stove, an energy aware device combined with an application in the background could recognize this, switch off the stove to prevent a fire and trigger an alarm message.

4.3 Standards and Protocols

4.3.1 Introduction

Standardized technologies and protocol stacks used for IT- or Smart Home-Networks should be used for data communication between energy aware devices and gateways or the internet itself. For protocols listed below, we reduced the list of possible networks to those who are standardized and commonly used and accepted within homes or for wide area networks. The reason for that is that users do not invest in a communication infrastructure only used by energy aware IoT devices, if another communication infrastructure is already installed.

In addition, the communication channels and protocols used must guarantee confidentiality, integrity and availability to be accepted in the market. The installation process must be simple and provide “plug and play” functionality – either for the owner itself or a technician who installs an energy aware device.

Most Smart Home systems are already able to measure and log energy consumption. Figure 1 below shows an example of a switchable power plug, which also measures energy consumption and can be integrated into a Smart Home system – for this example through a WLAN network. If the measurement and communication technology of a switchable power plug is integrated into a device, this device will be an energy reporting device, measuring and logging instantaneous energy consumption values. For energy aware devices an energy consumption forecast is a further function to implement.

Figure 1: Example of a Wi-Fi-Switch/Plug with energy measurement functionality

In the following chapters 4.3.2 and 4.3.3, we differ between short- and long-distance-range communication standards and protocols as well as for wired and wireless technologies, which could be used as data communication technologies for energy aware devices.

4.3.2 Short distance networks

With short distance networks, we mean technologies typically used to communicate within a house or an apartment.

Wireless Networks

Widely used and standardized wireless networks that could transmit data of energy aware devices, are: IEEE 802.11 (WLAN / Wi-Fi), Bluetooth, IEEE 802.15.4, ZigBee, Thread, Z-Wave, EnOcean and DECT ULE.

Wired Networks

Similar to the list for wireless networks above, also standardized wired network technologies and protocols could be used to transmit data of energy aware devices: IEEE 802.3 (Ethernet), PLC (e.g. HomePlug), KNX and Modbus.

4.3.3 Long distance networks (“out of house” / WAN)

To communicate data measured by energy aware devices “out of the house”, common wide area network (WAN) infrastructure from internet service providers (ISP) shall be used. This could be: DSL, cable TV access or fibre to the home.

For wireless WAN communication, the following technologies could be considered: 3G / 4G / (5G in the future) mobile phone standard, LoRaWAN, NB-IoT or Sigfox.

For low power wide area networks like LoRaWAN, Sigfox or NB-IoT certain limitations occur. Especially the length and the number of messages that can be transmitted are very limited for LoRaWAN and Sigfox (e.g. 140 uplink / 4 downlink messages per day). The limitations are mainly due to duty cycle of 1% (for sensors and gateways) because of the used ISM band.

4.3.4 Application layer protocols

Depending on network technology used for lower OSI layers, many different protocols on the application layer can be used. If the underlying network layers are based on the IP protocol, common application layer protocols and data structures to transmit energy measurement data are: HTTP(S), CoAP, MQTT, JSON and XML.

Other networks like ZigBee, Z-Wave, EnOcean, DECT, ULE … use their own protocols on the application layer: ZigBee Profiles, Z-Wave Protocol, EnOcean Equipment Profile and ULE Profile.

An application layer protocol combining multiple technologies is BACnet. BACnet was designed to allow communication of building automation and control systems for applications such as heating, ventilating, and air-conditioning control (HVAC), lighting control, access control, and fire detection systems and their associated equipment. The BACnet protocol provides mechanisms for computerized building automation devices to exchange information, regardless of the particular building service they perform.

4.3.5 Additional standards and protocols for smart grid support

EEBUS (www.eebus.org)

Goal of the EEBUS initiative is to interconnect different platforms for smart homes or smart grid. *"EEBUS is opposing the confusing array of protocols with a global language for energy."*

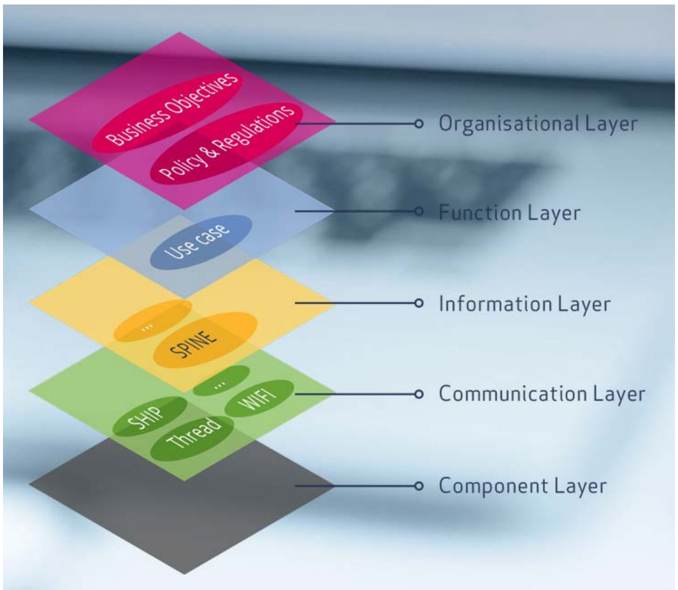

Figure 2: EEBUS layers

The EEBUS concept describes the abstraction and consolidation of existing established standards of in-house communication and offers the IP world an interface to the home, with the aim of enabling energy suppliers and households to exchange applications and services to increase comfort and efficiency. For this purpose, the EEBUS provides an application-neutral, standardized interface. A physical protocol (how bits are transmitted) and a semantic protocol (which bits result in a price signal for example) are defined.

Flexiblepower Alliance Network (FAN) (http://flexible-energy.eu/)

The Flexible Alliance Network has introduced a couple of software solutions and protocols listed below. Goal is to reach flexibility for the process of energy transition to renewable energy sources. Projects using FAN software frameworks and protocols have been realized in Denmark or the Netherlands for example.

- EFI (Energy Flexibility Interface) (http://flexible-energy.eu/efi/)

  EFI is a communications protocol to control multiple smart appliances (dish washers, heating, airconditioning, solar panels, car charging). All in order to signal the smart grid its energy flexibility. Because EFI is not interfering the control of the device itself, nor how the Smart Grid Technology works, it has the potential to become a universal language for all Smart Grid Services dealing with Energy flexibility.

- PowerMatcher: (http://flexible-energy.eu/powermatcher/)

  The PowerMatcher is a smart grid coordination mechanism. It balances Distributed Energy Resources (DER) and (flexible) loads. It can also be herded among Demand Response systems, but with a radical new vision. A vision we call Smart Transactive Energy.

  The PowerMatcher concept is based on the micro-economic principle of demand and supply. Supply and demand is one of the most fundamental concepts of economics and it is the backbone of a market economy. The PowerMatcher core application provides the market mechanism for the determination of the market equilibrium, while the devices, DER and flexible loads, work as actors for demand and/or supply.

  The PowerMatcher has been successfully tested and implemented in numerous test-beds in the Netherlands, Germany and Denmark, showing benefits for all stakeholders in the system, the prosumer, grid operator, and aggregator. From these test-beds we have developed a new learning; which we call the Energy Flexibility Interface (EFI), even more fundamental than the PowerMatcher.

- EF-Pi (http://flexible-energy.eu/ef-pi/)

  Formerly referred to as FPAI – is the software platform that makes it easier to connect Smart Home Appliances to a smart grid. Manufacturers can easily install drivers to connect the device to EFI. With a user-friendly interface, EF-Pi can easily be configured to various home appliances. EF-Pi runs on a small computer (like a Raspberry Pi), which in turn is connected to all your smart devices (via Bluetooth, WiFi or Zigbee) and with the smart grid via internet.

  The result: users can configure the appliances to their own needs/usability, monitor their energy consumption and choose with which Smart Grid they want to connect to.

Open Automated Demand Response (OpenADR) (http://www.openadr.org/)

OpenADR is an open and standardized way for electricity providers and system operators to communicate DR signals with each other and with their customers using a common language over any existing IP-based communications network, such as the Internet. As the most comprehensive standard for Automated Demand Response, OpenADR has achieved widespread support throughout the industry. The OpenADR standard provides energy suppliers with a standardized way to send fast, reliable and secure price and event messages to a wide variety of customer installed equipment such as rooftop solar, onsite energy storage, electric vehicle charging stations and energy management systems.

The OpenADR Alliance (located in San Ramon CA / USA) was formed 2010 by industry stakeholders to build on the foundation of technical activities to support the development, testing, and deployment of commercial OpenADR and facilitates its acceleration and widespread adoption.

Project Haystack (https://project-haystack.org/)

Project Haystack is an open source initiative to streamline working with data from the Internet of Things. We standardize semantic data models and web services with the goal of making it easier to unlock value from the vast quantity of data being generated by the smart devices that permeate our homes, buildings, factories, and cities. Applications include automation, control, energy, HVAC, lighting, and other environmental systems.

4.4 IT security

4.4.1 Cyber-attacks as general risk for all scenarios with energy aware devices

Energy aware devices are also a risk, because the electrical energy supply is part of our critical infrastructure and could be abused for criminal attacks. If devices with high loads can be controlled remotely, they could be used by cyber criminals to attack the stability of the electrical network, if groups with large numbers of such devices are switched on or off remotely.

Devices that communicate continuously the current consumption provide a lot of information about the inhabitants of a house or flat. Is someone at home? When did someone cook a meal last time? How often does the water boiler heat up? Since these are all personal data belonging to the inhabitant itself, privacy, data protection and integrity must be guaranteed for data being sent from energy aware devices.

Therefore, great care in terms of cyber security should be taken if a system of energy aware devices is being implemented and rolled out.

4.4.2 Data security and safety

In terms of data safety and security, energy aware IoT devices and all the hard- and software-system needed to implement the required functionality do not differ from other secure IoT systems and projects. For this report, we do not describe in detail and down to the bit-level of a data protocol how security shall be implemented.

The following standards and guidelines can be considered to help building and certifying a safe and secure system infrastructure of connected energy aware IoT devices: ISO/IEC 27000 family [36], BSI standards [37], NIST cybersecurity framework [38] and ISF Standard of Good Practice [39].

4.4.3 Data privacy policies

Regarding smart metering systems there are different laws existing in countries regarding privacy and data protection of meter readings. To install energy aware systems, one has to consider the different rules that can be applied. The following links inform about smart meter usage and installation in Germany or Switzerland regarding data protection rules and security: BSI Smart Metering Systems

[40], BFE Report «Schutzbedarfsanalyse Smart Metering in der Schweiz» [41] and EDÖB «Der Einsatz von digitalen Stromzählern» [42].

Because an energy aware device system does collect and log consumption data of single devices and not the total of a household – like a smart meter – one can log very detailed information of user behaviours and data protection rules applying for smart meters might even be more restrictive.

5 Concepts & Feasibility

5.1 Use cases, preconditions and opportunities

5.1.1 Applications with energy aware devices

Based on inputs from stakeholders, research and trends we see that the following use cases or applications could be realised with a system of energy aware devices. They range from load management over control of the energy aware devices for a certain service up to recognizing activities of daily life:

- Break down consumption (energy / costs)
- Collect data for optimization (energy / costs)
- Optimized control of devices
- Create device classes (energy efficiency label)
- Detect defective devices
- Integrate load control into SmartHome
- Record measurement data to balance energy
- Implement optimization of own consumption (apartment building, district)
- Optimize operations
- Advise customers (to optimize operation)
- Control critical infrastructure
- Recognize activities of daily life

5.1.2 Preconditions

The energy aware devices itself need to contain the following features to implement use cases or applications described above:

- Device announces his energy consumption
- Device announces his energy consumption forecast
- Control device via communication interface

Apart from technical features implemented in energy aware devices further preconditions need to be defined to successfully install a system of interoperable energy devices and services:

- Define requirements & standards for measurement accuracy
- Define requirements & standards for data security
- Define "in-house" data communication standards
- Define data communication standards for misc. electricity network layers

5.1.3 Opportunities

If the preconditions mentioned above are fulfilled, the following business opportunities are ready to implement the applications mentioned in chapter 5.1.1:

- Develop submetering modules for devices
- Develop SmartHome gateways (cross-platform)
- Develop data concentrators / gateways for metering infrastructure
- Develop components to optimize own consumption
- Develop software for energy aware services

5.1.4 Overview

The scenarios developed in the next chapter consist of a selection from applications, preconditions and business opportunities mentioned above. The following Figure 3 summarizes them and you will find a description of the elements in more details in chapter 10.1.

Applications		Preconditions	Opportunities
Break down consumption (energy / costs)	Record measurement data to balance energy	Device announces his energy consumption	Develop submetering modules for devices
Collect data for optimization (energy / costs)	Implement optimization of own consumption (apartment building, district)	Device announces his energy consumption forecast	Develop components to optimize own consumption
Optimized control of devices	Optimize operations	Control device via communication interface	Develop software for energy aware services
Create device classes (energy efficiency label)	Advise customers (to optimize operation)	Define requirements & standards for measurement accuracy	Develop data concentrators / gateways for metering infrastructure
Detect defective devices	Control critical infrastructure	Define requirements & standards for data security	Develop SmartHome gateways (cross-platform)
Integrate load control into SmartHome	Recognize activities of daily life	Define "in-house" data communication standards	
		Define data communication standards for misc. electricity network layers	

Figure 3: Applications, preconditions, opportunities

5.2 Scenarios

Respecting stakeholder's interests and needs and trends we identified several scenarios in which connected energy aware devices can be beneficial. Each scenario describes an implementation of a service relying on energy aware devices.

Optimize own consumption

If devices in a house can communicate their current or planned electrical consumption, "prosumers" like owners of solar systems are able to optimize the use of renewable energy sources in a more efficient way. The goal of this scenario is to use as much energy from the solar system as possible within the owner's house (e.g. for heat pump heating systems, water boiler, dishwasher …).

μ-Grid

If a solar system belongs to a μ-Grid and the produced solar energy is consumed by a community the basic goal is the same as with scenario above: use as much renewable energy as possible within the μ-Grid. Energy aware devices can help to balance the flow of renewable energy in μ-Grid.

Living in old age

For elderly people living alone in their own flat or house, energy aware devices can help recognizing activities of their daily life or detecting dangerous situations. E.g., cooking stove not switched off, light in bathroom has not been used for a certain time, etc.

Energy saving

Energy aware devices can tell very detailed when and how much energy they have used. This helps to inform people how much electricity every device has consumed and how much the energy consumption of a device costs.

If we see more flexible tariffs for electrical energy in the future, people can be supported in their awareness and might use devices when there is a lot of renewable energy available and the costs for energy are low.

Management of real estate

If real estate managers know in more details which devices (e.g. heating system) use energy and at which time, they are able to optimize the costs for electrical energy – even without an own solar system. If tariffs for electrical energy are getting more flexible, energy aware devices can help using electrical energy as soon as it is available at good conditions.

Balancing power

Devices with high loads (e.g. water boilers, heat pump heating systems) that can be switched off/on remotely and can communicate their current consumption and state, can offer balancing energy to the utilities. Depending on the current state of a device its behaviour can be controlled by utilities and/or network operators to stabilize the network infrastructure.

Avoid peak loads, stabilize network, load balancing

Devices with high loads (e.g. water boilers, heat pump heating systems, air conditioning systems) that can be switched off/on remotely and can communicate their current consumption and state can be used to stabilize the network and avoid peak loads, if the utility or network operator is allowed to control them remotely.

Switch devices / groups of devices in crisis situations

In critical or crisis situations, groups of energy aware devices with remote control interface can help the utility or network operator to stabilize the network. Devices with high loads (e.g. water boilers, heat pump heating systems, air conditioning systems) could be grouped and switched off/on to operate the network in a way, where the production and consumption of electrical energy are balanced.

5.2.1 Selection

For a deeper analysis, we have selected three scenarios in such a way that as many stakeholders as possible are involved and their interests are taken into account. In addition, the selected scenarios should cover the widest possible range of scaling of a service based on energy aware devices. The selected scenarios shall target a smart energy management. The most relevant scenarios are: “Energy saving”, “μ-Grid” and “Balancing power”.

Energy Saving

The scenario regards a single household with its habitants as main stakeholder. A feedback system that helps the habitants to save electrical energy considers appliances in one household. Other stakeholders involved are mainly standardisation bodies, the government that want people save energy, manufacturers that sell energy aware devices and providers of the feedback system.

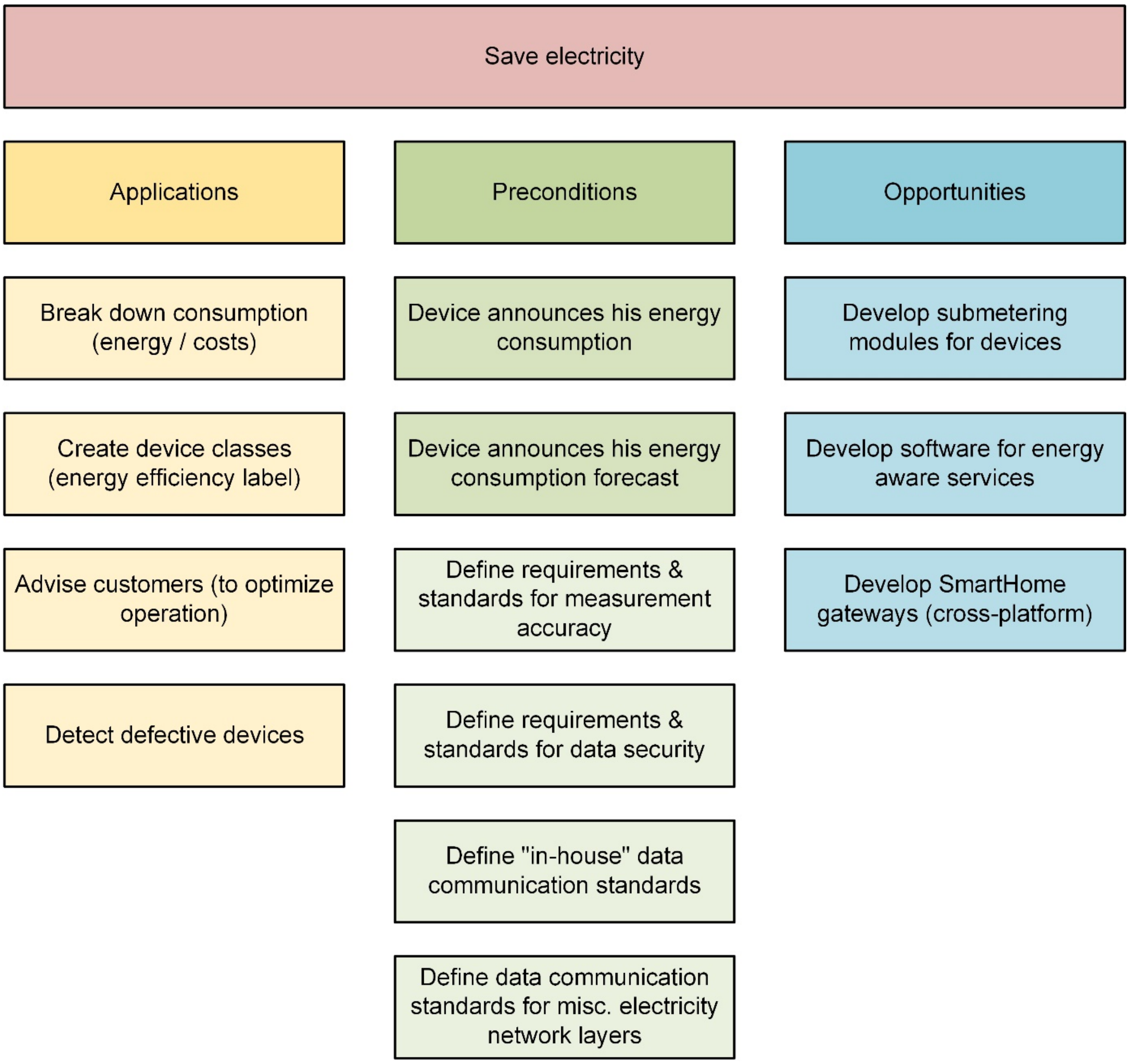

Figure 4: This graphic shows the possible applications, needed preconditions and business opportunities that are relevant to implement the scenario “energy saving”.

μ-Grid

The main stakeholder in a μ-Grid is its operator who wants to optimize the energy flow inside the μ-Grid. The μ-Grid consists of several apartments with all the connected appliances. The number of appliances is in the medium range and all the appliances are locally close together. Involved stakeholders, additional to the previous scenario, are mainly the operators of a μ-Grid.

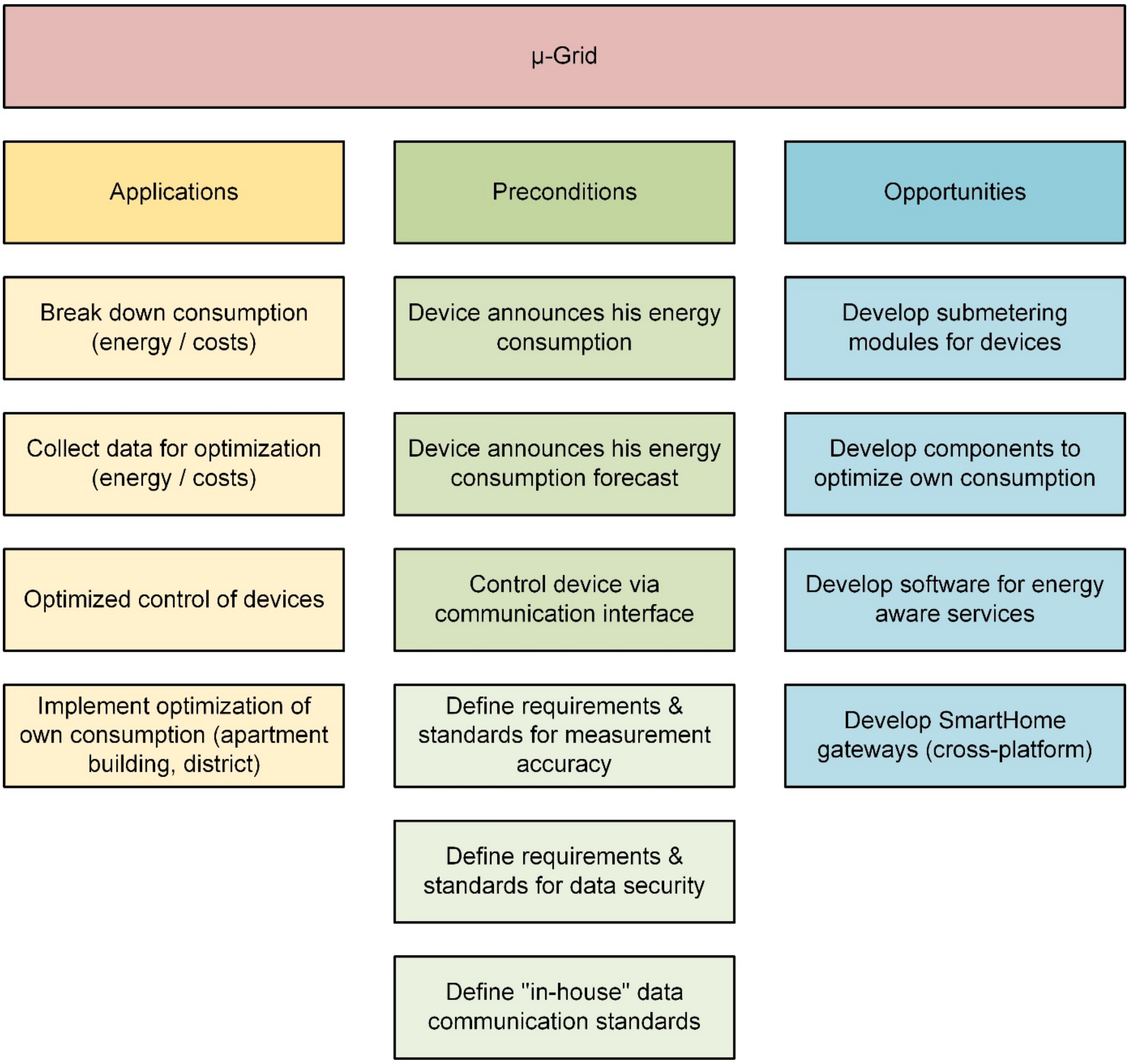

Figure 5: This graphic shows the possible applications, needed preconditions and business opportunities that are relevant to implement the scenario “μ-Grid”.

Balancing power

In this scenario we see a large-scale distributed network of a high number of connected devices forming a pool. The main stakeholder is the provider of balancing power, who does not own the connected appliances. The devices in the pool can be distributed over a large area. In this scenario the transmission system operator (TSO) is an additional stakeholder.

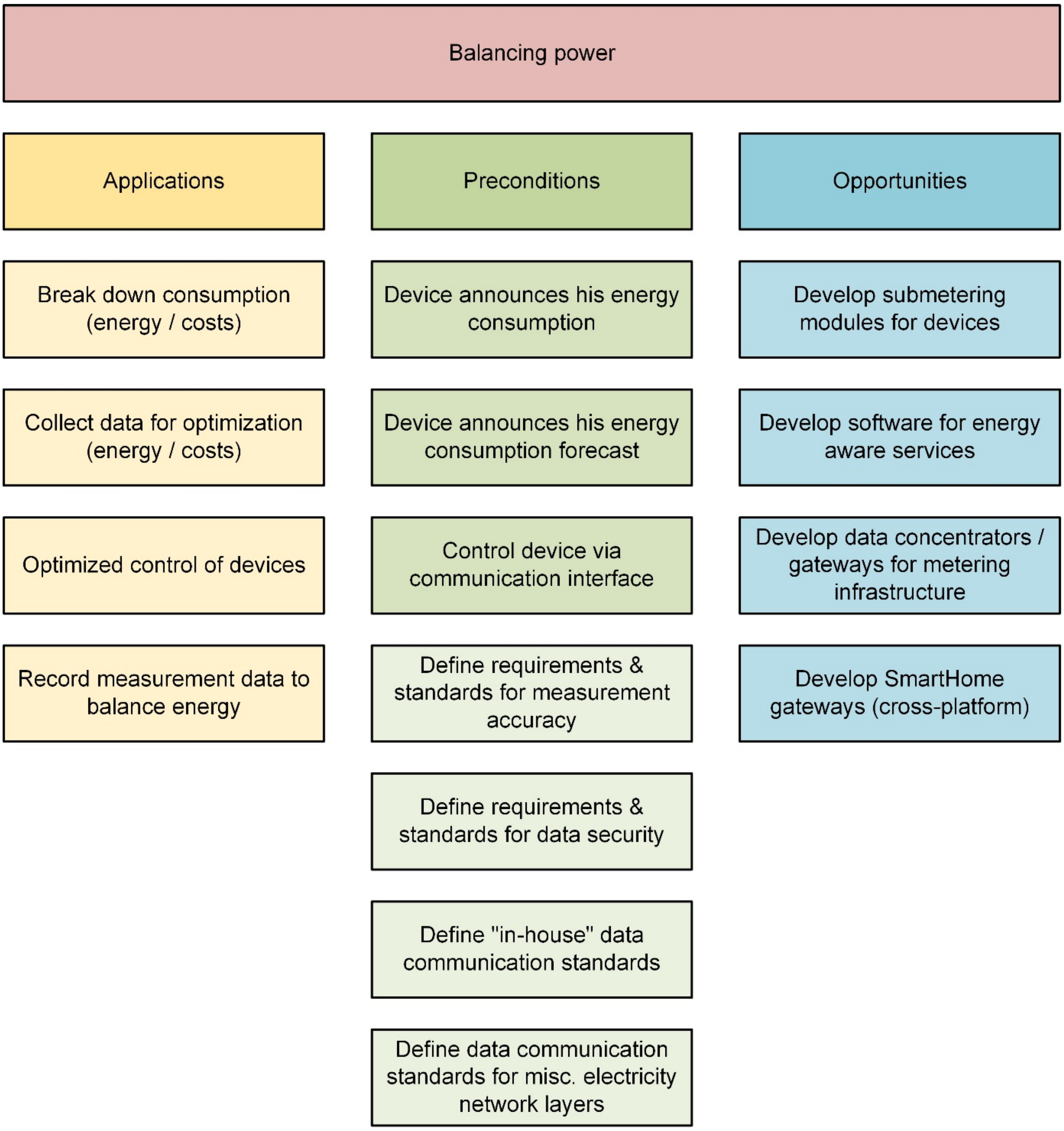

Figure 6: This graphic shows the possible applications, needed preconditions and business opportunities that are relevant to implement the scenario “balancing power”.

5.3 Systems Architecture

5.3.1 Network architecture

Based on these scenarios we designed a data communication network architecture as shown in Figure 7. Of course, not all possible electrical devices within a household are displayed here, but the different aspects of data communication, storage and processing we would like to present in the following chapters referencing to Figure 7.

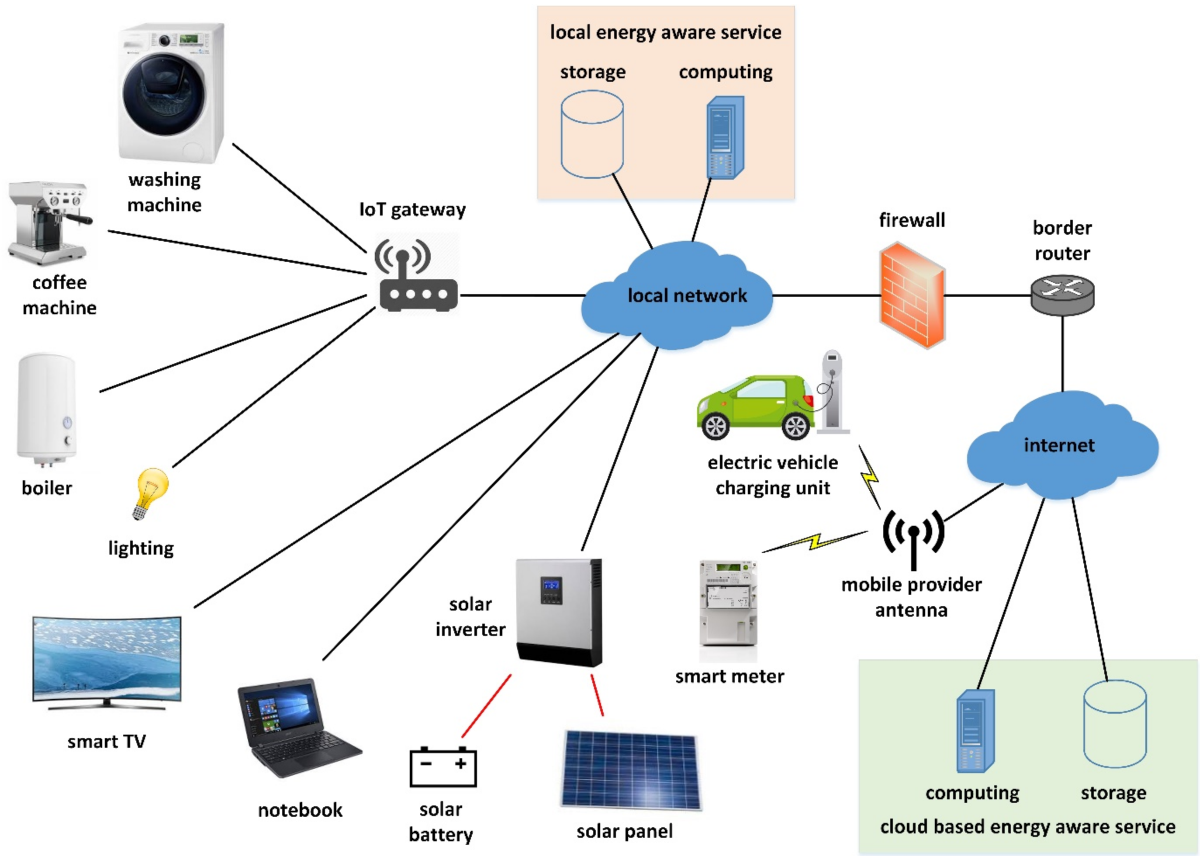

Figure 7: Network architecture including the energy aware service that can either run on local hardware or in the cloud

It is important to know, that end users don't want to spend money for an extra infrastructure that is used by energy aware devices only. The devices should connect to the existing network infrastructure which is common to most households today. Often having a WLAN border router and firewall to the internet service provider installed. Plug and play functionality should be implemented for the end devices for the installation whenever possible. If the installation is too tediously end users would not accept this.

The first criterion is how energy aware devices are connected to the data network (5.4) and with a second criterion we differentiate whether data services are being stored and processed locally or in the cloud (5.5).

5.3.2 Communication architecture

In Figure 8 the communication in a system built on connected energy aware devices (EA service) is shown as a sequence diagram. The communication can be differentiated into categories:

1. Data direct from device to the EA service

   The energy aware device sends its information via IoT gateway (if applicable) and firewall to the EA service which then stores the data for further evaluation (see 1 in Figure 8).

2. Data from device via a third-party cloud service to the service

   The energy aware device sends its data via IoT gateway (if applicable) and firewall to its third-party cloud service. An example is a smart-plug that is connected to the manufacturers cloud service. The EA service then requests data from the third-party cloud service so that it can store the data for further evaluation (see 2 in Figure 8).

3. Data from EA service to the device

   The EA service sends data via firewall and IoT gateway (if applicable) back to the energy aware device, for example to inform the user about the planned run-time of the appliance (see 3 in Figure 8).

4. Data from EA service to a display (e.g. an app on a smart phone)

   The user can request data, for example the actual power consumption of an appliance. The request is forwarded to the EA service via a firewall. The EA service then sends back the requested data via a firewall to a display that can be a dedicated display or an app on a smart-phone (see 4 in Figure 8).

5. Data from a superior service to the EA service

   If the EA service needs information from a superior service, e.g. from a TSO, the information is requested by the EA service and sent back to it by the superior service (see 5 in Figure 8).

6. Control commands from EA service to device

   After evaluating received data, the EA service sends control commands via a firewall and an IoT gateway (if applicable) to the energy aware devices (see 6 in Figure 8).

In Figure 8 the EA service is shown as one unit. The service can be composed of more than one element, for example the storage and the processing could be different parts of the service. For several cases sequence diagrams are described in more detail in 10.2.

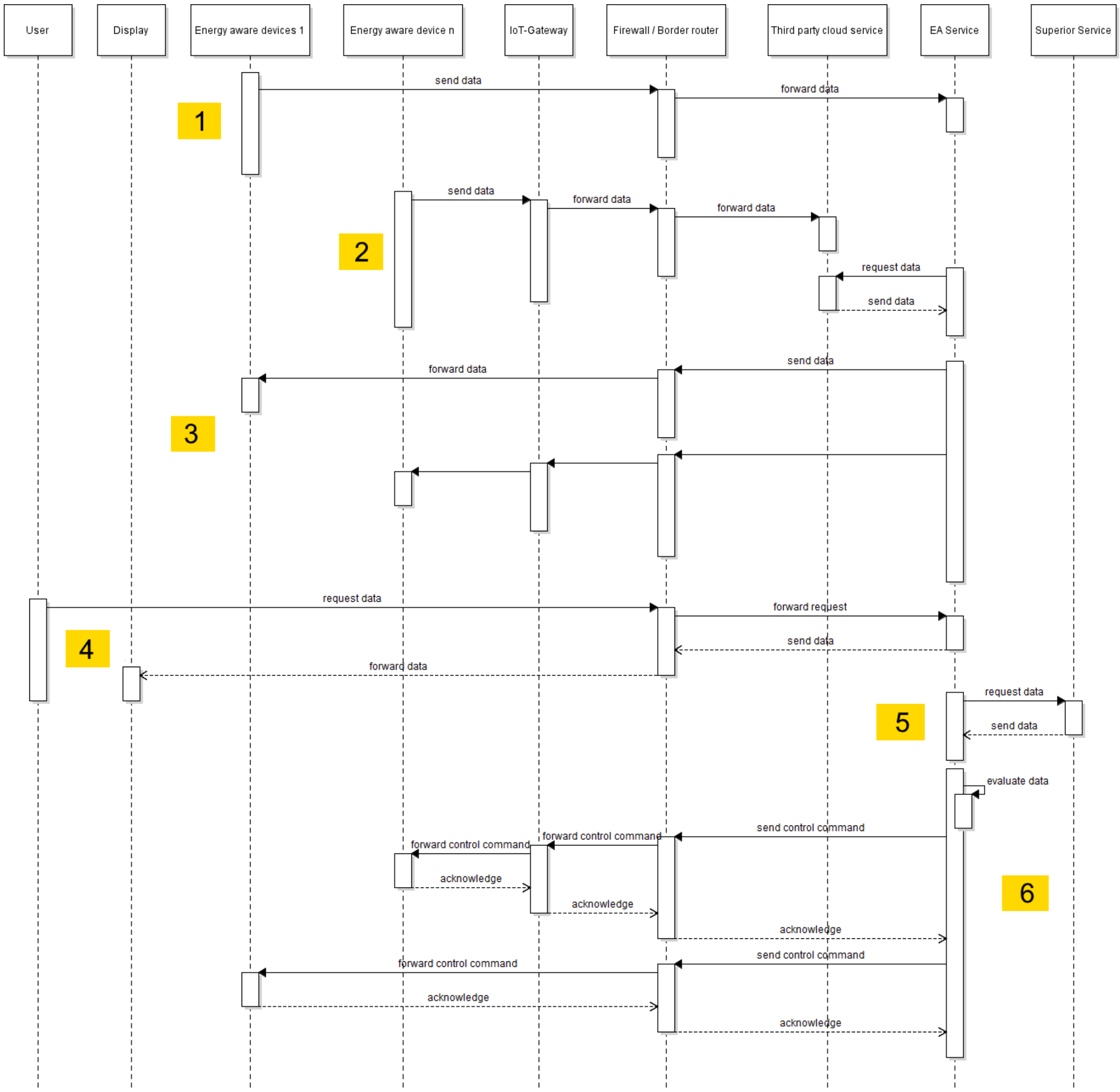

Figure 8: A sequence diagram showing various variants of communication between the elements in a system built on energy aware devices. The numbers in orange boxes refer to the numbers listed above.

5.4 Network connection of devices

5.4.1 Energy aware devices connected to the LAN or WLAN

A connection to the local network via ethernet cable or WLAN is available in almost every house or flat today. Many devices are already connected to network using the LAN or WLAN interface. These devices can simply communicate their energy consumption using the existing local area network connection (e.g. smart TV, notebook, tablet).

Most of the new devices that can be connected to the internet are equipped with a LAN or WLAN interface (e.g. dishwasher, multiroom audio speaker, robot lawn mower, etc.). Meaning that LAN or WLAN connectivity is a technology that is widely spread and accepted by end users today. To use the energy aware capability of devices connected to the LAN or WLAN most users don't need to install extra data communication hardware.

5.4.2 Energy aware devices connected via IoT gateway

Many IoT end-devices or sensors and actors of smart home systems do not connect directly to the local LAN or WLAN network for different reasons (legacy fieldbus system, insufficient range of WLAN, low power requirements of end-nodes, etc.). These devices are using an IoT gateway acting as media and data protocol converter to get access to the local network as shown in Figure 7 (e.g. smart light bulb, boiler).

If these devices shall become energy aware devices and communicate their consumption, give a forecast or shall be remotely controlled, the end user must install and maintain an extra IoT gateway – if not already existing.

5.4.3 Energy aware devices connected via mobile provider

There might be devices with a data communication interface, but a connection to the local network is not intended. In most cases they communicate to the cloud storage or service of the manufacturer or service provider. In Figure 7 the smart meter or EV charging unit are examples of such devices.

As an example: the smart meter sends its load profile data through 3G/4G/5G or LoRaWAN connection to the cloud storage of the utility. If these data are needed for an energy consumption analysis or to control other devices in a house, access to this particular smart meter data on the cloud storage device must be possible. Similar with the EV charging unit: it always sends its data directly to the cloud storage and service of the charging unit manufacturer. Having the advantage that manufacturer do not have to care about local network installations problems in case the charging unit would be connected to the local network of the end customer. But the same restriction here: all data go to the cloud services.

5.4.4 Extend local network range

If the WLAN coverage of a home is insufficient or LAN connections are missing and data connection to certain energy aware devices is not possible, the local area network coverage can be extended using range extenders like WLAN repeater, PLC transceivers or POF cable installations.

5.5 Services

5.5.1 Local storage and computing service

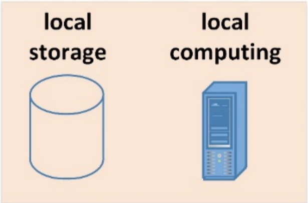

Figure 9: Local storage and computing service (see also Figure 7)

Depending where energy aware devices store their data or from where the devices can be controlled, one can distinguish between local storage and computing service architecture or cloud-based system architecture. Both having advantages or disadvantage.

Pros:

- Privacy / data security
- Standalone operation without internet connection is possible (for example a smart home system still works even without internet connection)

Cons:

- Local hard- and software needed
- Local administration and maintenance needed (firewall, software updates, vulnerability and patch management, etc.)
- Local support for a lot of different devices, interfaces, standards
- Scenarios for multiple users (optimization in communities or smart grid) not realistic
- Certain devices do not have an interface to communicate with local storage and data processing systems. They always transfer their data to the cloud storage of the manufacturer (e.g. EV charging unit Figure 7). Even if they are connected to the local network the manufacturer offers an API to access data only in the cloud.

5.5.2 Cloud storage and computing service

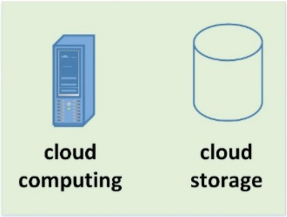

Figure 10: Cloud storage and computing service (see also Figure 7)

Since a lot of connected devices are communicating to a cloud service already today and can be accessed by smartphone or tablet apps via this cloud connection, an architecture where energy aware devices communicate their measurement data to the cloud can have several benefits:

Pros:

- No additional hard- and software needed at end user site
- No local maintenance and administration of storage or computing hardware
- Data aggregation for several end customers is possible
- Load balancing and electrical network optimization for huge number of devices, small network segment, certain category of devices down to a single household is only possible if data from all these households can be accessed at one place.
- Scalable infrastructure for cloud storage and services (data size, network connection, processing power)
- Low costs to run a powerful IT infrastructure

Cons:

- Privacy / data security
- If internet connection at end user’s home is not working the functionality is interrupted

5.6 Device Architecture

The basic components of an energy aware IoT device are shown as a simplified block diagram in Figure 11. The µ-controller as central data processing unit reads energy consumption data from an internal database depending on the current device state. If needed, an optional hardware measurement unit can measure the current energy consumption and send the information to the µ-controller. The data consumption can be transmitted via the communication unit to the data network.

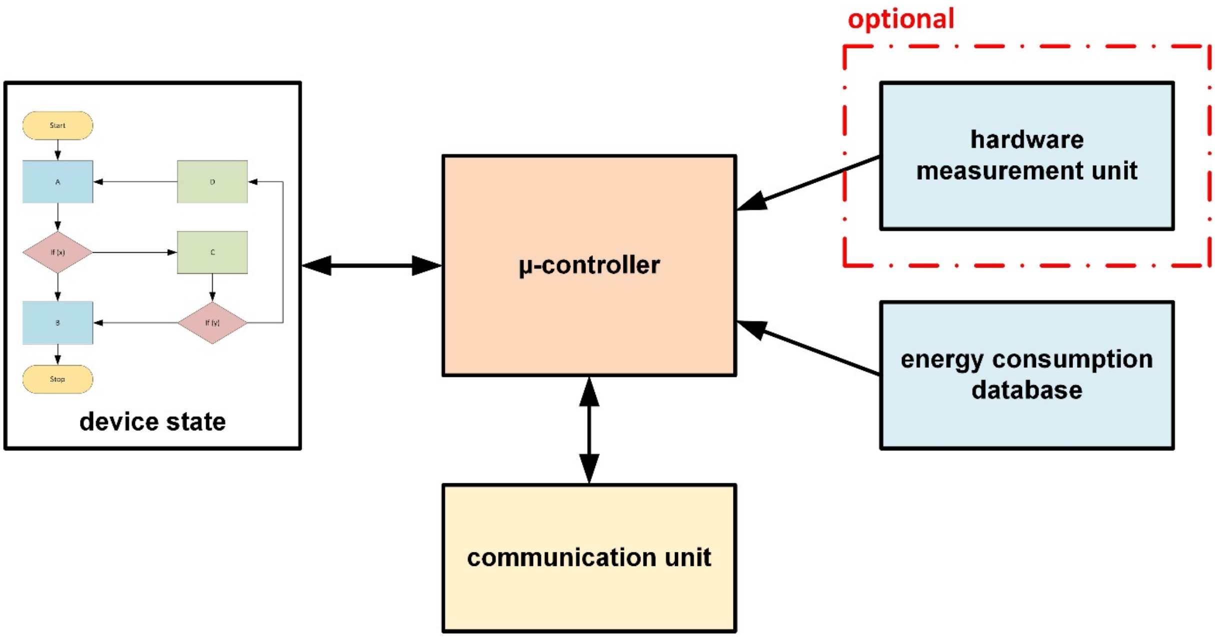

Figure 11: Device architecture

In case the device can be controlled from an external source, control commands can be received by the communication unit and transmitted to the application running on the µ-controller. With external commands, the state of the energy aware device could be affected.

5.6.1 Requirements for “energy awareness”

Basic requirement for energy awareness is the ability to send the current energy consumption via data communication channel to a data processing service. Depending on the use case for the energy awareness, the data processing service can be local or a remote cloud service (see chapter 5.5).

Which data are being transmitted to the data processing service depends on the scenario implemented with the energy aware devices. Useful information is:

- current energy consumption
- forecast of planned consumption or needed amount of energy
- state of the device (e.g. dishwasher: heating, rinse, drying, errors)

Not all electrical devices have to be energy aware. The scenarios documented in the chapters 6.1, 6.2 and 6.3 concentrate on different devices that potentially need to be energy aware in a household. Of course, appropriate devices are those using a lot of energy and are switched on during longer periods or permanently. In certain scenarios, it is also a benefit if the devices not only transmit data about their consumption, but also can be controlled remotely (see chapter 5.6.3).

5.6.2 Energy measurement

For most devices, an extra hardware chip for precise measurement of the actual energy consumption is not needed. Since a data communication interface is available to provide energy awareness, there is also a µ-controller built into the device to control operation and state. If the program running on the µ-controller knows the current state, it can get the energy consumption for this state from a lookup table or internal database of the device. E.g. a washing machine with its states heating, rinse, winding has a certain consumption for these operating states that can be measured in advance and stored to the internal database during development of an energy aware washing machine.

This means, if a device has a communication interface, energy awareness can be built in with – in most cases - minor extra hardware costs [43]. Maybe a small amount of memory is needed to permanently store the energy consumption for different process states.

For feedback systems, energy measurement and data transmission have to be in near real-time. Therefore, the measuring interval has to be in the area of some seconds [44]. To reach the goal for optimization use cases and scenarios, a measurement interval of several seconds to minutes should be sufficient.

It is not the idea to have very accurate and calibrated measuring systems implemented in energy aware devices. For most use cases, an accuracy of 5 – 10% would be sufficient. Ideally measuring can be built in software as described above with no extra hardware cost. We calculated the hardware costs for a single-phase measurement system having an accuracy < 10% to about USD 5.00. Even less if a large volume of components is ordered. And we estimated that even with knowing the state of a device and its associated energy consumption an accuracy of 10% can be reached by software. An issue not covered by estimating power consumption is increasing consumption by ageing effects or defects.

5.6.3 Remote device control

Energy aware devices that are having a communication interface can not only transmit information about their energy consumption, they could also be controlled remotely. In certain use cases this could help to balance the electricity network: as an example, if boilers could be switched on/off remotely and in large scale within several seconds.

A solar system owner could optimize the consumption of self-produced energy, if the state of household devices like washing machine, tumble dryer or dishwasher could be remotely controlled. E.g. the final heating and drying step of a dishwasher could be delayed if there’s not enough energy available from the solar system because the tumble dryer has not yet finished its drying process.

5.7 Common devices in households

5.7.1 Energy consumption of typical devices in a household

To estimate the potential of using energy aware devices in the described scenarios, we need to know their energy consumption. We do not analyse the devices itself but do consider average consumption based on energy consumption data in swiss households [45]. The consumption is listed in Table 1 and shown per application.

Application	Consumption [kWh]	Consumption [%]
Cooking / baking	300	7
Dishwasher	250	6
Refrigerator / freezer	275	6
Lighting	350	8
TV / audio	250	6
Home office	200	5
Washing machine	225	5
Tumble dryer	250	6
Small devices	250	6
Electric boiler	2'000	46
Total	4'350	100

Table 1: Energy consumption of devices in a household by application [45] for a two person household, without general electricity.

5.7.2 Additional costs for energy aware devices

As described in 5.6 power consumption can be estimated by knowing the internal state of a device if there is a dependence between state and needed power. In other cases, power consumption has to be measured. The latter then requires additional measuring hardware (Table 2).

An additional communication hardware is required for devices that typically are not connected, such as small devices used in the kitchen (coffee machine, kettle etc.). But the number of devices equipped with communication means is increasing. In Table 2 we consider the actual state of typical appliances to decide whether an additional communication unit is required or not. Therefore, the number of devices needing additional communication hardware will decrease in the next years.

Application / Device	M	C	Remarks
Cooking / Baking - Stove - Oven - Steamer	 - - -	 X X X	For heating it is typically easy to estimate power consumption
Dishwasher	-	X	
Refrigerator / freezer	-	X	
Lighting - LED lights - incandescent light - dimmable incand. light	 - - X	 X X X	For most lights it will be easy to estimate power consumption, the light is on or off. It gets harder for dimmable lights, particularly for incandescent lights that are controlled by a dimmer switch
TV / audio - Smart TV - Radio - Multiroom speaker	 X X X	 - - -	Estimation of power consumption can be hard because it may depend on video or audio content not only on the internal state
Home office - PC / Notebook - Charger for mobile devices - Router / Switches	 X - -	 - X -	For devices with varying power consumption depending on the actual activities it can be hard to estimate power consumption, it may be easier to measure it.
Washing machine	-	X	
Tumble dryer	-	X	
Small devices - Coffee machine - Kettle - Toaster - Mixer	 - - - -	 X X X X	For most devices it will be possible to estimate power consumption.
Electric boiler	-	X	

Table 2: This table shows whether a device easily can estimate its power consumption. M: measurement hardware needed, C: communication hardware needed.

In the scope of this study we do not analyse the detailed additional cost arising from the need of additional hardware for measurement and communication. We list whether additional costs are incurred and compare the costs qualitatively with the total costs of a device (Table 3). The estimation is done per application.

	Cooking / Baking	Dish washer	Refrigerator / freezer	Lighting	TV / Audio	Home office	Washing machine	Tumble dryer	Small devices	Electric boiler
Additional costs for communication unit	$	0	$	$	0	0	0	0	$	$
Additional costs for measurement unit	0	0	0	0	$	$	0	0	0	0
Costs compared with price of devices	m	m	m	i	m / i*	m	m	m	i	m

Table 3: The table shows if additional costs incur ($) or not (0) for hardware units per application and compares them with the price of the devices (m: moderate; i: immoderate). Costs and its comparison of course is dependent on the device and therefore have a variation in some applications. (*: depends on type of device)

6 Scenarios

6.1 Scenario “Energy Saving”

6.1.1 Scenarios Description

One of the corner posts of the energy strategy 2050 is to increase energy efficiency. Concerning electrical energy the goal is to save 13% in 2035 compared to the year 2000 [7]. Private households consume 33% of total electrical energy in Switzerland [46]. Assuming that households should contribute to energy saving according to their consumption, they should save 4% electrical energy.

Various authors have shown in their studies that consumers can save energy when they get a feedback of their consumption. The potential of savings in general is higher when the feedback is immediate and detailed for devices or group of devices. The authors report different potentials reaching from 20% down to no significant effect [47]. We assume that an energy savings potential of up to 8% can be realized [48] when using a feedback system and habitants are willing to change their behaviour.

Realising the potential of 8% means that households could reach the goal of the energy strategy by only changing their behaviour with help of a feedback system.

To realize a feedback system enabling people to save energy the system needs the energy consumption of each device in a household. An approach to get the energy consumption is to consult the documentation where the connected power and often the energy for a devices process is documented. A further approach is to analyse the power consumption provided by a smart meter or a dedicated metering device. There are energy consultants doing such kind of analysis. Both approaches cannot immediately inform the user about their energy consumption.

It exists a technology called NIALM (Non-intrusive appliance load monitoring) or load disaggregation that is able to analyse power consumption in real-time or offline. NIALM disaggregates the total power consumption into the power consumption of single devices. A real-time feedback system then can visualize this information. A drawback of NIALM is its accuracy. To disaggregate all devices in a household with connected power rates ranging from several W to kW a sample rate of some kHz or higher is needed [49]. This typically requires dedicated hardware that users have to install.

Using energy aware devices can eliminate some problems of NIALM: the devices are capable to provide the energy consumption in real-time, no need to do load disaggregation. A feedback system collects the information of the devices and visualizes it. Based on the architecture shown in Figure 7 a feedback system with energy aware devices consists of the energy aware devices that are connected to the local network at customers side (Figure 12). Depending on the communication protocols used the devices are either directly connected to the network via Ethernet or WiFi; or they are connected via a gateway that connects to the local network. The local network has to connect to the internet to have access to cloud services. Some devices use cloud services to collect and evaluate their data. Further, if the feedback system is implemented in the cloud it can avoid that people have to install additional hardware in their homes. The feedback system prepares the data for visualisation and users can have access to the data through a user interface which most probably will be a smart-phone or tablet.

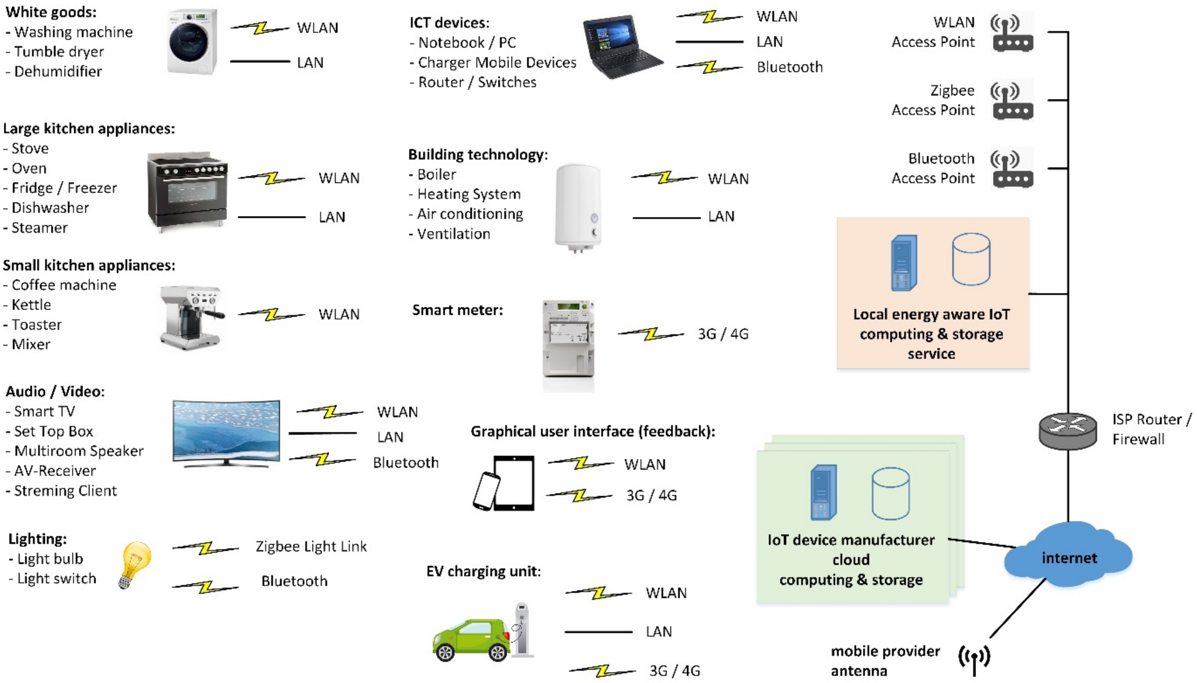

Figure 12: For scenario “energy saving” all devices present in a household are of interest and should be connected to the local network.

6.1.2 Devices Suitable to the Scenario

Looking at the energy consumption in households we see that the consumption in each of the different application is comparable to the others (Table 1). Therefore, from the point of view of energy consumption, potentially every device is applicable to the scenario “Energy Saving” and can contribute to energy savings. We will analyse the potential of energy saving in 6.1.3.

To enable habitants to save energy the feedback system has to visualize the energy consumption for each device. Further functions are the aggregation so that, for example, energy consumption can be shown per application as listed in Table 1. Each device therefore has to provide its current power consumption to the feedback system. The devices have to be equipped with corresponding hardware and software to estimate or measure and to communicate power consumption.

Implementing the scenario “Energy saving” enables habitants to know their energy consumption in real-time for each single device. They can analyse their consumption over time or the trends they show over time. Based on this knowledge it is possible to change their behaviour with the goal to save energy.

Furthermore, the feedback system is able to log power consumption data. This data can be used for an off-line analysis by an energy consultant.

6.1.3 Analysis

Saving Potential

We assume that the maximum energy saving potential mentioned above is 8%. We assume that the savings are evenly distributed among the applications listed in Table 4. With this study, we do not want to give any precise estimates of energy saving potentials, but rather want to show the extent to which electrical energy can be saved in a household and the appliances for which it can be saved.

We focus on energy savings initiated by changes in user's behaviour through a feedback. Therefore, an important criterion is the willingness of users to change their behaviour, so that energy consumption will be reduced. Some possible actions to save energy are shown in Table 4. Depending on user's attitude to energy saving they will change behaviour if their effort is not to high and their comfort is not negatively influenced. If it is important to a user that there is music in the background, he will not switch off the radio. For smaller devices that are seldom used people probably will not change behaviour. In the case of hot water usage, the willingness strongly depends on user's habits. For many people it is a question of comfort and wellness to take a hot and long shower. They will not change behaviour.

Application	Consumption		Saving	Possible actions to save energy	Willingness to change behaviour
	[kWh]	[%]	[%]		
Cooking / baking	300	7	< 0.5%	Use of covers, no pre-heating	Yes
Dishwasher	250	6	< 0.5%	Fill with more dish	Probably
Refrigerator / freezer	275	6	< 0.5%	Close door immediately	Yes
Lighting	350	8	< 0.5%	Switch off where not needed	Yes
TV / audio	250	6	< 0.5%	Switch off devices running in background	No
Home office	200	5	< 0.5%	Switch off devices running in standby	Yes
Washing machine	225	5	< 0.5%	Fill with more clothes, lower temperatures	Probably
Tumble dryer	250	6	< 0.5%	Fill with more clothes, lower temperatures	Probably
Small devices	250	6	< 0.5%	Less use of these devices	No
Electric boiler	2'000	46	< 4%	Reduce hot water consumption	Probably

Table 4: If the saving potential were distributed equally across the applications in most applications the saving is below 0.5%. Possible actions show how the potential could be realized.

Benefit of energy aware devices

Compared to load disaggregation technologies such as non-intrusive appliance load monitoring (NIALM), with energy aware devices we do not need the complex NIALM- algorithms with low accuracy particularly for devices with low connected power.

In a feedback system each device can be reported, even those with low power consumption

In general, knowing the power consumption of a device is of limited use for a user: for many people it is difficult to interpret the power consumption. Is a power consumption of 10W ok for a smartphone charger? And he cannot influence the power consumption. A TV needs its power when I want to watch the soccer match. Energy aware devices do not improve this situation compared to NIALM or knowing the connected power from the documentation.

For devices with higher power consumption such as a boiler: the actual power consumption does not motivate for more efficient behaviour, because the power consumption is not directly dependent on my actions. When I'm washing my hands, the boiler will not consume energy immediately. An energy aware boiler does not improve this situation.

To realize the potential of energy saving the user has to (let) analyse his past energy consumption (for example by an energy consultant) to decide for measures to reduce energy consumption. Energy aware devices can improve the level of detail for this analysis. But to save energy, the strategy will be to begin with the devices with high energy consumption.

Another point of view is the use of a feedback system itself. Often a feedback system is used when it has been installed for several weeks, but after that period users did not use it anymore [50]. This behaviour strongly depends on the design of the feedback system; but energy aware devices do not add a benefit concerning the long-term use of a feedback system.

Conclusion for Scenario "Energy Saving"

For the scenario "energy saving" the potential of energy saving for a single device or application is low.

The willingness to change behaviour depends on user's attitude and the device. Some devices are for user's comfort where they want to use the device without any limitation. For other devices they possibly change behaviour.

Even when the potential for a single device is low, the overall potential of energy savings for a household can reach up to 8% of the total consumption per year. But it depends on the user's attitude to energy saving.

There is low to no additional benefit of energy aware devices compared to classical feedback systems based on NIALM-technology.

6.2 Scenario «µ-Grid»

6.2.1 Scenario Description

"Microgrid is a localized group of electricity sources and loads that normally operates connected to and synchronous with the traditional centralized electrical grid (macrogrid), but can also disconnect to "island mode" — and function autonomously as physical and/or economic conditions dictate." [51]

In a µ-Grid it is of great interest to manage the energy consumption according to its production (preferably by renewables) and storage capabilities. The energy produced should 1) be consumed immediately, 2) stored locally or 3) fed into the mains grid. In a µ-Grid the managing system should minimize the energy fed into the grid due to low prices paid for the energy. Storage for electricity currently is limited. Therefore, the consumption should be as synchronous to production as possible. Figure 13 shows an example of a situation with a battery storage. Consumption is synchronized to production to a high degree. The energy needed in excess to production comes from the battery.

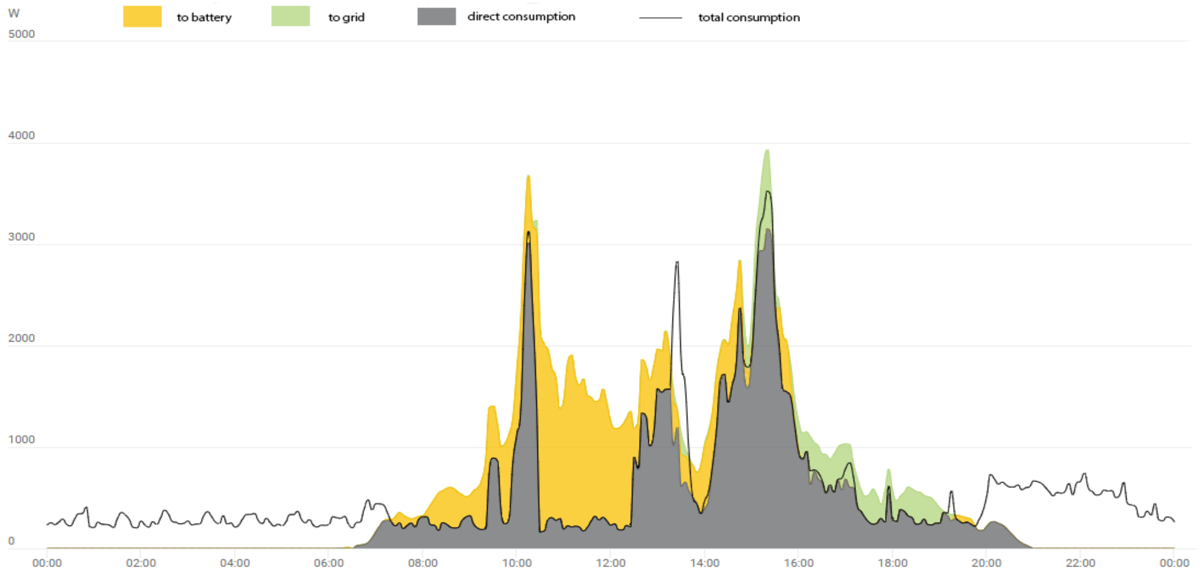

Figure 13: This graphic shows a synchronisation between production and consumption which is not perfect (at 12:30). Due to the fact that a storage is present the additional energy is provided by the storage and not the grid.

The energy management can be achieved by controlling each device in the µ-Grid. In addition to the devices with a high consumption, such as heat-pumps, in this scenario we also look at devices in the households. A boiler for example should run when energy production is high. Additionally, appliances such as dishwasher, washing machine and tumble dryer as well as charging station for electrical vehicles are of interest for energy management [52].

From the point of view of communication and networks the system is comparable to the scenario “energy saving”. The difference is that only devices suitable for load shifting are of interest for this scenario (Figure 14).

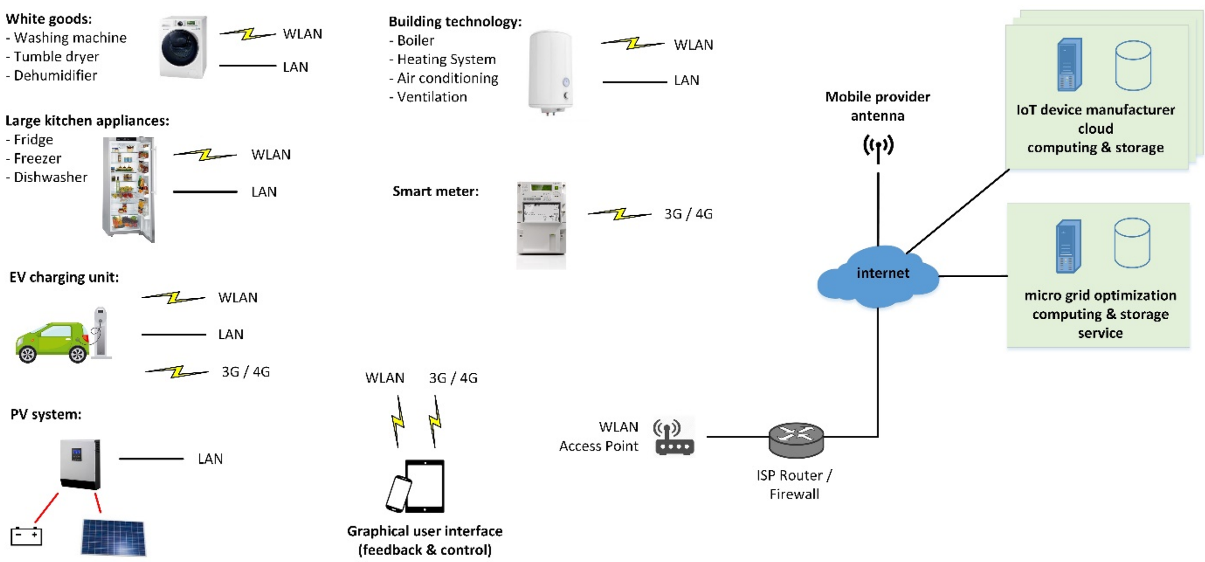

Figure 14: The scenario µ-Grid consists of devices suitable for load shifting that are connected to the local network. The local network is connected to the internet. The µ-Grid management service runs in as a cloud service.

The control of the appliances in the µ-Grid mainly means to shift the operating times of the appliances (load shifting). The scheduling of all appliances results in a total energy consumption that is synchronized as close as possible to production. The managing system could optimize the load shifting by analysing devices actual power consumption together with the overall consumption measured by the smart meter. Optimisation will strongly benefit from forecasts of future energy consumption [53].

The boiler, as an example of an appliance not requiring any user interaction, is a suitable load for load shifting but only if the water temperature is below its maximum temperature. Therefore, the boiler should communicate its future energy demand.

Other appliances have user interaction, such as a dishwasher. The user starts the dishwasher manually, he also can enter a time to delay the start of the dishwasher. In future, the user could enter the latest end time of the dishwasher. This enables the dishwasher to generate a forecast to predict the amount of energy that is needed in a certain time-window (e.g. 1kWh before 5 pm).

A µ-Grid also contains energy production, often a solar system. These also not only should provide actual power production but also its forecast. Production depends on weather conditions; therefore, its prediction will base on weather forecasts.

Having the forecasts of all consuming and producing devices the managing system can calculate a time-table of operating times of the consuming appliances. The time-table respects the time limits given by the users and the constraints given by production's forecasts. Based on the time-table the managing system then can shift the appliances inside the resulting time window. A bidirectional communication between the appliances and the managing system is needed to perform the load shifting. This requires the appliances to accept control commands from outside the device.

An impact of load shifting for users is that they do not know anymore the exact runtime of the appliances. For better acceptance the appliances or a smartphone app should show information of the scheduled operating times [52].

6.2.2 Devices Suitable for Scenario

For an energy management system (EMS) in a µ-Grid the shifting of loads is essential. Therefore, only devices suitable for shifting are applicable. Such devices are those where a user does not require an immediate reaction. A dishwasher can do its job independently from the user. But a TV or a mixer has to run exactly then when users use the device. Another criterion is the energy consumption. Only devices with a significant consumption are of interest for load shifting.

Suitable devices are dishwashers, washing machines, tumble dryers and refrigerators / freezers each with 225 ... 275 kWh energy consumption per year; and boilers with 2'000 kWh energy consumption per year (Table 5).

In the scenario "µ-Grid" we do not consider room heating and charging stations for electrical vehicles because it can be assumed that in µ-Grids the heating and charging stations are typically managed centrally and do not belong to a household.

6.2.3 Analysis

Potential of shiftable Energy

The potential of the switchable energy can be at most as high as the energy consumption of the suitable devices. Beside the amount of shiftable energy an EMS has to respect the time period in which shifting can be applied. The time period depends on user's requirements (a user wants the dishwasher to be finished at 5 pm) or on insulation issues (the better a boiler is insulated the longer the time period can be). Table 5 shows the amount of shiftable energy and the time period.

For devices with user interaction (dishwasher, washing machine, etc.) the time period lies in the range of some hours. For example, the user starts the dishwasher in the morning and wants it to have finished at 5 pm. For devices without user interaction the time period depends on the insulation and user's behaviour (opening the door). The latter is the reason for assuming a time period of some hours for refrigerator and freezers although they may conserve an acceptable temperature for 24 h. A boiler typically is designed in a way that it requires heating only once a day.

Device	Max. Potential [kWh/y]	Percentage of household's consumption	Time period
Dishwasher	250	6%	hours
Washing machine	225	5%	hours
Tumble dryer	250	6%	hours
Refrigerator / freezer	275	6%	hours
Electric boiler	2'000	46%	day

Table 5: This table shows the potential of shiftable energy per household. It also shows the time period in which shifting can be applied.

Acceptance for Shifting

User's acceptance is a key factor for load shifting and depends on the respective device. For refrigerators and freezers a certain acceptance is given; but only if the temperatures in the devices never get out of limits; and when users keep full control over them [54]. Another issue is people's fear that goods in the refrigerator get damaged when it is controlled from outside and where they do not fully understand its operation [55].

Electric boilers work completely in the background. It can be assumed that acceptance for load shifting is given as long as it is guaranteed people never run out of hot water.

Another problem arises with dishwashers and washing machines. The duration while the dirty dishes are in the dishwasher must not be too long. Or the clothes should not be left wet in the washing machine for too long. Some accept longer durations, others not.

Benefit of energy aware devices

For the optimisation a µ-Grid EMS needs current power consumption and a forecast of energy needs for the next hours [53]. Power consumption can be gained using submetering for each device with the impact of high costs. Another approach is to use NIALM what allows to estimate power consumption by disaggregating data out of a smart meter with limited accuracy. The EMS then has to calculate a forecast based on historical data. Forecasting can be hard to perform for a single device that is user operated, such as a washing machine.

Energy aware devices that provide current power consumption and a forecast of future energy requirements reduce the problems of low accuracy using NIALM. Power consumption is measured or estimated with reasonable accuracy and the forecast can be calculated based on the process knowledge stored in the device and the user interactions.

Conclusion for Scenario “µ-Grid”

For scenario “µ-Grid” the potential of suitable devices (devices that can be shifted and the user accepts it) can help to optimize the energy management. But not every device suitable from energetic viewpoint can be used: the user does not accept a fridge to be shifted.

Overall, the potential can reach 50% of the consumption of the households and therefore is considered to be significant.

Compared to NIALM-based optimisation the energy aware approach includes forecasts of energy demand. Therefore, an EMS is able to improve the energy management based on future data. Further, accuracy for NIALM under real life conditions can be poor.

6.3 Scenario «Balancing Power»

6.3.1 Scenario Description

Consumption and production in the power grid must be synchronized at all times to ensure that it remains stable. Usually this is not the case which is why balancing power is needed. Positive balancing power in the case consumption is higher than production can be provided by increasing production or decreasing consumption. In the case of production being higher than consumption negative balancing power is provided by decreasing production or increasing consumption. Depending on the time of reaction in the case of a difference between production and consumption we have primary (seconds), secondary (several seconds) or tertiary (15 minutes) balancing power [56]. To participate in the market of secondary power a provider must have a capacity of at least 5 MW, and he has to offer available balancing energy on a weekly base [56]. The secondary balancing power in Switzerland reaches peaks of +/- 400 MW [57].

A provider can reach the limit of 5 MW secondary balancing power not only by having access to high loads or sources but also by pooling a number of smaller loads or sources. The latter is the idea for the scenario “balancing energy”: pooling a high number of energy aware devices in households to provide balancing power (Figure 15). Not only heat pumps and boilers as in existing systems. Other devices suitable for balancing power have to be shiftable and show a reasonable connected power: dish washer, washing machine, dryer, charging station for electrical vehicles.

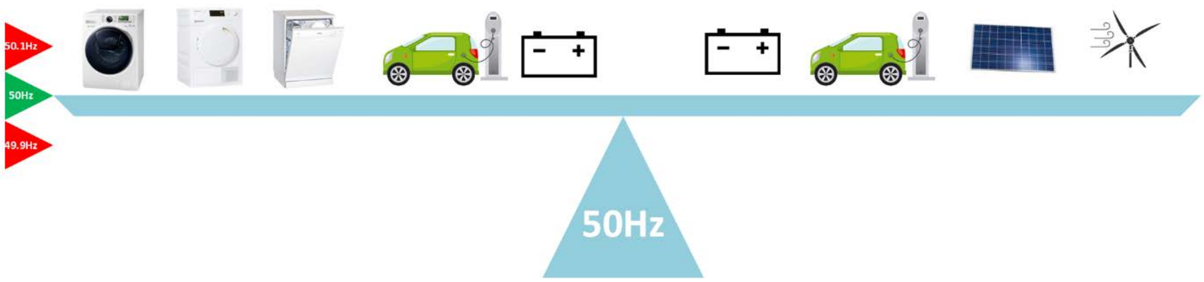

Figure 15: Devices in the residential can support the stabilisation of the grid by providing balancing power. Potential devices can be consuming and producing devices.

A provider of balancing power needs access to the devices participating in the balancing power pool so that he can control them according to the needs of the grid.

From the point of view of communication and networks the system is almost the same as in the scenario “µ-Grid”. The difference is that a transmission system operator (Swissgrid in Switzerland) is an additional player in the system (Figure 16). Swissgrid submits a call for tenders every week and gets offers from the market participants. In the case of an event Swissgrid requests the amount of balancing power to solve the actual problem. The provider then has to provide balancing power according to his offer.

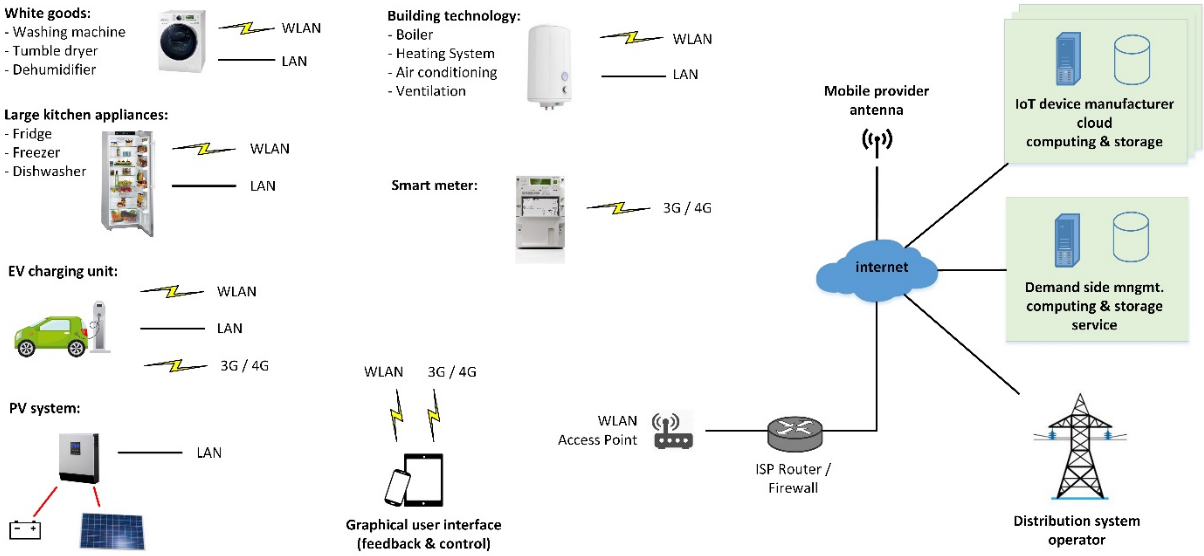

Figure 16: The scenario "balancing power" consists of devices suitable for load shifting and having a high connected power that are connected to the local network. The local network is connected to the internet. The balancing power management service runs in as a cloud service. As an additional player a distribution system operator, such as Swissgrid in Switzerland, demands balancing power.

The provider may not switch on or off devices without respecting user's preferences. Comparable to the scenario "µ-Grid", in the scenario "balancing power" same user's requirements apply. The user must have the possibility to define via a user interface latest end-times for the devices or a minimal state of charge for electrical cars. Based on this information the provider can calculate schedules and knows in which time windows the devices can be shifted. In the case of a balancing power request from the transmission system operator, the provider then has to decide, relying on the schedules, which devices he can control to deliver the requested amount of balancing power. The energy aware devices have to provide actual power consumption and a forecast of power consumption.

A bidirectional communication between the appliances and the managing system is needed to perform the load shifting. This requires the appliances to accept control commands from outside the device.

An impact of load shifting for users is that they do not know anymore the exact runtime of the appliances. For better acceptance the appliances or a smartphone app should show information of the scheduled operating times [52].

6.3.2 Suitable Devices

For a balancing power management system load shifting is essential. Suitable devices are the same as described in the scenario "µ-Grid" (6.2.2). In the case of balancing power an important criterion is the total power all the devices in a pool can draw or release.

In the scenario "balancing power" we consider charging stations for electrical vehicles, because in the scenario we assume participants addressed by a balancing power provider usually are residents not living in a µ-Grid. The addressed residents may have more control over the used infrastructure, such as a charging station for EVs.

6.3.3 Analysis

Potential of balancing power in households

In Table 1 we have shown the energy consumption of a typical two persons household. This is close to the average household having 2.25 persons. Therefore, we base the analysis on the consumption of a 2-persons household. For the calculation of the potential we assume that in a pool the number of devices is high so that we can calculate with an average power: the devices do not all run at the same time, the runtimes are equally distributed over time. This leads to potential that is lower than it could be, when all devices are operated at the same time. Our approach takes into account that not all devices can be operated at arbitrary time, for example, a boiler that has reached its upper temperature limit may not heat more.

In Switzerland ~25% of the 3.7 Mio [58] households have an electrical boiler. With an average consumption of 2’000 kWh per household we get a total consumption of 1.85 TWh, leading to an average power of ~210 MW. Compared to the peaks of +/- 400 MW secondary balancing power this is a significant amount of power that could be used for balancing the grid. When looking at a single household, a boiler has an average power of ~0.22 kW. This means, a household could contribute with an amount of 0.22 kW to balancing power by providing the boiler. In other words, a pool should have at least 23’000 boilers to reach the limit of 5 MW necessary for providing secondary balancing power (Table 6).

For the white goods washing machine, tumble dryer and dishwasher the total consumption per household is 725 kWh per year resulting in an averaged power of ~0.08 kW. The potential for Switzerland is ~300 MW. To have pool consisting only from white goods, 61’000 households have to participate in the pool at least.

Potentially refrigerators and freezers are suitable for providing balancing power. These appliances are able to store thermal energy and therefore are shiftable. With an average power consumption of 275 kWh per household and year it results an average power of ~30 W. While this is quite a low number the total average power in Switzerland reaches ~110 MW. Providing balancing power by only using refrigerators and freezers needs at least 167’000 households to reach the 5 MW limit.

When households with electrical boiler, white goods and refrigerators / freezers are considered a single household contributes with 0.34 kW to balancing power. All households in question (25% of 3.7 Mio.) result in an averaged power of 310 MW. To reach the limit of 5 MW for secondary balancing power the pool has to include at least 14’600 households.

Device	**Average power CH [MW]**	**Average power household [kW]**	**# of households to reach 5 MW**
Electrical boiler	210	0.22	23’000
Dishwasher, washing machine, tumble dryer	300	0.08	61’000
Refrigerator / freezer	110	0.03	167’000
Household with boiler, white goods and cooling devices	310	0.34	14’600
Household with boiler and white goods	290	0.31	16’100

Table 6: For suitable devices the average power for all devices in Switzerland and per household is shown. It also shows the number of devices required to reach the limit of at least 5 MW to be eligible to provide secondary balancing power. Switzerland has 3.7 Mio. households, where ~25% have an electrical boiler (925’000).

Over all, the potential of all households in Switzerland is interesting for providing balancing power because they can provide an amount of balancing power in the range of max. needed peaks of +/- 400 MW secondary balancing power. The number of at least 14’600 households for a pool is an acceptable number that a provider can achieve.

Potential of balancing power from charging stations for electrical vehicles

Switzerland has had an inventory of 14’500 electrical cars in 2017 [59]. The energy consumption is estimated to be about 29 GWh for charging the cars, assuming a consumption of 18 kWh / 100 km and 11’000 kilometres travelled per year [60], [61]. This results in an average power of 3.3 MW for all electrical cars in Switzerland, and 0.23 kW for each car. A pool should consist of at least 22’100 cars. These numbers apply assuming all electrical vehicles are charged equally distributed over the day. Thus, the potential of balancing power shown is conservative and can be higher in reality. Further, the number of electrical vehicles will increase in the next years.

This might be hard to achieve because almost all cars should be part of such a pool. But there will be an increase of electrical cars in the next years. In 2035 it is assumed to have an energy consumption of 1.5 – 2.9 TWh for charging electrical cars, depending on the underlying scenario [8]. The averaged power then reaches 170 – 330 MW. Assuming the average power per car does not change dramatically, the number of cars required for a pool remains at 22’100 cars.

	Average power CH [MW]	Average power per EV [kW]	# of EV to reach 5 MW
Electrical vehicles 2017	3.3	0.23	22’100
Electrical vehicles 2035 (BAU)	170		
Electrical vehicles 2035 (COM)	330		

Table 7: The averaged power of all electrical vehicles (EV) in Switzerland will increase strongly in the next years. Depending on the underlying scenario an amount of 170 – 330 MW could be reached.

Acceptance for Shifting

As already described in the scenario “µ-Grid”, user’s acceptance for load shifting is of great importance. Same arguments apply for refrigerators, freezers, white goods and boilers.

A new aspect are electrical vehicles. The user is very sensitive in the case of shifting the charging or even draw power out of the cars battery. It is important that the load shifting does not affect daily routine[62] to have a certain acceptance. One of main concerns is about trust in battery technology and about battery degradation [63]. People often charges their vehicles even the state of charge is above 50%, to be sure the next time they use the vehicle it will be fully charged.

Benefit of energy aware devices

As in the scenario “balancing power” the management system for balancing power needs to know current power consumption. This information is needed to decide whether a device can be switched on or off. Further it is required to know the forecast of power needs so that the operation of the device does not exceed limits such as time limits given by a user or temperature limits in the boiler. Actual power consumption can be measured with sub-metering for each device which implies additional costs for the meters. The approach of NIALM enables to replace the sub-meters by a centralized measurement and to disaggregate the data. This data then could be used to calculate a forecast what can be hard for user operated devices (dishwasher, washing machine, tumble dryer) [64].

Energy aware devices that provide current power consumption and a forecast of future power requirements reduce the problems of low accuracy using NIALM. Power consumption is measured or estimated by the device itself. The device due to its knowledge about its own process is able to calculate the forecast of power requirements and the time windows where the device can be shifted.

Conclusion for scenario “balancing power”

For the scenario “Balancing Power” the suitability of devices is comparable to the scenario µ-Grid: devices that can be shifted and the user accepts the shifting. These devices can have the potential to provide balancing power. But not every device suitable from a viewpoint of reasonable potential can be used: users tend to not accept a fridge to be shifted.

Overall a household can provide up to about 0.34 kW of balancing power. A charging stations for electrical vehicles adds a power of 0.23 kW. A provider has to pool at least 16’000 households (with boiler and white goods) to reach the limit of 5 MW to be eligible to provide secondary balancing power. An impact of the required number of households or charging stations is that the management system has to coordinate many devices over a large area.

Compared to NIALM-based optimisation the energy aware approach includes forecasts of energy demand. Therefore, the system is able to improve the power management based on future data. Further, accuracy can be better than achieved by NIALM.

7 Discussion of results

7.1 Discussion of Scenarios Analysis

Does energy awareness add benefits over other technologies that can disaggregate the energy consumption for a single device?

In the scenarios we have analysed how energy aware devices can contribute to the goals of the respective scenario. We have focused on the residential area and excluded commercial and industrial area. The conclusions for the latter two areas may be different from the conclusions for residential field. Additionally, we have compared the approach with energy aware devices to other approaches. These are namely NIALM and sub-metering which we consider as suitable alternative approaches to reach the goals of the scenarios. The analysis must therefore always be seen in the context of the respective scenario. In this way we evaluate energy awareness in close connection with the problem to be solved and not isolated from it.

In the scenarios “µ-Grid” and “balancing power” we clearly see a benefit of energy aware devices. This results mainly from our extended definition of energy awareness also containing forecasts and external control.

The part of energy reporting supports the services that are required in every of the described scenarios by providing current power consumption. But this also could be done using the mentioned alternative approaches. An important factor are costs to implement the energy awareness. It depends on the device what additional hardware is required and whether the costs have a reasonable proportion to the total cost of a device. For larger devices such as white goods or TVs the costs are reasonable. But for small devices such as lamps costs for energy awareness may be too high.

Do devices have to be controllable?

We have started with a proposal for a definition for energy aware devices. Our definition is not limited to energy reporting, but also extends to forecasting and the ability to control the devices from outside. In the scenarios analysis, we then showed whether the external control is required.

For the scenarios “µ-Grid” and “balancing power” the external control of devices is a key feature. The devices must be able to receive information from the managing service to know when they should run or pause. As a consequence, energy devices have to implement a bidirectional communication.

Is forecasting relevant?

In the scenario “energy saving” forecasting is not needed. But in the scenarios “µ-Grid” and “balancing power” forecasting is a key feature of the managing services. Therefore, forecasting has to be implemented in energy aware devices. The forecasting typically can base on the device’s knowledge of the energy demand during its own process. A device should send its forecast when the process has been started to the managing service.

Another case is the programming of a device by a user. When the user has delayed the start of a process or gives a time limit until the process has to be finished, the device can send this information combined with the energy demand as a forecast to the managing service.

For which devices energy awareness is suitable?

In the scenario analyses we have shown that not all devices are equally well suited for use. Therefore, not every device must be made energy aware. Most suitable devices are those with a high energy consumption compared to the total consumption in a household; or those with a high connected power to add a significant part of balancing power. Suitable devices have to be shiftable and users have to accept the shifting. The devices identified are namely white goods (dishwasher, washing machine, tumble dryer), boilers and charging stations for electrical vehicles. Also heat pumps can be considered because they fulfil the criteria for suitable devices. We did not analyse heat pumps in more details because they are typically not under direct control of residents in the case of a µ-Grid with central heating system. There also exist solutions for balancing power using heat pumps in Switzerland.

7.2 Discussion Outside the Described Scenarios

When regarding only at the features energy aware devices can provide (reporting of current power consumption, forecasting of energy demand and external controllability) we believe that this technology can be advantageous over other approaches. The devices itself know their processes and power requirements best.

Reporting current power consumption needs measurement or estimation in the device. Implementing the reporting can be done at low costs because often it can be done by pure software solutions. Only in exceptional cases where power cannot be estimated by knowing internal state or where it is too complicated to estimate it, a measurement hardware is needed. To keep costs low such measurement hardware is limited in accuracy. Alternatively, power consumption can be measured external by sub-meters to obtain high accuracies, if needed, typically resulting in high costs.

One of the main benefits of energy aware devices is that no disaggregation is needed. Disaggregation is limited in accuracy concerning the detection of the correct device and the evaluation of the accurate power consumption. The accuracy further depends on the number of devices to disaggregate and on the resolution of the measurement in time and amplitude.

A further general advantage of energy aware devices is the forecasting that a device can do the best. Any external forecast has to analyse power consumption data and predict future consumption, without knowing the internal state of the device. Therefore, forecasts done by the device itself will be more accurate.

The controllability of energy aware devices opens for new applications that have not been possible to implement so far. The scenarios “µ-Grid” and “balancing power” are only two examples.

The benefits have to be set into the context of a concrete problem that has to be solved.

8 Conclusions and outlook

8.1 Conclusion

Energy aware devices should implement three functionalities

1. reporting of current power consumption,
2. providing a forecast of energy demand and
3. being controllable from external systems.

This functionality enables the realisation of more applications than when only having a selection of functions, e.g. reporting. The benefit of energy aware devices strongly depends on the scenario where they are applied. Depending on the scenario, not every device must be energy aware because not every device is suitable for the respecting scenario.

In general, energy aware devices have the potential to be beneficial. But the benefits always must be set into the context of a concrete problem that has to be solved.

8.2 Next steps after end of project

The scenarios "µ-Grid" and "balancing power" show some common properties: each connected energy aware device sends its actual power consumption or production and the forecast to a managing service. The service then calculates a schedule and controls the operation times of the devices by sending back control commands to the energy aware devices.

In this study we have focused on a definition of energy awareness and how to use energy aware devices in different scenarios. Further work has to be done to tackle the challenges resulting from the scenarios applications. We recommend initiating further studies, research projects and pilots in the following topics.

8.2.1 Optimisation Algorithms

Smart energy management based on device's forecast is different from current approaches. Algorithms have to be developed and adapted that are able to receive and evaluate data coming from all the connected energy aware devices. The evaluation comprises the calculation of an optimized schedule of possible devices runtime. This has to be done in a way that production and consumption is in balance or the required balancing power can be provided.

To increase user's acceptance of shifting the devices the algorithms have to respect user's requirements such as latest end time of a washing machine or minimum state of charge of an electrical vehicle. Depending on the device the algorithm has to respect that once a device has started, the process cannot be interrupted arbitrarily. This will lead to some intelligence running in the device so that the device finally decides how its process is running.

This remains one of the open questions: What part of the logic of a service has to run on the device and what part in the managing service? The approaches can range from start/stop commands (logic of service is completely at services side) to sending constraints to the device (a part of the logic then has to be implemented in the device). If a part of service's logic has to run in the device, next questions arise: Who does implement the logic in the device? Who is responsible for updates?

Attention has to be paid on changing conditions. Particularly in the scenario "µ-Grid" where the goal is a balance between power production and consumption situations may arise where more power is requested than available. Asking the user whether the starting of the dishwasher shall be delayed from initial planning may reduce acceptance because further user interaction is required. Also overriding limits given by the user may reduce acceptance.

8.2.2 Potential of energy aware devices

In the study we have estimated the potential of energy aware devices in relation to the scenarios considered in quite general terms. For example, we did not distinguish between the sizes of a household or a family's income level. Therefore, before implementing a scenario, further studies and simulations have to be performed to prove that the goals of a scenario can be reached. Field tests have to show the benefit of energy aware devices.

8.2.3 Improving forecasting for energy aware devices without direct user interaction

Energy aware devices without direct user interaction (for example a boiler) cannot always provide a precise energy forecast (compared to a dish washer where the user enters the desired latest end time). The hot water consumption depends on user's behaviour which depends on a variety of external influencing factor. With machine learning it might be possible to improve the forecasting of hot water consumption by only knowing the past energy consumption. But before doing so, it has to be evaluated whether a forecast that predicts user's behaviour will be beneficial compared to the prediction a boiler could calculate based on its actual and desired water temperature.

Further devices without user interaction are energy sources such as solar systems. Their production depends on weather conditions and therefore a forecast of energy production has to respect a weather forecast. Such a weather forecast should be as local as possible to improve accuracy. But again, the question is: how much accuracy is needed? Further questions: Do local weather forecasts that base on global weather models improve productions forecast? Does the forecast need local observations (for example observation of sky and clouds)?

8.2.4 Definition of a protocol

The implementations of the scenarios require exchange of information: current power consumption, forecast of power demand and control commands. To enable multivendor-capability a protocol incorporation all required information has to be defined. The protocol for energy aware devices has to go beyond pure energy reporting.

For the forecast an energy aware device shall be able to communicate its energy demand for the process that has been selected by the user and it also shall include the timetable when energy is needed based on a delay the user has entered. An issue to define is a forecasts horizon which might vary between several hours (in the morning when leaving the house, the start of the washing machine is delayed so that it has finished at evening latest) up to a day (the boiler can be delayed by a day).

The control commands have to be represented in the protocol. Control commands can range from directly controlling a device (start / stop now or at a certain time) to provide a schedule of energy demands (use a certain amount of energy in a certain time period). In the latter case the device controls its process itself but respecting the conditions. A protocol can support both variants of control commands.

A protocol for energy aware and connected devices could cover many facets: different types of devices, different scenarios or different implementations of a service. Therefore, an open question is: One protocol for all devices and all scenarios? Or some variants of the protocol for specific devices (e.g. boiler without user interaction, dishwasher with user interaction, generators such as solar systems, batteries)?

A goal that should be pursued is to standardize the protocol to ensure that all energy aware devices are compatible. The process for standardisation can be challenging because typically manufacturers often try to use their own proprietary protocols to create customers loyalty.

8.2.5 Business Model

A business model can determine whether a scenario can be successfully implemented or not. While the operator of a µ-Grid can determine which devices are used in the apartments, a provider of balancing power has no control over which devices are used in the participating households. Therefore, the provider has to develop a business model that motivates people to use energy aware devices to provide balancing power. This is particularly important as a sufficient number of devices must be pooled to provide balancing power. To successfully reach enough people who will cooperate with the provider, people need to see a clear benefit. It can be assumed that monetary incentives are efficient measures.

Suitable business models still need to be found in order to provide sufficient incentives for the stakeholders involved, particularly for the participants in the pool. At the same time, the model must also be attractive for the provider. Only when enough customers, thanks to interesting business models, are willing to cooperate with a balancing power provider such scenarios can be successful.

9 References

[1] B. Nordmann and A. Meier, ‘Energy Aware Devices - Study of Policy Opportunities’, Final Report IEA-4E EDNA, Oct. 2016.

[2] A. Díaz, W. Wimmer, S. Tomek, and A. Klapproth, ‘Scoping Study Energy Efficient Smart Metering’, May 2012.

[3] M. Friedli, L. Kaufmann, F. Paganini, and R. Kyburz, ‘Energy Efficiency of the Internet of Things - Technical Report FINAL’. Apr-2016.

[4] ‘global warming | Definition, Causes, & Effects’, Encyclopedia Britannica. [Online]. Available: https://www.britannica.com/science/global-warming. [Accessed: 06-Jul-2018].

[5] ‘Climate Change in Switzerland - MeteoSwiss’. [Online]. Available: https://www.meteoswiss.admin.ch/home/climate/climate-change-in-switzerland.html. [Accessed: 06-Jul-2018].

[6] ‘The Paris Agreement’. [Online]. Available: https://www.bafu.admin.ch/bafu/en/home/topics/climate/info-specialists/climate--international-affairs/the-paris-agreement.html. [Accessed: 06-Jul-2018].

[7] ‘Energiestrategie 2050: Standardreferat’. Bundesamt für Energie, 18-Jan-2018.

[8] P. De Haan, R. Bianchetti, S. Rosser, A. Märki, and I. Erny, ‘Szenarien der Elektromobilität in der Schweiz - Update 2018’, 05-Mar-2018. [Online]. Available: https://www.ebp.ch/sites/default/files/unterthema/uploads/2018-03-05_EBP_CH_EmobSzen_PKW_2018_1.pdf. [Accessed: 02-Jul-2018].

[9] ‘Electric Vehicle Battery: Materials, Cost, Lifespan’, Union of Concerned Scientists. [Online]. Available: https://www.ucsusa.org/clean-vehicles/electric-vehicles/electric-cars-battery-life-materials-cost. [Accessed: 06-Jul-2018].

[10] ‘Four charts that show the future of battery storage - Australian Renewable Energy Agency’. [Online]. Available: https://arena.gov.au/blog/arenas-role-commercialising-big-batteries/. [Accessed: 06-Jul-2018].

[11] Admin2, ‘Solar-Akku: Preise, Kosten und Wirtschaftlichkeit’, Solaranlagen Portal. [Online]. Available: https://www.solaranlagen-portal.de/solar-akku/solar-akku-preise-kosten.html. [Accessed: 06-Jul-2018].

[12] ‘BiB – Weltbevölkerung und regionale Bevölkerungsentwicklung in Europa – Atlas zur Weltbevölkerung’. [Online]. Available: https://www.bib.bund.de/Publikation/2018/Atlas-zur-Weltbevoelkerung.html?nn=9859434. [Accessed: 06-Jul-2018].

[13] ‘IoT numbers vary drastically: devices and spending in 2020’, We speak IoT, 06-Oct-2017. .

[14] D. Feldges, ‘V-Zug verlässt die Komfortzone | NZZ’, Neue Zürcher Zeitung, 13-Dec-2017.

[15] ‘Top Trends in the Gartner Hype Cycle for Emerging Technologies, 2017’, Smarter With Gartner, 15-Aug-2017. [Online]. Available: https://www.gartner.com/smarterwithgartner/top-trends-in-the-gartner-hype-cycle-for-emerging-technologies-2017/. [Accessed: 05-Jul-2018].

[16] ‘Lageberichte MELANI’. [Online]. Available: https://www.melani.admin.ch/melani/de/home/dokumentation/berichte/lageberichte.html. [Accessed: 06-Jul-2018].

[17] ‘HACKMAGEDDON’, HACKMAGEDDON. [Online]. Available: https://www.hackmageddon.com/. [Accessed: 06-Jul-2018].

[18] ‘SR 235.1 Bundesgesetz vom 19. Juni 1992 über den Datenschutz (DSG)’, 01-Jan-2014. [Online]. Available: https://www.admin.ch/opc/de/classified-compilation/19920153/index.html. [Accessed: 13-Jul-2018].

[19] ‘Datenschutz-Grundverordnung der Europäischen Union’, May-2018. [Online]. Available: https://www.edoeb.admin.ch/edoeb/de/home/dokumentation/rechtliche-grundlagen/Datenschutz%20-%20International/DSGVO.html. [Accessed: 13-Jul-2018].

[20] B. für Energie, ‘Elektrogeräte brauchen immer weniger Strom’, 17-Nov-2016. [Online]. Available: http://www.bfe.admin.ch/energie/00588/00589/00644/index.html?lang=de&msg-id=64531. [Accessed: 13-Jul-2018].

[21] ‘UVEK - Öffnung des Strommarktes’. [Online]. Available: https://www.uvek.admin.ch/uvek/de/home/energie/oeffnung-strommarkt.html. [Accessed: 13-Jul-2018].
[22] ‘Die drei Stufen der Regelenergie’, BKW Blog. .
[23] D. Ventura, D. Casado-Mansilla, J. López-de-Armentia, P. Garaizar, D. López-de-Ipiña, and V. Catania, ‘ARIIMA: A Real IoT Implementation of a Machine-Learning Architecture for Reducing Energy Consumption’, in Ubiquitous Computing and Ambient Intelligence. Personalisation and User Adapted Services, vol. 8867, R. Hervás, S. Lee, C. Nugent, and J. Bravo, Eds. Cham: Springer International Publishing, 2014, pp. 444–451.
[24] W. Li, T. Logenthiran, V. T. Phan, and W. L. Woo, ‘Implemented IoT-Based Self-Learning Home Management System (SHMS) for Singapore’, IEEE Internet Things J., vol. 5, no. 3, pp. 2212–2219, Jun. 2018.
[25] K. Razzaq Malik, T. Ahmad, M. Farhan, F. Ullah, K. Amjad, and S. Khalid, ‘Multiagent Semantical Annotation Enhancement Model for IoT-Based Energy-Aware Data’, Int. J. Distrib. Sens. Netw., vol. 12, no. 6, p. 9103265, Jun. 2016.
[26] M. S. Mahdavinejad, M. Rezvan, M. Barekatain, P. Adibi, P. Barnaghi, and A. P. Sheth, ‘Machine learning for Internet of Things data analysis: a survey’, Digit. Commun. Netw., Oct. 2017.
[27] A. Vaughan, ‘Subsidy-free renewable energy projects set to soar in UK, analysts say’, The Guardian, 20-Mar-2018.
[28] S. Pfeifer, ‘Subsidy-free renewable projects on “cusp of breakthrough”’, Financial Times, 28-Mar-2018. [Online]. Available: https://www.ft.com/content/1960c6fe-2dea-11e8-a34a-7e7563b0b0f4. [Accessed: 16-Jul-2018].
[29] ‘More than 2.5 GW subsidy-free solar in Europe’, PV Europe, 11-May-2018. [Online]. Available: http://www.pveurope.eu/News/Markets-Money/More-than-2.5-GW-subsidy-free-solar-in-Europe. [Accessed: 16-Jul-2018].
[30] C. Q. Choi, ‘A Road Map to 100 Percent Renewable Energy in 139 Countries by 2050’, IEEE Spectrum: Technology, Engineering, and Science News, 23-Aug-2017. [Online]. Available: https://spectrum.ieee.org/energywise/energy/renewables/100-percent-renewable-energy-for-139-countries-by-2050. [Accessed: 16-Jul-2018].
[31] ‘Study: 100% renewable electricity worldwide is feasible, and cheaper than business-as-usual’, TreeHugger. [Online]. Available: https://www.treehugger.com/renewable-energy/study-100-renewable-electricity-worldwide-feasible-and-cheaper-business-usual.html. [Accessed: 16-Jul-2018].
[32] ‘100-percent renewable German energy system possible – study’, Clean Energy Wire. [Online]. Available: https://www.cleanenergywire.org/news/reactions-eu-air-quality-lawsuit-100-renewables-possible-study/100-percent-renewable-german-energy-system-possible-study. [Accessed: 16-Jul-2018].
[33] M. Z. Jacobson, M. A. Delucchi, M. A. Cameron, and B. A. Frew, ‘Low-cost solution to the grid reliability problem with 100% penetration of intermittent wind, water, and solar for all purposes’, Proc. Natl. Acad. Sci., vol. 112, no. 49, pp. 15060–15065, Dec. 2015.
[34] M. Flaute, A. Großmann, C. Lutz, and A. Nieters, ‘Macroeconomic Effects of Prosumer Households in Germany’, Int. J. Energy Econ. Policy, vol. 7, no. 1, pp. 146–155, Jan. 2017.
[35] ‘Prosumers_drive_increasing_demand_for_smarter_solar_building_solutions__28.11.2017.pdf’. [Online]. Available: http://www04.abb.com/global/seitp/seitp202.nsf/e308f3e92d9a8fc5c1257c9f00349c99/72f93e9f98c3464cc12581e600292c7d/$FILE/Prosumers_drive_increasing_demand_for_smarter_solar_building_solutions__28.11.2017.pdf. [Accessed: 16-Jul-2018].
[36] ‘ISO/IEC 27001 Information security management’. [Online]. Available: https://www.iso.org/isoiec-27001-information-security.html. [Accessed: 21-Jul-2018].
[37] ‘BSI - IT-Grundschutz - BSI-Standards’. [Online]. Available: https://www.bsi.bund.de/DE/Themen/ITGrundschutz/ITGrundschutzStandards/ITGrundschutzStandards_node.html. [Accessed: 21-Jul-2018].
[38] N. Keller, ‘Cybersecurity Framework’, NIST, 12-Nov-2013. [Online]. Available: https://www.nist.gov/cyberframework. [Accessed: 21-Jul-2018].

[39] ‘The ISF Standard of Good Practice for Information Security’, Information Security Forum. [Online]. Available: https://www.securityforum.org/tool/the-isf-standardrmation-security/. [Accessed: 21-Jul-2018].
[40] ‘BSI - Smart Metering Systems’. [Online]. Available: https://www.bsi.bund.de/DE/Themen/DigitaleGesellschaft/SmartMeter/smartmeter_node.html. [Accessed: 21-Jul-2018].
[41] ‘Smart grids’. [Online]. Available: http://www.bfe.admin.ch/smartgrids/index.html?lang=de&dossier_id=06636. [Accessed: 21-Jul-2018].
[42] ‘Digitale Stromzähler’. [Online]. Available: https://www.edoeb.admin.ch/edoeb/de/home/datenschutz/technologien/der-einsatz-von-digitalen-stromzaehlern.html. [Accessed: 21-Jul-2018].
[43] S. Beletich, ‘Energy Aware Devices, The Future of Device-Level Energy Reporting’, presented at the 2016 Australian Summer Study on Energy Productivity, Sydney, 24-Feb-2016.
[44] none, ‘Overview of Residential Energy Feedback and Behavior-based Energy Efficiency’, 1219691, Feb. 2011.
[45] ‘Typischer Stromverbrauch in Schweizer Haushalt’.
[46] ‘Gesamtenergiestatistik 2017’. [Online]. Available: http://www.bfe.admin.ch/themen/00526/00541/00542/00631/index.html?dossier_id=00867. [Accessed: 25-Jun-2018].
[47] K. Buchanan, R. Russo, and B. Anderson, ‘The question of energy reduction: The problem(s) with feedback’, Energy Policy, vol. 77, pp. 89–96, Feb. 2015.
[48] C. McKerracher and J. Torriti, ‘Energy consumption feedback in perspective: integrating Australian data to meta-analyses on in-home displays’, Energy Effic., vol. 6, no. 2, pp. 387–405, May 2013.
[49] K. C. Armel, A. Gupta, G. Shrimali, and A. Albert, ‘Is disaggregation the holy grail of energy efficiency? The case of electricity’, Energy Policy, vol. 52, pp. 213–234, Jan. 2013.
[50] S. S. van Dam, C. A. Bakker, and J. D. M. van Hal, ‘Home energy monitors: impact over the medium-term’, Build. Res. Inf., vol. 38, no. 5, pp. 458–469, Oct. 2010.
[51] ‘Microgrid’, Wikipedia. 28-Jun-2018.
[52] A. G. Paetz, T. Kaschub, P. Jochem, and W. Fichtner, ‘Load-shifting potentials in households including electric mobility - A comparison of user behaviour with modelling results’, in 2013 10th International Conference on the European Energy Market (EEM), 2013, pp. 1–7.
[53] N. Amjady, F. Keynia, and H. Zareipour, ‘Short-Term Load Forecast of Microgrids by a New Bilevel Prediction Strategy’, IEEE Trans. Smart Grid, vol. 1, no. 3, pp. 286–294, Dec. 2010.
[54] A. Abdisalaam, I. Lampropoulos, J. Frunt, G. P. J. Verbong, and W. L. Kling, ‘Assessing the economic benefits of flexible residential load participation in the Dutch day-ahead auction and balancing market’, in 2012 9th International Conference on the European Energy Market, 2012, pp. 1–8.
[55] W. Mert and W. Tritthart, 1 Get smart! Consumer acceptance and restrictions of Smart Domestic Appliances in Sustainable Energy Systems. 2013.
[56] M. Beck and M. Scherer, ‘Überblick Systemdienstleistungen’. swissgrid, 12-Apr-2010.
[57] C. Imboden, ‘Teilnahme industrieller Regelleistungs-Anbieter am Schweizer SDL-Markt’, 21-Nov-2016. [Online]. Available: https://www.aramis.admin.ch/Default.aspx?DocumentID=34766&Load=true. [Accessed: 02-Jul-2018].
[58] ‘Haushalte’. [Online]. Available: https://www.bfs.admin.ch/bfs/de/home/statistiken/bevoelkerung/stand-entwicklung/haushalte.html. [Accessed: 03-Jul-2018].
[59] ‘Strassenfahrzeuge – Bestand, Motorisierungsgrad’. [Online]. Available: https://www.bfs.admin.ch/bfs/de/home/statistiken/mobilitaet-verkehr/verkehrsinfrastruktur-fahrzeuge/fahrzeuge/strassenfahrzeuge-bestand-motorisierungsgrad.html. [Accessed: 02-Jul-2018].

[60] G. Fetene, C. Prato, S. Kaplan, S. Mabit, and A. Jensen, ‘Harnessing Big-Data for Estimating the Energy Consumption and Driving Range of Eletcric Vehicles’, 30-Jul-2015.
[61] ‘Leistungen des privaten Personenverkehrs auf der Strasse. Methodenbericht 2017. Zeitreihe bis 2016. - Korrigierte Version vom 31.10.2017 | Publikation |’. [Online]. Available: https://www.bfs.admin.ch/bfs/de/home/statistiken/mobilitaet-verkehr/erhebungen/pv-l.assetdetail.3682549.html. [Accessed: 05-Jul-2018].
[62] A.-G. Paetz, P. Jochem, and W. Fichtner, ‘(15) Demand Side Management mit Elektrofahrzeugen – Ausgestaltungsmöglichkeiten und Kundenakzeptanz’, ResearchGate, 15-Feb-2012. [Online]. Available: https://www.researchgate.net/publication/265805369_Demand_Side_Management_mit_Elektrofahrzeugen_-_Ausgestaltungsmoglichkeiten_und_Kundenakzeptanz. [Accessed: 04-Jul-2018].
[63] ‘(15) The neglected social dimensions to a vehicle-to-grid (V2G) transition: A critical and systematic review’, ResearchGate. [Online]. Available: https://www.researchgate.net/publication/321237450_The_neglected_social_dimensions_to_a_vehicle-to-grid_V2G_transition_A_critical_and_systematic_review. [Accessed: 04-Jul-2018].
[64] M. Gerber, P. Huber, A. Rumsch, and A. Paice, ‘Prediction of domestic appliances usage based on electrical consumption’, in submitted to Energy Informatics, Oldenburg, Germany, 2018.

10 Appendix

10.1 Appendix 1: Applications, Preconditions, Opportunities (description)

10.1.1 Applications of energy aware devices

Break down consumption (energy / costs)
Energy aware devices allow the consumer (or utility) to break down the electrical energy consumption of a household into the consumption for individual devices. Including the tariff structure for electrical energy, the energy costs to run each device can be calculated as well.

Collect data for optimization (energy / costs)
Collected data about the electrical energy consumption for each energy aware device are important basic information to optimize the use of electrical energy. Energy consumption could be optimized to reach different goals: low costs, low energy consumption, stable electricity network, use own energy if solar system installed, etc.

Optimized control of devices
As soon as a strategy for optimization to use electrical energy is defined, controllable energy aware devices can be switched on or off individually to reach optimization goals.

Create device classes (energy efficiency label)
Data records for energy consumption of energy aware devices can be compared to data records of similar devices or “best in class” devices. Depending on measurement and comparison results the device can be assigned to a certain efficiency class.

Detect defective devices
If there exists a data record history for energy consumption of energy aware devices, the current consumption of a device can be compared to earlier data or a “master-record” from the manufacturer of a device. If a device is broken or defective (e.g. a seal of a fridge door), one could detect the changed behavior of a device.

Integrate load control into SmartHome
If a SmartHome gateway can communicate with energy aware devices, the devices could be integrated into the SmartHome system. In this case, the SmartHome system could control electrical loads within a house.

Record measurement data to balance energy
Recorded and real time measurement data of individual devices can help to balance the electrical energy consumption. With these information shiftable loads (e.g. water boilers) can be switched on/off to stabilize the electrical network.

Implement optimization of own consumption (apartment building, district)
If the prosumer is a group of households within an apartment building or district and not a single household / family-house with its own solar system, the optimization of own electricity consumption is more demanding. In such a situation, energy aware devices can even better support the optimization of energy consumption between different households. Depending on the current production of the solar system, individual devices in different households can be switched on/off. Having energy aware devices installed, there is a use case or business case to develop devices that optimize the own consumption of electrical energy distributed over multiple households.

Optimize operations
Aggregated and combined consumption of real-time data from energy aware devices or forecasts can help utilities or network operators to optimize the production and distribution of electrical energy.

Advise customers (to optimize operation)
An application could advice people - in a friendly way - when to use/not use their energy aware devices (e.g. start washing machine). Different reasons and optimization strategies can be input parameters for such an application: solar system production, low/high tariff, network load, power plant out of order, etc.

Control critical infrastructure
The production and distribution of electrical energy is a part of our “critical infrastructure”. If someone can successfully run a cyber-attack against a system of energy aware devices – especially if the devices can be controlled remotely – he can also destabilize the electrical energy production and distribution system.

Recognize activities of daily life
Detailed data about electricity consumption within a household in real-time contains also information about “activities of daily life”. Such data profiles for example could help to find out how elderly people are doing. If they cook regularly a meal, do their washing, switch off the stove, etc. The data could support other sensors within a house enabling people to live in their own home as long as possible.

10.1.2 Preconditions (Devices)

Device announces his energy consumption
An electrical device can communicate its electricity consumption regularly (e.g. every 10 s) through a secure standardized data communication network to a data server. The data server can be a local device or an external server (e.g. cloud service of the utility).

Device announces his energy consumption forecast
Depending on its state, an electrical device can communicate a forecast for its electricity consumption (e.g. for the next 6 h) through a secure standardized data communication network to a data server. The data server can be a local device or an external server (e.g. cloud service of the utility).

Control device via communication interface
An electrical device (e.g. heat pump of a heating system) can be controlled through a secure standardized data communication network. This enables utilities or network operators peak clipping or load balancing in their networks. Owners of solar systems can optimize the consumption of electrical energy with devices that have communication channel to control them.

10.1.3 Preconditions (Standards)

Define requirements & standards for measurement accuracy
To reach a certain accuracy for the measurement of its own electrical energy consumption, standards need to define minimal requirements for energy aware devices. The standards shall also define which values are measured (e.g. active energy, reactive energy) and in which intervals new values can be sent over communication channels.

Define requirements & standards for data security
All data communication channels to energy aware devices need to provide confidentiality, integrity and availability. To implement secure data communication for such devices, standards need to be defined from well-known and accepted standardization organisations.

Define "in-house" data communication standards
Many standards today describe “in-house” data communication for short distances. From physical layers up to application layers for smart home installations. To install energy aware devices and components like communication gateways from different manufacturer, data communication standards need to be defined. Only if all products support defined standards, an implementation of system for energy aware IoT devices is possible.

Define data communication standards for misc. electricity network layers
If the energy consumption of devices shall be communicated not only “in-house”, but also to the utilities and network operators (maybe in an aggregated form), there is a need for standard data communication protocols for these upper layer control systems of electricity networks. If there are no standards available to communicate current consumptions and forecasts coming from devices, one has to define data communication standards for these different layers.

10.1.4 Opportunities

Develop submetering modules for devices
A use case (or business case) could be that a manufacturer for metering devices would develop standardized submetering modules for energy aware devices. These submetering modules must fulfil standards according to measurement accuracy, data communication and data security.

Develop SmartHome gateways (cross-platform)
Gateways for smart home installations could be extended to process data from energy aware devices or control them. Smart home gateways have to be compliant to the data communication and security standards for energy aware devices.

The gateways could have the ability to optimize the own consumption of electrical energy or costs according to the tariff model.

Develop data concentrators / gateways for metering infrastructure
Data concentrator or gateways for metering infrastructure could be extended to process data from energy aware devices or control them. These concentrators / gateways have to be compliant to the data communication and security standards for energy aware devices.

Develop components to optimize own consumption
Today prosumers (households with own production and consumption of electrical energy - e.g. own solar system) basically want to consume the energy they produced themselves with 1st priority. Energy aware devices can give them the possibility to know what the state and consumption of energy aware devices are. Depending on the current production of the solar system, individual devices can be switched on/off. Having energy aware devices installed, there is a use case or business case to develop devices that optimize the own consumption of electrical energy.

10.2 Appendix 2: Communication Architecture

The logical communication architecture can be designed in a variety of different ways documented in the following chapters: all data could go to the cloud storage or being stored and processed locally. Some manufacturer of IoT devices will store data from their devices in their own manufacturer cloud. An API to the manufacturer cloud service will allow to read data into local or cloud storage area.

Also designs where data are pre-processed and aggregated locally and copied afterwards to the cloud storage could be a possible scenario.

10.2.1 Store power consumption and forecast in cloud

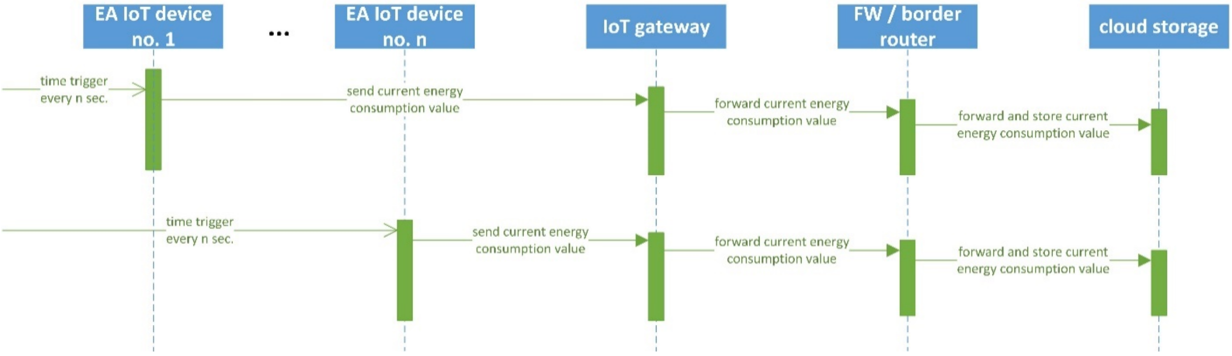

Figure 17: Store all power consumption and forecast data of device through IoT gateway to the cloud

If power consumption data are stored in cloud storage, each energy aware IoT device sends its current power consumption to the cloud storage service. Figure 17 shows the sequence diagram for energy aware IoT devices connected to the IoT gateway.

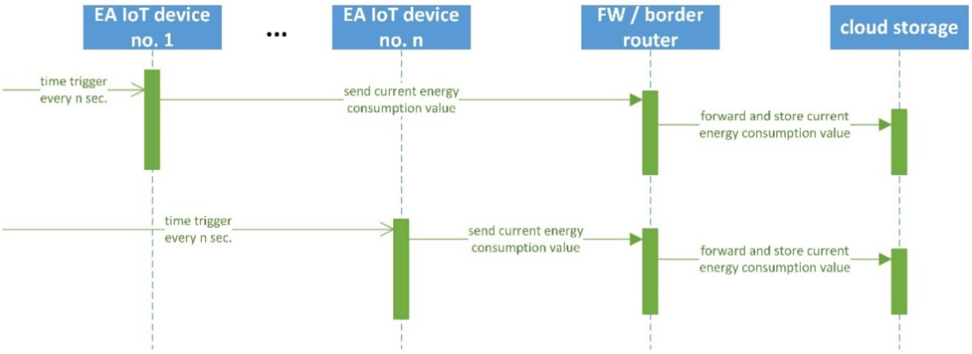

Figure 18: Store all power consumption and forecast data of device without IoT gateway to the cloud

Figure 18 shows the sequence diagram for energy aware IoT devices that are connected directly to the local network of a household.

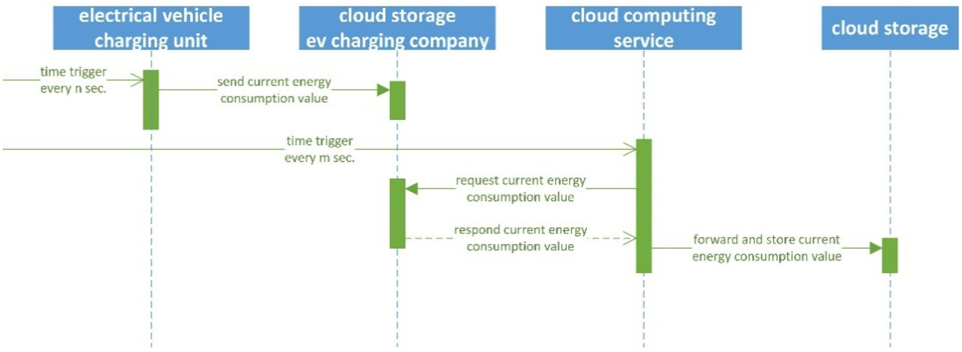

Figure 19: Copy power consumption to cloud storage from cloud storage of IoT device manufacturer

Figure 19 shows the sequence diagram if energy aware IoT devices are connected directly to a cloud storage device of the IoT device manufacturer (e.g. “electrical vehicle charging unit”). In this case, the current consumption data and – if available – forecast data need to be read from the cloud storage area of the device manufacturer and are being stored to the cloud storage where all the other energy aware IoT devices store their consumption data.

Storing data in the cloud has the advantages and disadvantages listed below:

Advantages:

- data of all energy aware device stored in one place
- scalable cloud data storage resource if number of energy aware IoT devices increases
- less administration overhead
- logical grouping of data from IoT devices into different hierarchical groups with different access rights
- data access for different stakeholders and use cases are easy to implement
- local firewall doesn’t need to allow incoming network traffic

Disadvantages:

- cloud storage as single point of failure
- needs continuous and stable internet connection from IoT device to cloud storage
- concerns about data security and privacy if data stored on cloud storage

10.2.2 Store and process power consumption data locally

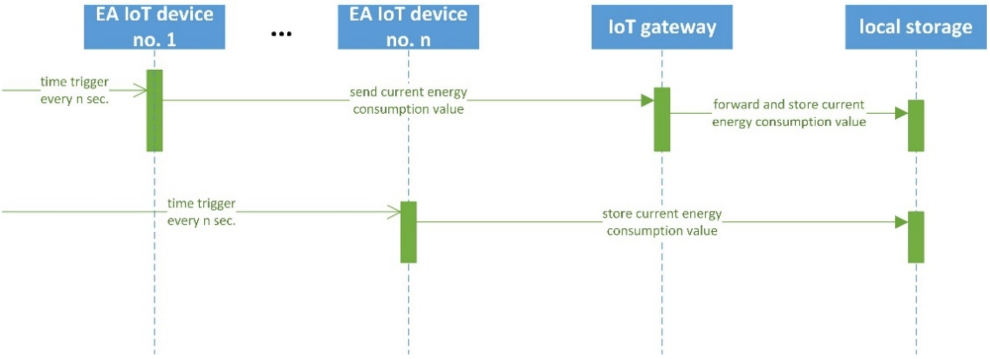

Figure 20: Energy aware IoT devices store data on local storage

Instead of sending energy and consumption data to a cloud storage device, one can store data also on a storage device connected to the local network. Every household would have its own data storage and processing device. Remote access to energy consumption data on a local storage device should be blocked from the firewall. Figure 20 displays the communication messages to the local storage from IoT devices that communicating over an IoT gateway or are connected directly to the network.

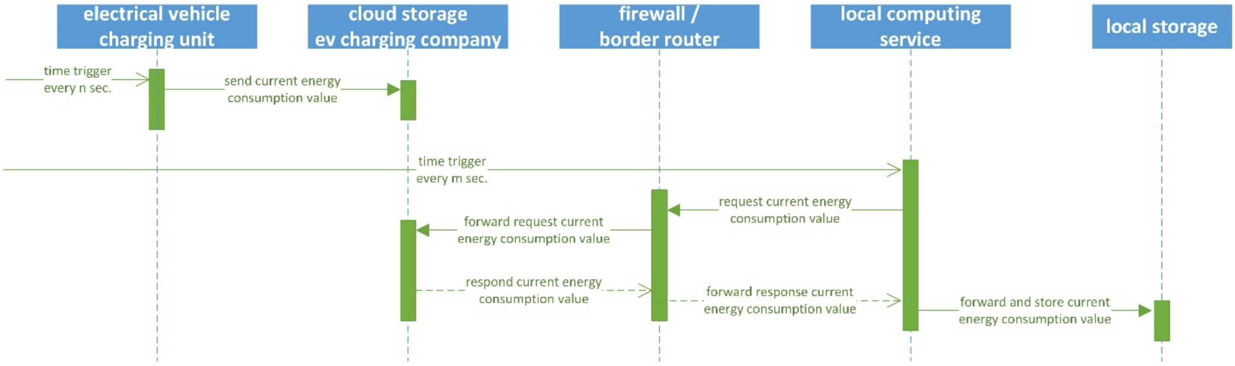

Figure 21: Copy power consumption to local storage from cloud storage of IoT device manufacturer

To get data from energy aware IoT devices that store consumption data to the cloud storage of the IoT device manufacturer, a local computing service needs to read this data and store it to the local storage (see Figure 21).

If power consumption or forecast data are stored locally, there are advantages or disadvantages as well for such a scenario. Of course, many advantages of a cloud storage architecture are disadvantages for local storage architecture and vice versa.

Advantages:

- data does not leave the local area network: data security and privacy
- no permanent internet connection needed

Disadvantages:

- individual maintenance (e.g. software update) of local storage and processing equipment needed
- use cases where consumption data of more than one household are needed cannot be implemented (e.g. “peak clipping” for utilities)
- for energy aware IoT devices that are communicating to a cloud storage of its manufacturer (e.g. “electrical vehicle charging unit”) internet access is needed anyway
- if remote access to consumption data of IoT devices is needed, the firewall needs to allow inbound data traffic

10.2.3 Store power consumption and forecast locally / store aggregated data to cloud

To minimize concerns about data security and privacy, single point of failure, etc. one could store all current or forecast data of energy aware IoT devices on a local network storage device. A local computing device could aggregate and pre-process the measured data and forward the result of consumption for a household in total – not for individual devices – to a cloud storage.

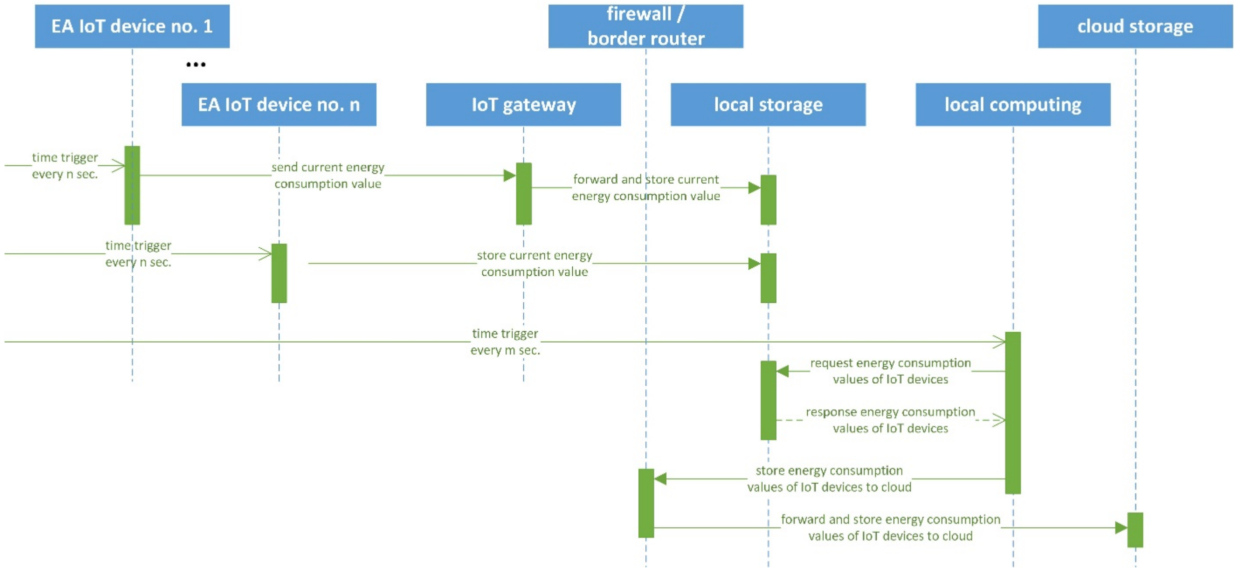

Figure 22: Store data locally and forward it to the cloud

Energy aware IoT devices send their data to a local storage device first. After that, a local computing device reads and aggregates data from the local storage and sends it to the cloud storage (see Figure 22). The software program running on the local computing devices transfers the data needed finally to the cloud storage.

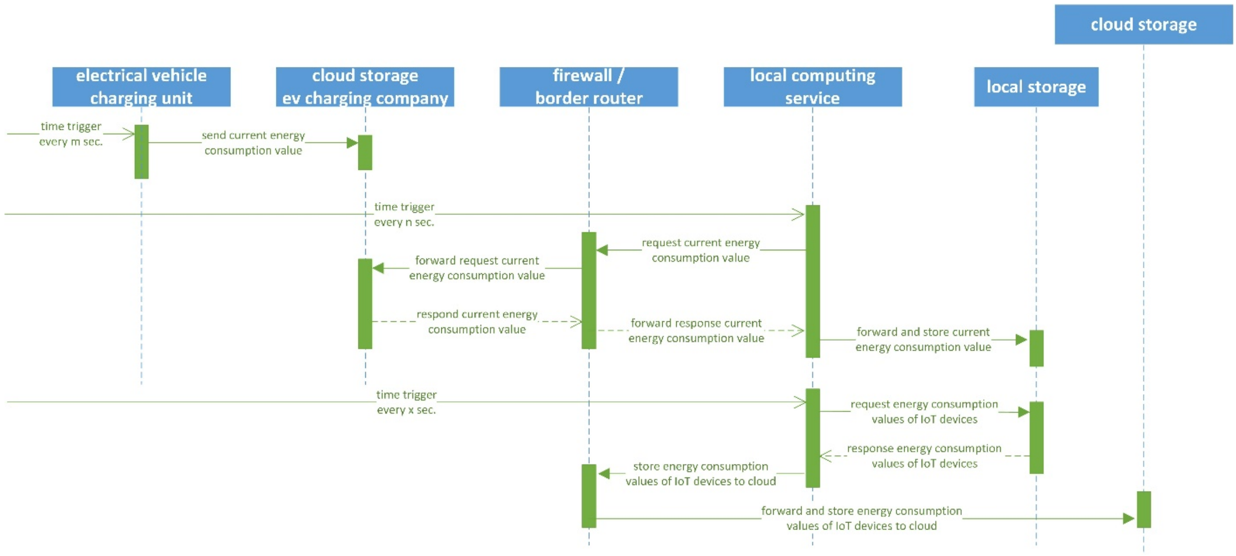

Figure 23: Copy power consumption to local storage from cloud storage of IoT device manufacturer and forward it to the cloud

For IoT devices, which store consumption and forecast data to the cloud of the manufacturer, an additional step is needed to collect and store the data values into the local storage (see Figure 23). After that and similar as shown in Figure 22, a local computing device reads and aggregates data from the local storage and sends it to the cloud storage.

Advantages:

- data of individual devices do not leave the local area network straight away: data security and privacy
- software on local computing service decides which data are copied to the cloud
- no permanent internet connection needed

Disadvantages:

- individual maintenance (e.g. software update) of local storage and processing equipment needed

10.2.4 Switch devices remotely and individually in every household

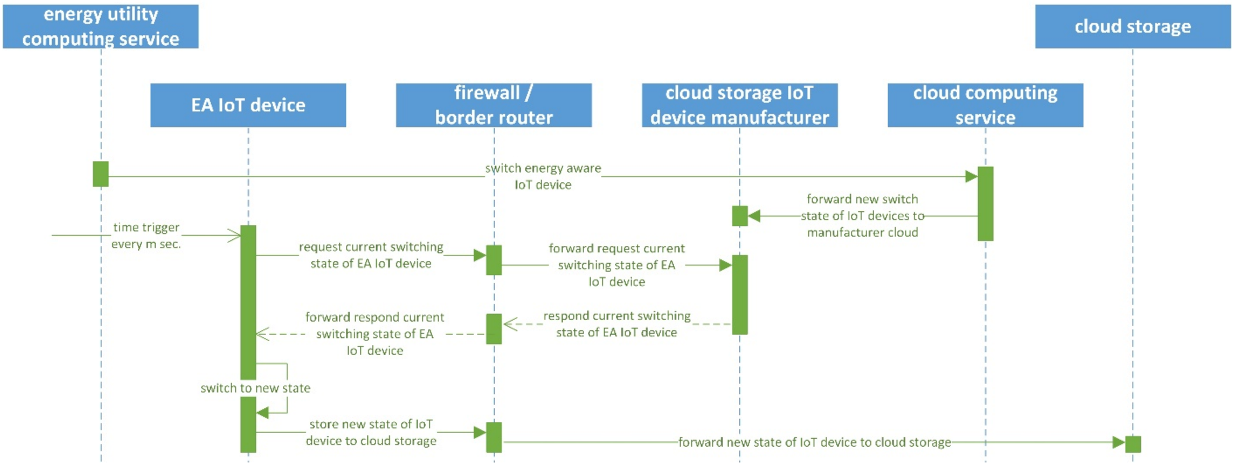

Figure 24: Remotely and individually switch energy aware IoT devices in households

Because of IT security, one cannot control the state of energy aware IoT devices directly through the border router and firewall of a household from an external device connected to the internet (e.g. from the server of the energy utility).

Therefore, switching the state of an IoT device needs several steps. Initially, the energy utility sends the new state for a certain IoT device to a cloud cloud computing service. The cloud computing service forwards this new state to the API of a cloud storage service from the IoT device manufacturer, which works as main interface to the IoT device itself.

The energy aware IoT device checks regularly the cloud storage service from its IoT device manufacturer. If the state of the IoT device should be changed, the IoT device sets the new state and stores the current status information to the cloud storage at the end.

10.2.5 Switch devices in local environment

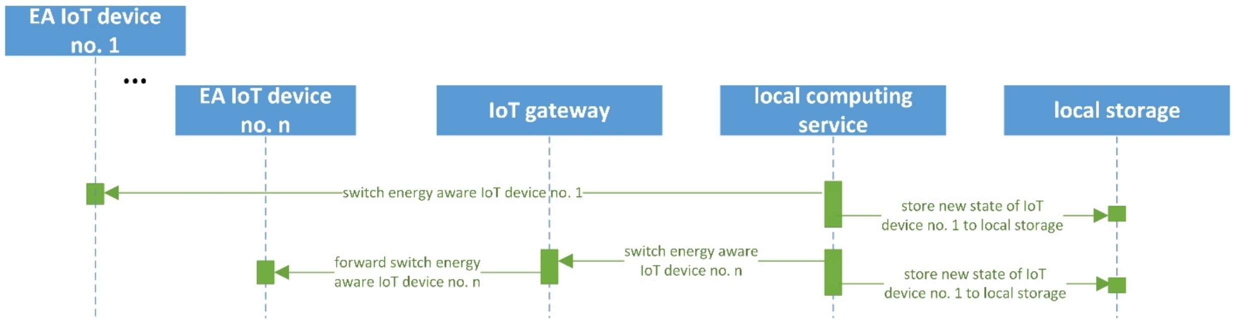

Figure 25: Switch energy aware IoT devices in local environment only

If energy aware IoT devices are only used and accessed within a local network, a local computing service can access them directly or via IoT gateway (see Figure 25 above) and set their operating state (e.g. switch on/off). Provided that the IoT device itself or the IoT gateway have an API to control them directly from the local network.

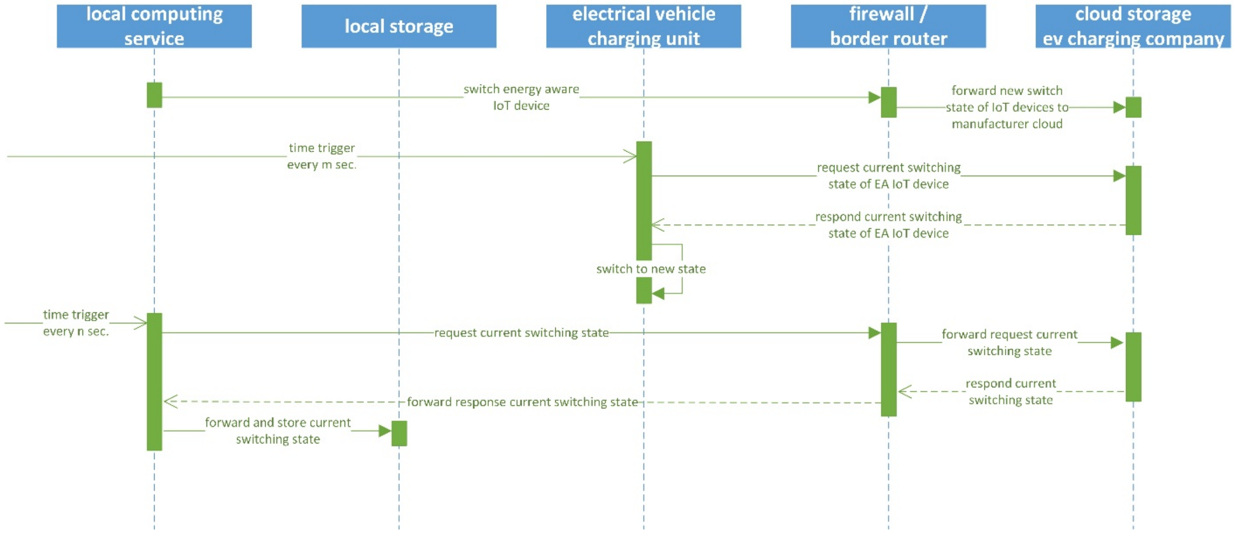

Figure 26: Update state of energy aware IoT device if the device is not part of the local network

For energy aware IoT devices, that are not integrated to the local network (e.g. “electrical vehicle charging unit”) – and if only local computing services should access the IoT device – the local computing service needs to access the cloud storage / service through firewall / border router to set a new state of the device.

Figure 26 displays a scenario where the local computing service controls the “electrical vehicle charging service” and finally stores the current state to the local storage.

10.2.6 Switch groups / categories of devices

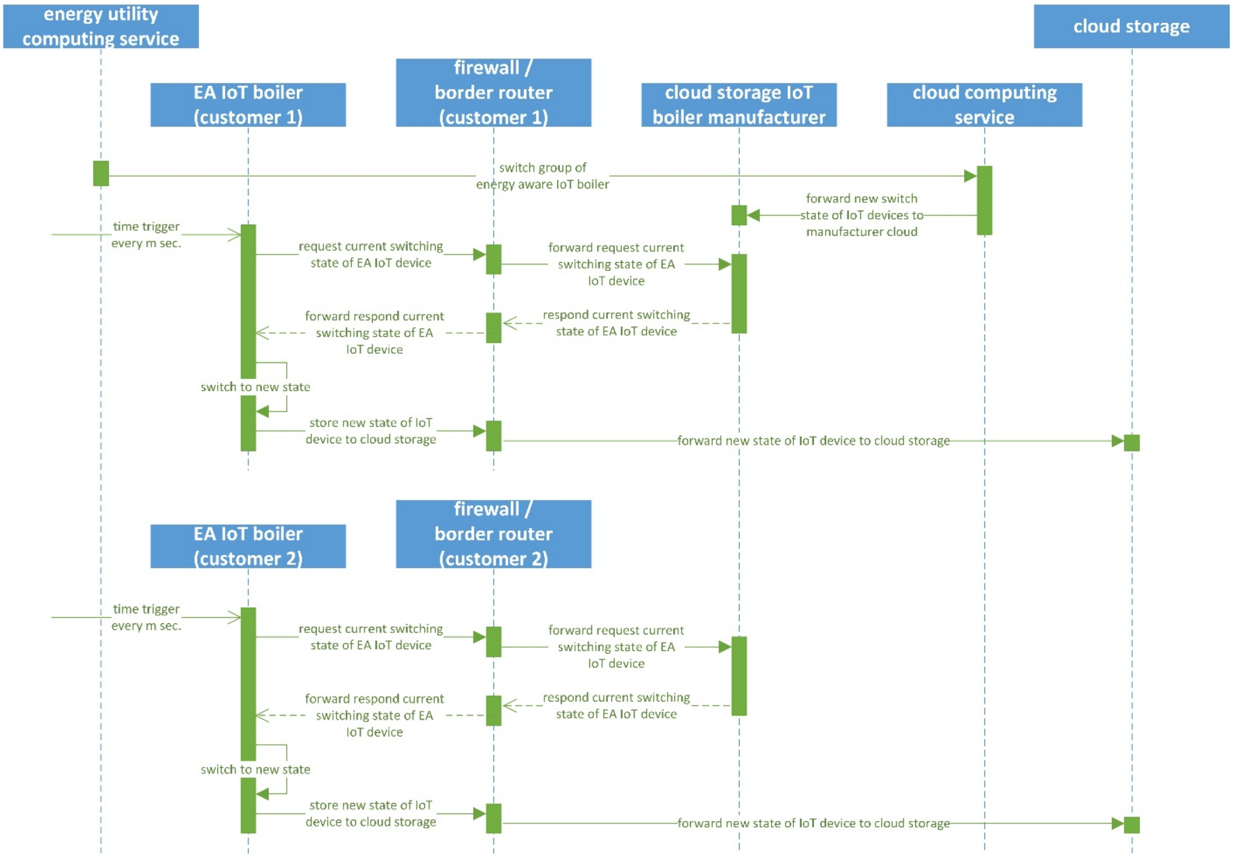

Figure 27: Switch group or category of energy aware IoT devices

To control a group or category of devices (e.g. boilers or heat-pumps for heating systems), the energy utility computing service can send a control request to the cloud computing service, which forwards this request and set the new state to the individual cloud service of the IoT device manufacturer. Regularly the IoT devices check for their new state on the IoT manufacturer cloud. If the state has changed, it updates its state and stores it to the cloud storage.