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Faculty of Science and Technology of the University of Coimbra

# Development and monetization of an energy data and analytics platform

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*para os meus pais e avós*

## Resumo

Energia é uma questão global preocupante. Melhorar a eficiência energética presente é essencial para atingir um desenvolvimento sustentável, sendo ainda uma das formas mais limpas, rápidas e eficazes de atacar o consumo energético e a dependência de combustíveis fósseis[1]. O mercado energético residencial é responsável por uma componente relevante do consumo energético global, representando 26,65%[2][3] deste na Europa apenas, e onde 20% dessa energia é desperdiçada[4]. Em contrapartida, este é um mercado fragmentado e muito dependente da atitude e circustâncias de cada cidadão, apresentando-se como um grande desafio na melhoria da eficiência energética.

Existe assim um esforço importante de evangelização e inovação a ser desenvolvido neste sector, de forma aplicar eficazmente a politica energética atual[5][6] e atingir resultados concretos. Vários conceitos têm surgido neste contexto que se apresentão como promissores, tais como a Smart Grid, Cleantech, Open Data e até mesmo o potencial da chamada Internet of Things. Todos estes elementos permitirão aos consumidores, *utilities* e governos proporcionar a mudança de hábitos de melhorar a performance energética presente.

O trabalho apresentado nesta tese de mestrado consistiu em desenvolver uma plataforma aberta com o objectivo de ajudar consumidores a atingir o seu potencial de poupança energética. Os seus desafios são: criar uma solução tão agnóstica ao hardware quanto possivel, suportando as principais fontes de dados; fornecer métricas e simulações de consumos que permitam compreender o impacto dos seus hábitos e escolhas, bem como monitorizar o seu progresso; explorar o potencial da Internet of Things e da Cloud no contexto da gestão de energia residencial. Por fim, ter como objectivo desenvolver uma solução pronta para entrar no mercado e que seja eficaz e sustentável no seu esforço de eficiência.

# Abstract

Energy is a global, pressing issue. Improving energy efficiency is key to achieve sustainable development, while being one of the cleanest and quickest ways to impact energy consumption and reduce fossil fuels dependency[1]. The residential market is responsible for an important part of the global energy consumption, with 26,65%[2][3] in Europe, and where 20% of all energy is wasted[4]. On the other hand, being a fragmented market, and highly dependent on individuals convictions and circumstances, it presents a great challenge for energy efficiency increase.

Hence, there is a crucial effort of evangelization and innovation to be made, in order to effectively execute current energy policies[5][6] and achieve objective, concrete results. Some concepts appear in this context as important enablers, such as the Smart Grid, Cleantech, Open Data and even the potential of Internet of Things. All these will have a key role in providing the consumers, utilities and governments, tools to drive change and improve efficiency.

This master thesis work consisted in developing a open, as in data and communication, platform to help residential consumers understand and achieve their savings potential. Its challenges are: to build a pro-hardware agnostic solution, supporting the main open data sources available and enlarging the potential interested consumer base; provide actionable metrics and consumption simulations that give insight to the user and help understand the impact of habits and choices; explore the potential of Internet of Things and cloud based energy management. Achieve this in a market-ready solution that can be sustainable and effectively drive change.

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*Try not to become a man of success but rather to become a man of value.*

Albert Einstein

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# Chapter 1

# Introduction

In this introduction will be presented the overall context of the Master thesis. It covers the motivation for this work which should justify the theme and goals selection. It will be presented the bigger picture project to which this work fits into, and how they are integrated by this thesis scope. Finally, a report structure is offered for a better understanding of the topics covered in each chapter and section.

## 1.1 Motivation

### 1.1.1 Context

Energy is a topic of global concern. We have been using the available resources in an unsustainable way while creating destructive secondary effects. This stoped being a problem to became a fact. The questions now translate to how can we turn this trend around?

Unfortunately, the answer won't be present in this thesis. But this change in habits will only be achievable with a global effort, fought in every point where energy is produced, transported and consumed. In this long tail of different energy issues, the residential market appears. Our homes are responsible for 26,65%[2][3] of energy consumption in Europe alone. And yet, studies show that 20%[4] of this energy is wasted in many bad habits or ineffective use of energy consuming devices. In the energy consumed at home, electricity is the easiest to measure and control effectively. It is on this subtype of energy this work will focus.

If we waste 20% other studies show that we can recover at least 5-15%[7] with some level of behavior change through direct feedback mechanisms. This data is solid, yet it is mainly achieved in pilots created for validation, frequently within a eco-friendly country. Real world scenarios are harder to improve, where technology, geography and culture separate our homes in very different cases.

The Smart Grid deployment will provide data and in some case interesting tools to improve energy efficiency. This trend is also enforced by the several policies and governmental efforts presented lately[5][6].

In this overall context we end up with fragmented ecosystem, where improvements are difficult and implemented in different gears. This fragmentation slows down the adoption of many solutions in this field, while offering frequently a broken for the consumer, which is the key stakeholder in this process.

### 1.1.2 Convergence

Intelligent Sensing Anywhere (ISA) is a Coimbra based telemetry company that has worked in the energy field since its establishment and recently has been working in monitoring and control systems for the residential market. Their first approach was the iMeter, that is presently being replaced by Cloogy.

The know-how of ISA regarding hardware and telemetry is solid, so it would create little value to work on something that already as a team knowledgeable for the matter. However, Cloogy can be a key element in any home energy management strategy, which makes it an interesting product to follow and work with. Hence the question was what could be developed while adding value to this ecosystem?

In the preliminary research for this thesis, some padrons emerged that eventually gave body to this work. Solutions like Cloogy are very focused on the hardware and are generally developed by companies with a hardware background, such as ISA. Still, present technology and specially web and mobile applications are currently ubiquitous in our day-to-day lives. This led to the challenge of creating a web and mobile service that builds upon the monitoring systems and leaps forward beyond the web applications on this field.

The web and social media are now a must have in any strategy of communication, awareness and evangelization[8], and even utilities are starting to understand that they need to use this channels to improve their costumer relationship[9][10]. This new technology wave offers a premium challenge for the diverse and fragmented stakeholders of home energy management came together to serve the consumer and drive energy efficiency. This necessity of consolidation in a new communication frameworks is already acknowledge by the White House[5] which has been promoting open standards and consumer education with a focus in the User Experience.

Looking on the present offerings of top of the shelf metering solutions like TED5000[1] and Current Cost[2] show that this user experience has been a second priority, and the web/mobile interfaces for this systems are generally outsourced our very raw offerings. Hence the first goal was to build a web platform that gathers data from all the top sold, open systems, and presents data in a effective, coherent service.

Beyond that, it stands out that in home displays and simple data presentation tend to become ineffective in the long term, since the novelty wears off[11]. This presents another challenge of retention and sustainable savings that can be tackled with the platform offered by the web through a two-way interaction were the user not only sees data, but interacts with it, and gets feedback and challenges. Eventually, even a social layer can be added to this, were the consumer can compare his performance with Facebook friends and neighbors.

This approach is already present here and there in some home energy management company offerings like OPOWERs or Simple Energy. However, there is still a vacuum of a open, as in data, solution that enables the innovation necessary to tackle this energy issue, as championed by the White House with the Green Button[5]. This open mindset creates a perfect match that empowers the future to come of smart cities and Internet of Things, making a potential key element in the future home energy management ecosystem, as the web service that connects everything, educates the consumer, and manages the elements to effectively reduce energy consumption.

And this resumes the motivation and vision for this work, which focused on creating this innovative service and deliver it to the consumer directly in the time frame of this thesis, hoping to learn and evolve from the experience beyond that.

## 1.2 Project

The vision presented in the last section evolved into a project that eventually grew beyond it. In this section, the overall project will be presented. Following that, the scope of this master thesis in the context of the project is defined, and concrete objectives are set for this work.

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[1] http://www.theenergydetective.com/

[2] http://www.currentcost.com/

### 1.2.1 Goals

The general goals with this project are:

- To provide an easy yet effective way to monitor energy consumption
- To act as catalyzer for consumers to improve efficiency and cut waste
- To measure developments and results of consumers actions
- Be global, market and hardware-wise

To achieve these goals successfully, this can only be done with a focus on usability and ease of use, on the top of a powerful analytics engine and a global hardware support.

### 1.2.2 Team

The overall project is to broad and complex to be tackled by one person. Hence, a small team was formed to engage the problem, picking the members carefully to cover all the top technical topics necessary, and complement this master thesis work.

- A Designer, to create an effective interface and a functional user experience.
- An Informatics Engineer to focus on the mobile applications.
- An Informatics Engineer to be primary responsible of the web development necessary.

The team is then completed by the author of this thesis, focused on the hardware integration, data analysis, and exploration of Internet of Things potential

#### The role of a Physics Engineer

Building such platform may be seen as an unlikely fit for an Physics Engineering master thesis. However this challenge requires an also unlikely set of skills. It is true that most of this work is programming and web development, yet it would be difficult for a person with a different background to effectively deal with data analysis and communication systems, while understand the meaning of each data point.

### 1.2.3 Business Model

This work title hints clearly to the underlying effort of making this platform financially sustainable. This was a focus of the project since the beginning. The development and validation of such business model is a work by itself that was effectively developed continuously during the time span of this thesis. However such effort will only by lightly mentioned in the final conlusion, since it adds limited value to an engineering master thesis.

## 1.3 Thesis Scope

In the project context, this master thesis focuses on the following scope:

**An architecture that enables cloud-based home energy management** build for the future with a vision of innovation and integration with the energy related Internet of Things.

**Data Analysis** that provide meaningful, actionable insight for the user to track and improve energy performance, while respecting the meaning of data.

**Simulations** that try to model and predict future energy consumption of a given home, considering the characteristics supplied and the weather forecast. This will be the most experimental and uncertain aspect of this work, and it should be understand that it will be most likely a mere first step for such prediction models.

**Integration with monitoring solutions** making the platform stand out by its broad support of monitoring solutions, in a effort to make it hardware agnostic and this way create convergence in a otherwise fragmented ecosystem.

## 1.4 Report structure

This report covers a wide range of topics, mostly well known. The special value of it may be seen on the intersection of such subjects, maximizing value for the final user.

The second chapter is about the current state of the energy market and ecosystem, to give a grasp about the needs and opportunities that can and should be covered. It also serves as an implicit, broader presentation on the motivation to develop work on this field. It ends with a state of the art analysis of the solutions available in this space and theirs overall specifications.

The third chapter gives an overview of the platform. It covers the communication and integration options and use cases available, between power monitoring devices of several types and the respective infrastructure. The architecture and technological options made for the implementation are also presented.

The fourth chapter presents the integration between the platform and the several data sources relevant to our platform. Further systems to be supported in the future and possible performance improvements are also covered.

The fifth chapter presents the data analysis and modeling features used in the platform. A simulations engine for home consumption is presented. It also considers what could be the future work to improve such analysis.

Finally, this master thesis ends with a conclusion, concerning the overall scope of this work, providing some insight about the general achievement of the proposed goals, and reasoning what may lie ahead in this field.

# Chapter 2

# Energy

## 2.1 Introduction

Energy is critical to our society way of life. It is also a very broad subject; hence our best change to improve this field is to tackle problem by problem in each battlefront. Electricity production, transport and consumption are an example of that. This process is currently very inefficient in several of its steps, requiring improvements in the overall process. That is the mission of the Smart Grid technology, presented lightly in the next section.

In this thesis however, the focus is reducing waste in the consumer house. In the average home, 20% of energy is wasted and contrary to the industrial market, the cost is more lightly overlooked. People generally don't even fully grasp how much they pay for energy. The ones that do generally do not know how they can optimize their consumption, or don't have the right information and motivation to tackle inefficiencies.

Hence there is a clear need for solutions that engage the consumer in some way, providing the information and tool to optimize theirs energy performance. Some of this tools and processes are presented in section 2.3

These efficiency effort might be greatly enabled by the Smart Grid and some concepts that arise from it, such as demand response, which prices energy differently for each instant depending on the energy that can be produced in that time-frame. This increases production and transport efficiency, but still requires a informed and alert consumer to use it's full potential.

This new energy ecosystem with real-time, actionable information has hence the potential to improve greatly our society energy efficiency in the residential market. [12]

## 2.2 Smart Grid

The Smart Grid concept focus on expand the current state of energy distribution through the implementation of digital technology in the process, allowing a more precise monitoring and control of the energy flow. With the Smart Grid, societies can have a more flexible, accessible, reliable and economic electricity networks.

This wealth of information and control gives room to a new interaction between all the stakeholders of electricity networks, from the users to the utilities producing and delivering energy. This will unlock potential to more user-centric services, more liberalized markets and a increment on efficiency in every link of the electricity flow[13]. The gap between wholesale and retail prices should also be reduced, resulting hopefully on lower energy costs for the consumers[12].

The more interesting vision for this project is the potential to engage users and counter the present apathy and disinformation towards utilities and energy in general [7][14]. It presents a unique opportunity for utilities improve this relationship, providing new services and promoting energy efficiency. The more liberalized and agile competition between utilities should also benefit the consumers with lower prices and/or better quality of services[15].

This context which is by itself positive for the consumer, can be greatly improved if utilities move to a more consumer-centric framework, giving more control to the users about their energy[16] and information[17][18][5].

From the ecosystem point of view, open standards have proved to be a powerful enabler of innovation. By providing easy and open access to the network and its communication protocols, the innovation on this space will be democratized to smaller players with disruptive potential. Without an open baseline, innovation is limited to and by the lobbying power of the set players in the space, reducing the potential of evolution in this space [16].

This innovation effort has been pushed in the agenda of the European Energy Policy[17][18] and the White House Energy Policy[5], being the most notable evidence the Green button and the surrounding effort to create value around it[19].

## 2.3 Home Energy Management

This is somewhat a recent field, yet many solutions and concepts have been developed and are now trying to engage the market[20][21][22][23][14].

The main drivers for the adoption by the consumer of this type of systems are [24]

- Monetary savings
- Lower ecological footprint
- Increased convenience
- Higher transparency
- Technological orientation

However, some of the customer needs are not being completely met by market offers, such as convenience, transparency and usability. This proves that if it is true that people are ready to adopt this kind of technology, the solutions offered are not yet matching the customer needs[24].

In the following subsections, a more methodic analysis of Home Energy Management processes and market solutions is presented. It also separates the academic studies and concepts from the products offered by the industry.

### 2.3.1 Literature Review

Here a simple state of the art review will be presented, based on the most relevant research topics on the context of Home Energy Management.

#### Energy Management with the Internet of Things

Most of the present technology aimed to increase energy efficiency is based in sensing and monitoring energy consumption, using the information to provide feedback to the consumers and drive change. However, on high-end and industrial markets, smart energy management solutions start to appear [25][26][27], where this sensors are complemented with actuators to effectively manage energy consumption through automated and/or remote controlled systems.

Various concepts for this kind of automation have already been tested in common households with lower cost solutions. Some of this systems offer remote control through mobile applications that connect to Home Area Networks, were a network of sensors and actuators enables remote monitoring and controlling, creating together potential for effective savings[28][29].

Some concepts take a step further and create simple but effective automation by turning on and off electrical appliances automatically in response of the presumed presence of people in the house, using mobile phones as indicator[30]. Others explore the possibility of smart management of heating and cooling solutions with a network of sensors that can indicate current state of the home and consumer presence[31][32]

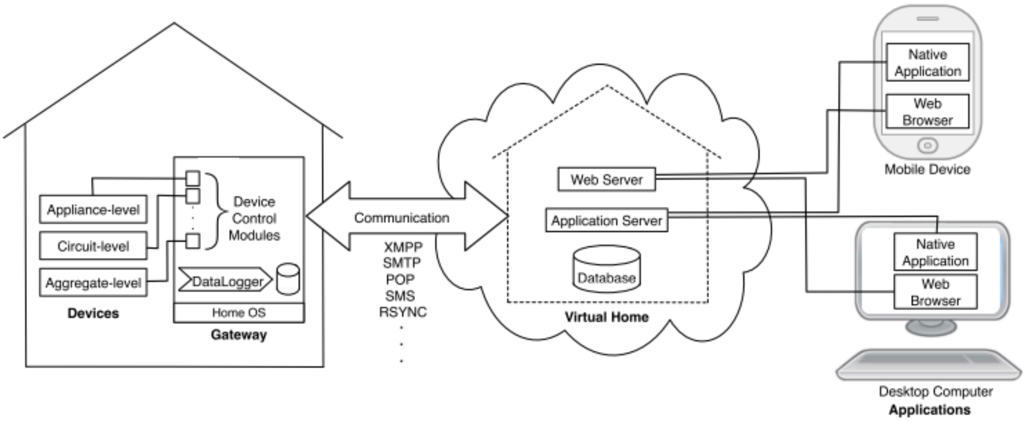

Figure 2.1: HITS: A Cloud-Based Flexible Architecture for Home Energy Management [29]

### Load disaggregation

This is one of the most sought out solutions to help empower consumers about their energy, by presenting the energy consumption of each appliance while monitoring just the whole house. Such feat can be achieved by desegregating the load monitored in the several appliances using their unique electric signature[33].

Still, in practice, researchers yet failed to present an accurate, working algorithm which can effectively make such disaggregation with standard, mass market meters[34][35]. The state of the art seems to indicate that this will only be effective using data with great granularity, collected at a frequency above 1Hz. This soft threshold implies that most power meters in the market today are unfit to provide accurate data. Even with smart meters, it may be necessary to push the technology deployed in everyone's home forward to achieve the so called holy grail of energy efficiency with precision[36].

### Behavior Science

This may be the less technical topic presented in this thesis, yet its importance driving user savings is crucial. It proves that pure tech and great products alone are not enough to achieve our saving goals. Since in many cases great savings can only be achieved with a change of habits, the process to induce changes in consumer behaviors is a critical issue.

It can be said that the first part of this process is the importance and

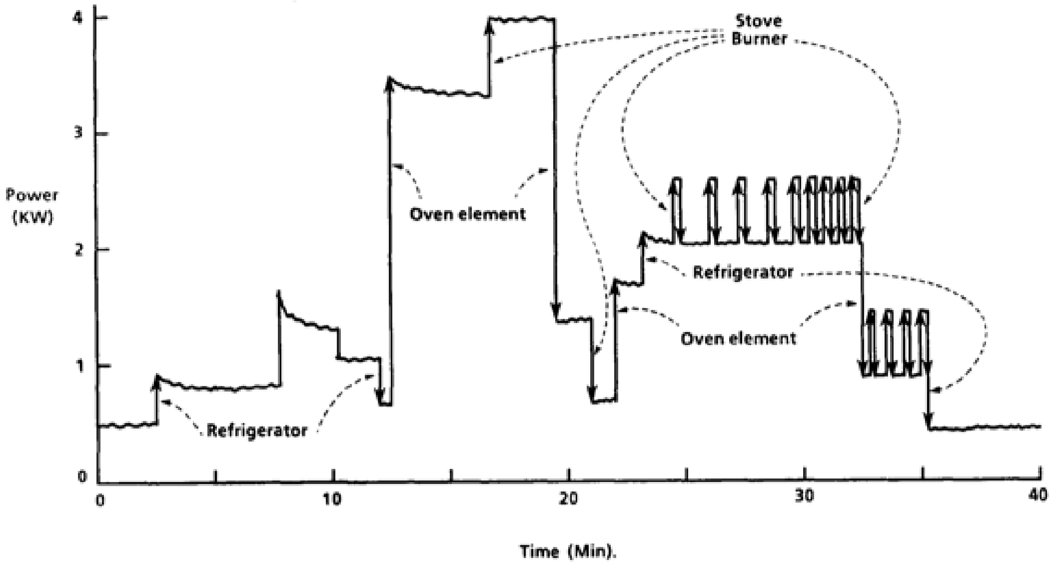

Figure 2.2: Power versus time (total load) shows step changes due to individual appliance events[33].

impact of energy consumption feedback, and how to optimize such feedback in order to achieve the best results. It has been since proved that indirect feedback allows 0% to 10% reductions, while direct feedback results in 5% to 15% reductions [37].

Feedback is unarguably good and drives change. Yet, its novelty wears off. Long term engagement solutions are required for continued savings [22][37]. Such engagement in the form of a constant interaction and feedback may help reduce rebound effects[38][39] as the ones presented in [40], and that has created some discussion in the scientific world.

Taking the behavior science for a different level, much progress has been made with the gamification of energy consumption, appealing to the competitive nature of humans. This approach works particularly well in some demographics and cultures, achieving great improvements in performance [23] [41][42].

In the more simple interactions such as smart billing, which consists in sending detailed reports to consumers about their energy consumption, the basic decision of offering energy efficiency programs in opt-out or opt-in, results in dramatically different results due to the customer inertia to refuse [22]. The characteristics of the households also have a meaningful impact on results [43]. Energy efficiency programs should offer different approaches for different customer segments, or eventually consider a complete, fully featured offer for the overall market, with the risk of making it to confuse.

The impact of web as a information channel and its response from users still requires more broad study. Some pilots have occurred with different results, and different approaches, achieving savings from 0,04% to 17%. Yet it seems to be clear that more than the web, which can be more easily accessed by some generations than others, the way the feedback is displayed impacts clearly the final outcome. Data visualization may have a bigger role on improving energy performance than the technology itself.[7]

## 2.3.2 Hardware solutions

We can divide the energy monitoring systems in two types: smart meters which consists on a communicating utility main meter; and a so called power meter, a device that is most likely redundant to the utility meter, that measures energy consumption and reports it. In this section, exemples of both are mentioned.

### Current Cost

Current Cost is one of the top sold power meters in the present. This system consists of a basic clamp and transmitter that communicates with a display through RF in the 433MHz band[44][45]. The gateway, which sends the data for the web, is optional for the Current Cost Envi kit, but required to send data automatically for the web.

The tabletop display shows data in real time, with a refresh rate close to 12 seconds[44]. However the resolution of data sent to the web is of just 5 minutes.

The data when communicated for out of the Home Area Network is then sent to the a data warehousing backend, which is integrated into Cosm, formerly known as Pachube. Cosm also offers a simple dashboard for users visualize better their data. [46].

Current Cost data can also be visualized on the web using third party web applications such as Enio, Plotwatt and Bidgely, which are presented in section 2.3.3

**Cosm, ex-Pachube** Pachube changed its name for Cosm last May[47], after making a brand for itself as a Internet of Things cloud enabler. It is focused on feeds of data that are streamed into the service by smart sensors. Users see it as a simple, effective way to store data online, and visualize it in a very basic interface. It also offers some rules that configure a response

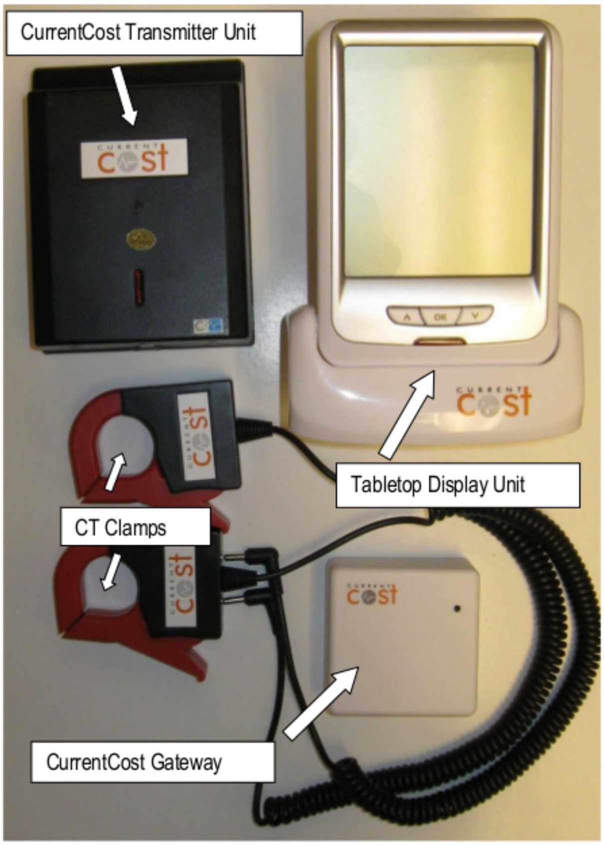

Figure 2.3: Current Cost Envi [44]

to predefined variations of the data values collected. This response is mostly through HTTP Hooks.

The use of Cosm as backend for Current Cost netSmart gateway allows accessing the data easily through Cosm REST API, which is one of the core features of the Cosm platform. On a more technical view, it should be mentioned that though Current Cost collects values every 5 minutes, Cosm only presents updates every 10 minutes. It is unclear where this buffering occurs, but it is most likely on the Current Cost Gateway.

Cosm also provides a web sockets service, although in beta[48]. This allows to a more efficient and faster communication of data, since the overhead of, sometimes fruitless, polling is avoided[49][50]. However the current instability of the web-sockets standard is used as reason for it not be supported in several cloud hosting providers, such as Heroku[1], the one chosen initially to host our service. Hence, the use of web-sockets as a protocol to import

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[1] http://heroku.com

Current Cost data from Cosm isn't a practical, production-ready option for now, although it was tested successfully in a development environment.

Cosm also provides some level of privacy, being the user able to choose between keeping the feed public or make it private, using an API-key as security token.

Cosm REST API has some restrictions to safe keep its performance, being the biggest the data one can ask for in a request. Independently of the time window, it sends no more than 360 data points. To achieve this it changes the data granularity. In order to get the full precision of data present one can not ask for more than 6 hours of data [51].

### The Energy Detective

This system is also web enabled and a reference on energy monitoring in the United States of America. It is a more raw solution, with bulkier parts but also of superior quality. Studies have shown that The Energy Detective (TED) present greater accuracy, standing out from other solutions[44]. Yet it loses in the global market, maybe due to the user experience it offers and the high price tag. The system bought for development and testing cost around three times the price of the others.

However the tools offered to communicate data to the cloud differs substantially from the other systems presented.

Instead of naturally posting the data stream to some default backend, TED offers an option to configure the system to post directly from the gateway to a given service[52]. This requires a different and more customized process to collect its data, since it is necessary to configure our platform to respond as expected to the system.

TED data can also be visualized on the web with third party apps such as Plotwatt, Bidgely, My Eragy which are mentioned in section 2.3.3.

### Open Energy Monitor

Open Energy Monitor[2] is a open source initiative based in the United Kingdom to create a complete open source system to monitor and understand energy consumption. Although it is more unreliable and less user-friendly, this project and similar provide a very interesting test subject, while shedding light about what users are looking for in this space. Its architecture is still similar to Current Cost Envi or TED, as can be seen on Figure 2.3.2

It is developed as a whole, open source solution, delivering also some web based open source software to present data in a more rich way. What

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[2] http://openenergymonitor.org/emon/

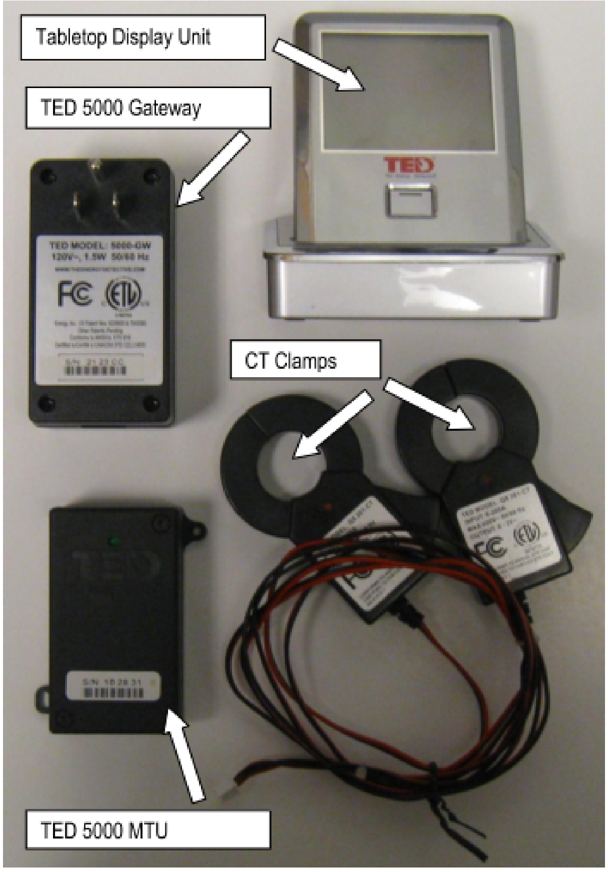

Figure 2.4: The Energy Detective 5000[44]

started as a small open source project, now has a growing community and even a company named Megni [3] was set up to facilitate the distribution of the system.

### Cloogy

Cloogy is a soon to be launched product by Coimbra based, Intelligent Sensing Anywhere. This power meter is the evolution of iMeter, an older energy monitoring system developed by the same company. It is on the final stage of development and testing, so it should be available to the public in the coming months. Hence, there is not much information publicly available, although access was given to several alpha and beta versions for testing. A picture of the kit can be seen in figure 2.3.2

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[3] `http://megni.co.uk/`

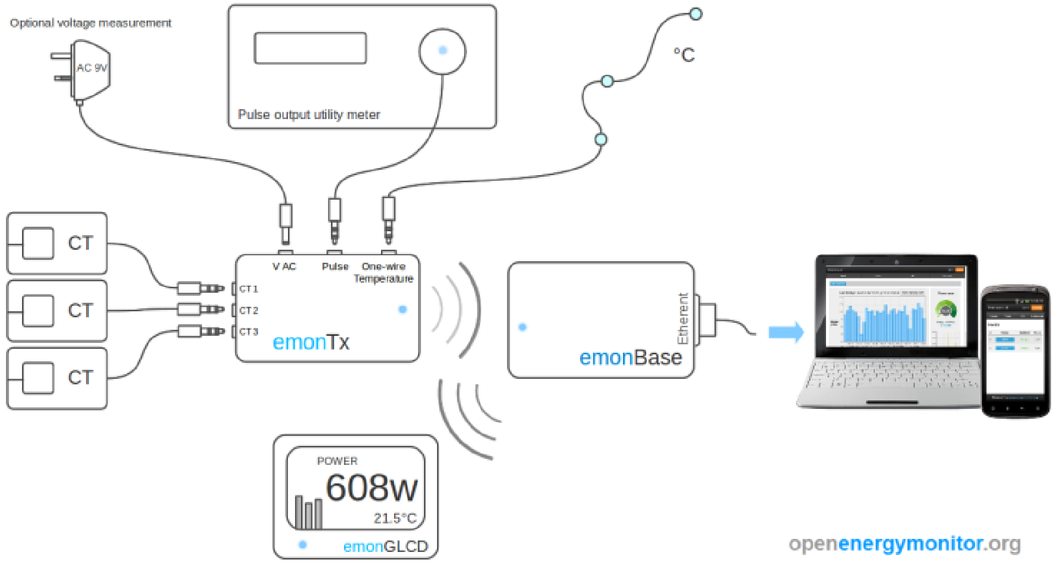

Figure 2.5: The Open Energy Monitor system [53]

It can be said that from a technological perspective, it will be comparable to Current Cost Envi or TED. Unlike these, however, it offers smart plugs that can be bought in kit or separately. These smart plugs allow monitoring individual appliances by being installed in the respective socket, but more interesting, they also allow to be controlled remotely, turning on and off the power supply to such appliances.

Its unique selling point will probably be on the improved web and mobile support and hardware user experience. However being the web and mobile apps be presented as an important, however complementary part of the system, it still to be seen what kind of development and improvement this will receive on the long-term.

### Smart meters

These systems are monitoring solutions deployed by utilities for billing inside the consumer house, being the most visible element for final users of the Smart Grid. This meters are able to communicate consumption data in real-time to the utilities allowing to better match the consumer needs with the necessary energy production and transports.

These systems may or may not be considered as a Home Energy Management solution. It will depend if the data acquired helps the user to take control of his energy consumption. But the trend in the market shows that

Figure 2.6: Picture of a Cloogy Kit

smart meters might be a enabler and even a critical link for a smart, digital energy management system by providing precise data in real-time.

This data, if properly used in benefit of the user, allows for tracking energy consumption and improve consumers' notion of energy spending, through services implemented on top of such data.

Hence, the Smart Grid and its Smart meter rollout may not only improve network efficiency, but also drive change in consumers' homes. This precious data will be available quickly for a great fraction of world population, resulting on a great, growing market ready for innovation, as long as data is open to innovation as presented in the section about Smart Grid.

### 2.3.3 Software solutions

#### Opower

Opower[4] presents itself as a utilities customer experience company. Their goal is to offer a new energy experience to utilities customers through new platforms of interactions. Their approach uses several complementary means of information, such as home energy reports, online tools, energy alerts, customer service representatives and the so called insight engine, that treats the data to make it actionable.

Their biggest edge for savings is the exploration of behavior science and

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[4] http://opower.com/

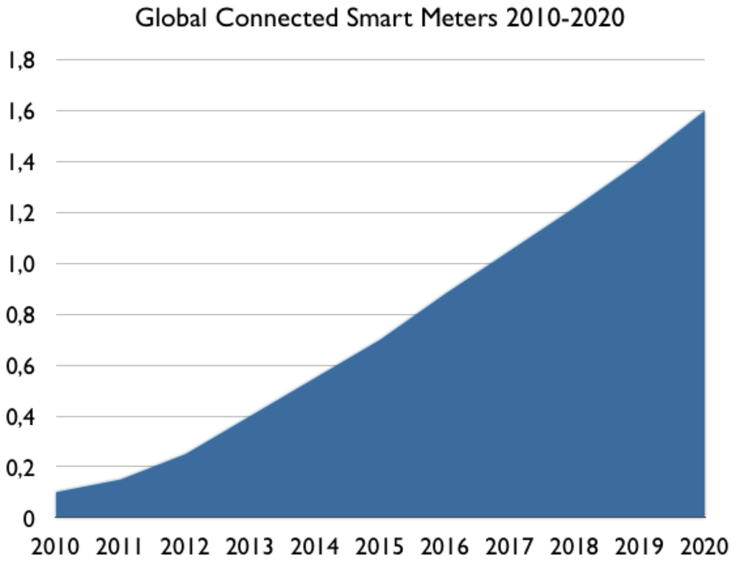

Figure 2.7: World deployment predictions for smart meters in Billions[54]

the human competitiveness in a subtle way, by comparing consumers' consumption with similar households.

Opower energy efficiency program which is mostly focused on the home energy reports have attained savings of up to 3,5% annually on average[55][7]. It is a respectable value for an average of savings in a real world market. Yet it should also be said that utilities are the one and only client of Opower, looking for a solution of engagement. Although utilities are willing, and sometimes enforced to, sacrifice some financial results on energy efficiency and the consequent customer retention, it makes sense to consider that they are not interested in explore the complete saving potentials of Home Energy Management.

On a more recent and experimental effort, Opower has been working with smart thermostats[57][58], and more direct gaming experiences through their partnership with Facebook[59].

### Eragy

This United States Company is more close to hardware and automation. It provides simple energy monitoring integrating with The Energy Detective, Blue Line and eGauge[5], but is also integrated with automation and security solutions such as the ones from Control4. They provide real time moni-

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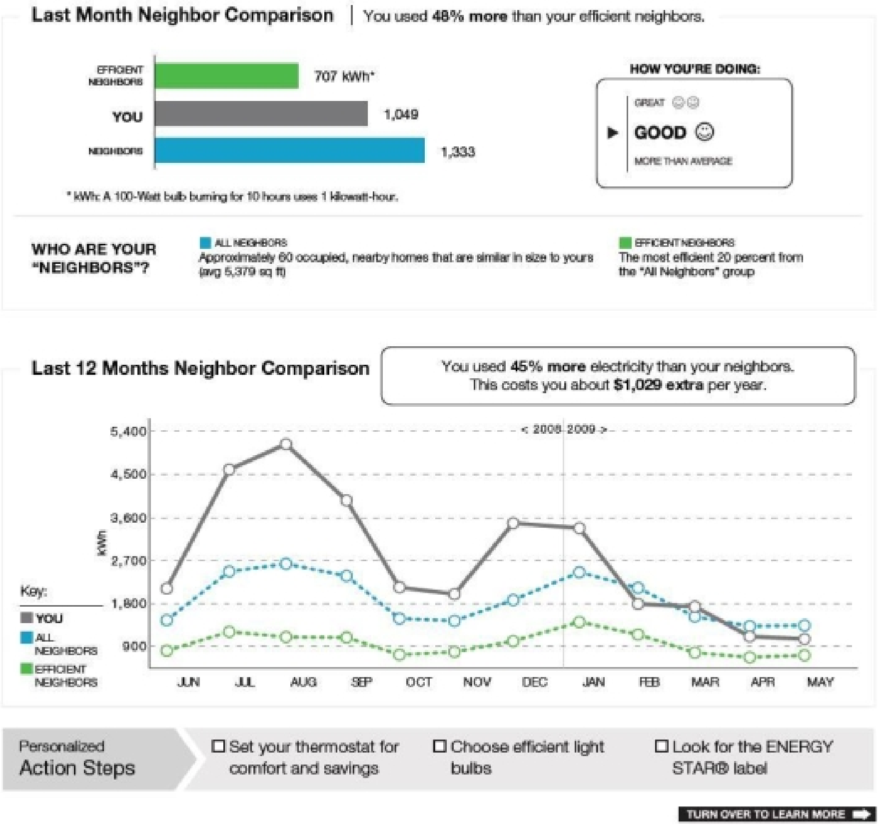
[5] http://www.eragy.com



Last Month Neighbor Comparison | You used **48% more** than your efficient neighbors.

* kWh: A 100-Watt bulb burning for 10 hours uses 1 kilowatt-hour.

WHO ARE YOUR "NEIGHBORS"?

ALL NEIGHBORS Approximately 60 occupied, nearby homes that are similar in size to yours (avg 5,379 sq ft)

EFFICIENT NEIGHBORS The most efficient 20 percent from the "All Neighbors" group

Last 12 Months Neighbor Comparison

You used **45% more** electricity than your neighbors. This costs you about **$1,029 extra** per year.

Personalized Action Steps

☐ Set your thermostat for comfort and savings

☐ Choose efficient light bulbs

☐ Look for the ENERGY STAR® label

Figure 2.8: Example of a Energy Home Report by Opower[56].

toring and enable energy management linking to automation through their closed and apparently straightforward service[26]. The platform is apparently closed, but ready to integrate with other systems for each partnership developed.

### Plotwatt

This service is more focused on the web, providing a more accessible platform. Its focus is on disaggregation of household energy data collect with of the shelf Power Meters[60][61]. Generally, as presented before, this hardware data sampling rate limits the precision of such algorithms[36]. However, it isn't easy to understand at which level of disaggregation plot watt can go, or in other words, which is the accepted error margin.

Plotwatt can be said to be working on making it hardware agnostic through the support of a wide range of power meters such as The Energy Detective, Wattvision, Current Cost and others. Still, Plotwatt does not offer an API for integration, which makes it a closed solution. It should also be noted that to make data disaggregation, data granularity is key. Hence it makes sense to limit hardware support to devices that enable effective disaggregation, since that is the focus of their offering.

The service offer is very similar to Bidgely[6], hence the latter won't be considered individually.

### Tendril

Tendril is a platform, more focused on the utilities market. It presents itself as a open, secure, scalable platform, supporting integration with enterprise applications[7]. Being their focus the utilities, in practice they collect data from smart meters of partner/client utilities and then provide them through the API, while providing also integration with complementary systems such has the Tendril thermostat, and the Tendril in home display[62].

So on the end the user can't really choose the system of monitoring, since he cannot put data in the platform, nor can the user take advantage of his smart meter data to control devices such as web-enabled thermostats. In this context, the platform may be promoted as open, yet it is limited by Tendril partnerships and utility clients[63]. Hence, it still doesn't offer a completely and truly open platform, agnostic to data sources and actuator devices, focused on the value for the final user.

It also offers an array of complementary services such as home energy reports, a basic web app and other features more focused on the utilities such as Demand Response, Load Control and Distributed Generation solutions[8]. Tendril seems to be interested in fostering the development of applications over their platform. This makes Tendril a very interesting partner to serve the final consumer with applications of added value.

The latest effort shown is Green Button connect, which aims to be a Green Button powered apps marketplace, that uses Tendril as middleware to get the data from supported utilities and theirs smart meters[64].

## 2.3.4 Mixed solutions

### Alertme

Based on the UK, Alertme[9] has a less focused offer. The Alertme platform is a end to end solution, combining energy monitoring, security[65][66] and

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[6] http://bidgely.com

[7] http://www.tendrilinc.com

[8] http://www.tendrilinc.com/platform/technology-approach/

[9] http://www.alertme.com

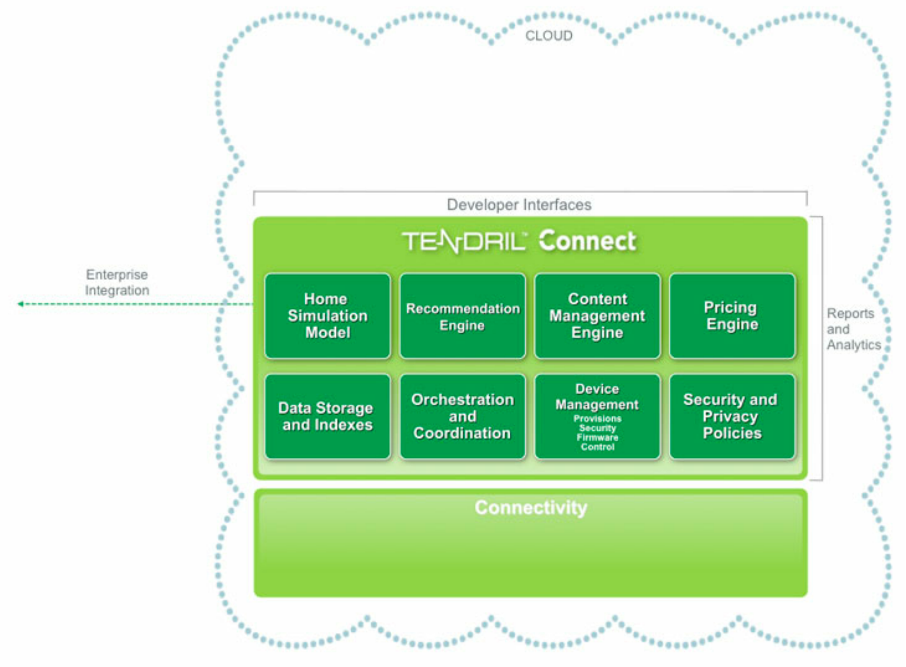

Figure 2.9: Tendril platform

automation, although it seems to have been leaning more into a smart energy position. They provide the sensors for energy, movement and carbon dioxide, educators for controlling electrical appliances, and a software solution to control this system via web and mobile.

They once allowed the energy data to be analyzed and presented through Google Power Meter (a deprecated web monitoring app by Google[10]), yet the Alertme solution is closed.

## 2.4 The Green Button

This program was started by the United States Chief Technology Officer Aneesh Chopra, after the success of a similar effort with health data[67][68]. The goal was to rally utilities across the country to offer theirs costumers' energy data on a open standard, making room for innovation and energy education. Presently, energy data of 27 million houses can be consulted via the Green Button[11] data standard[69], with more utilities working to offer it in the future[70][71].

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[10] http://googleblog.blogspot.pt/2011/06/update-on-google-health-and-google.html

[11] http://www.greenbuttondata.org/

This creates easy access to data that can be used by consumers and third-parties to improve energy management, efficiency and planning[64]. The drawback so far is that due to privacy concerns the data can only be accessed with user interaction. This creates friction for the consumer in services that aim for heavy data crunching and/or long term user retention, since the user needs to approve each data access which leads to time wasted on importing and data analysis. However, the standard is still evolving [72], so there is hope that a more scalable version Green Button appears in the future.

## 2.5 Overview

Table 2.1 presents an overall comparison of the HEM solutions presented before and other relevant systems. Analyzing all the ecosystem of Home Energy Management presented, we can see the lack of open cloud platforms that enable innovation with low costs. The only contender on such view was arguably the Google Power Meter, which was all in all a very simplified platform, and the HITS concept[29] proposed in the literature. This open platform should champion and support the open standards existing and in development.

We also see that with the Internet of Things, there will be lot of potential in connecting energy management with security[65] and even domotics for a more transparent and effective experience for the user, making room for great efficiency gains[26]. This requires a truly open platform, allowing data easily in and out through clear APIs and/or Protocols, while providing some level of intelligence and data visualization in the middle of this transaction.

This should be the vision of our platform.

| Solution | Platform | Openness | Web offering | Target |
|---|---|---|---|---|
| Current Cost Envi | Home-centric | API for data output | Dashboard | Consumer |
| HITS concept[29] | Cloud-centric | API for data output | - | Developers |
| The Energy Detective | Home-centric | API for data output | - | Consumer |
| Open Energy Monitor | Home-centric | Open | Monitoring and light analysis | Hobbyists |
| Cloogy | Home-centric | Closed, so far | Monitoring and control | Consumer |
| Opower | Cloud-centric | Closed | Monitoring and analysis | Utilities |
| Eragy | Cloud-centric | Closed | Monitoring and control | Consumers |
| Plotwatt | Cloud-centric | Closed | Monitoring and disaggregation | Consumer |
| Tendril | Cloud-centric | API for data output | Monitoring | Utilities |
| AlertMe | Home-centric | Closed | Monitoring and control | Consumer |
| Verizon HEM | Hybrid | Closed | Monitoring and control | Consumers |
| Nucleus Energy Monitor | Home-centric | Closed | Monitoring and control | Consumer |
| WattsUp | Home-centric | API for data output | - | Consumer |
| Wattvision Power Monitor | Home-centric | API for data output | Monitoring | Consumers |
| Plugwise | Home-centric | Closed | - | Consumers |

Table 2.1: Comparison of different solutions proposed for HEM, expanded and reviewed from [73]

# Chapter 3

# The Platform

In this chapter, the overall platform is presented. The first section covers the communication with the different models and complementary systems, and how the interoperability can be maximized while keeping a light, straightforward architecture. After, a small mention on the development tools is made, that explains the selection of the programming languages and frameworks for this work. To finish, a implementation section covers how this platform eventually came to be, explaining the architecture and how the possibilities of this system.

## 3.1 Communication

To create a hardware agnostic platform, it is necessary to provide an easy way to adapt and use method to upload the acquired data.

The TCP/IP is a confirmed technology, globally available at present homes and monitoring devices. However, higher-level protocols still need to be analyzed and prioritized. Different types of metering solutions are more easily integrated with some protocols than others. Hence, in the following subsection the main options are presented, with each strengths and weaknesses.

### 3.1.1 MQTT

Message Queue Telemetry Transport[1] (MQTT) is a lightweight publish subscribe open protocol working over TCP/IP, developed for sensors and actuators for use with low bandwidth and unreliable communications, developed

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[1] http://mqtt.org/

by IBM[74]. Recently it was adapted for Wireless Sensor Networks through the MQTT-S specification[75].

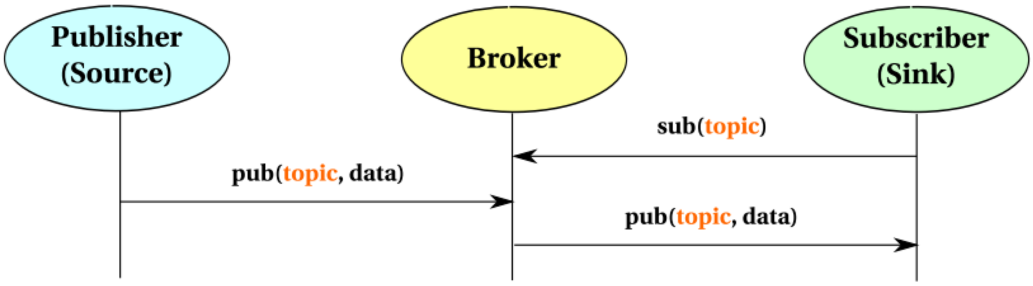

Figure 3.1: The Topic based Publication/Subscription model[76]

MQTT was originally developed to provide an open middleware for data in SCADA systems, making possible and somewhat simple connect the SCADA telemetry systems with other high-level enterprise applications. Its potential has a middleware for Automatic Meter Reading and real time power monitoring was even explored early by IBM[77]. Hence, it presents a strong offering for an agnostic middleware for communication has requested for this work.

The main advantages for MQTT are:

- Open protocol
- Has a reasonable community and broad use
- Brokers are available in the most popular languages
- More efficient than using polling, which makes it less demanding of network and CPU performance, while making it more scalable
- Enables real time/push communication

However there are some issues. These are

- Not really used in the generality of our potential data providers
- Has limited security

### 3.1.2 DLMS/COSEM

DLMS[2] stands for Device Language Message Specification and is an application Layer protocol[78]. COSEM stands for COmpanion Specification for Energy Metering and defines an object oriented data model for metering[79].

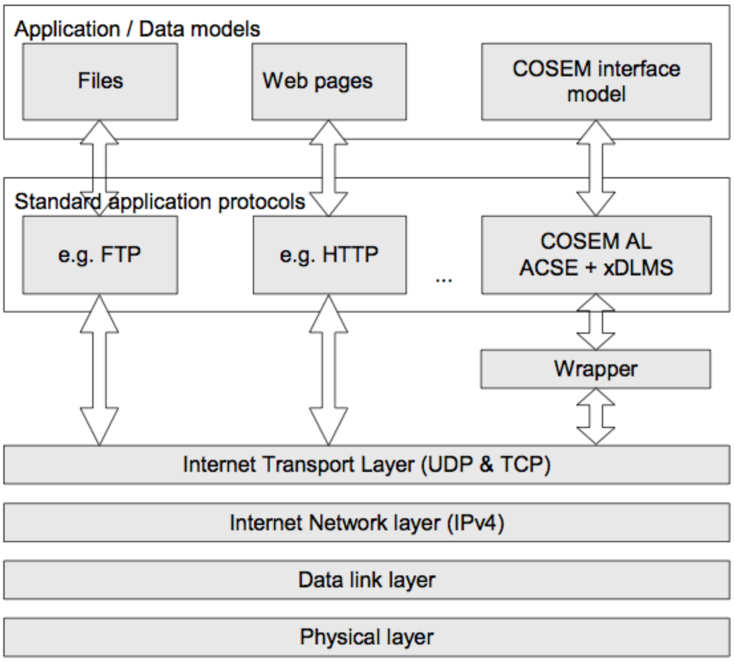

Figure 3.2: Example of a DLMS/COSEM stack[80]

This standard was created for remote reading and control of energy meters (electricity, gas) and water, with a great focus on interoperability which is enabled by the combination of the application layer protocol, DLMS, and the data model, COSEM [81], which allows for easy integration with different infrastructure using protocols such as TCP/IP, PLC and Zigbee[82]

This standard association has been successful in Europe, being the main standard for Automatic Meter Reading in the roll-out of the European Smart Grid[83].

Being the default solution for utilities to communicate with Smart Meters, this protocol support is eventually necessary to ever achieve a truly hardware agnostic. On the other hand, this can only be used in production systems with utilities permission, which requires business development to create partnerships for some form of data sharing. This partnerships can only

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[2] http://www.dlms.com/

be developed in a case by case manner and depend on each infrastructure, so it is possible and perhaps interesting to integrate our service not directly with the Smart Meters, but on a higher level with utilities middleware.

Other drawback of DLMS/COSEM support is the cost to access the materials and the complexity of the standard, which makes its implementation impossible in this master thesis scope.

### 3.1.3 HTTP with RESTful architecture

The Hypertext Transfer Protocol (HTTP) is an application-level protocol that was a key enabler for the World Wide Web. It is generic, stateless and object oriented, providing a light and fast solution for communication in distributed, collaborative information systems[84].

Over HTTP several patterns and approaches have appeared, but Representational Status Transfer stands out as the most common solution for web applications to provide data due to its simplicity and focus on data state[85].

RESTful Web Services, also known as REST APIs are hence the default door to web applications data, providing a powerful but simple tool for integration between systems [86]. This creates opportunities for quick prototyping and mashup between web apps and other systems in the physical world. A recent and great example of this is Cosm, formerly known as Pachube, which while offering a straightforward yet complete REST API helped spread the Internet of Things concept[87].

This integration potential is heavily enabled by the omnipresence of Internet which provides a existing infrastructure that can be easily used to integrate the Internet of Things. The so called Web of Things where sensors and actuators can be interacted with as any other HTTP resources is an interesting trend[88] which offers a perfect match with the overall goals of our project.

### 3.1.4 Overview

In this section three different communication possibilities were presented. Each represents, more than a protocol, a different attitude for the platform. There are still many more potential contenders for the default solution to the communication needs of this project. Here only one example of each approach was mentioned. These approaches also work on different levels of integration. DLMS/COSEM gets the data from the smart meters; MQTT provides a good solution to integrate infrastructure effectively between modules; HTTP REST is the solution for data exchange on the web. This can be visually understand with figure 3.1.4, where we can see that DLMS and

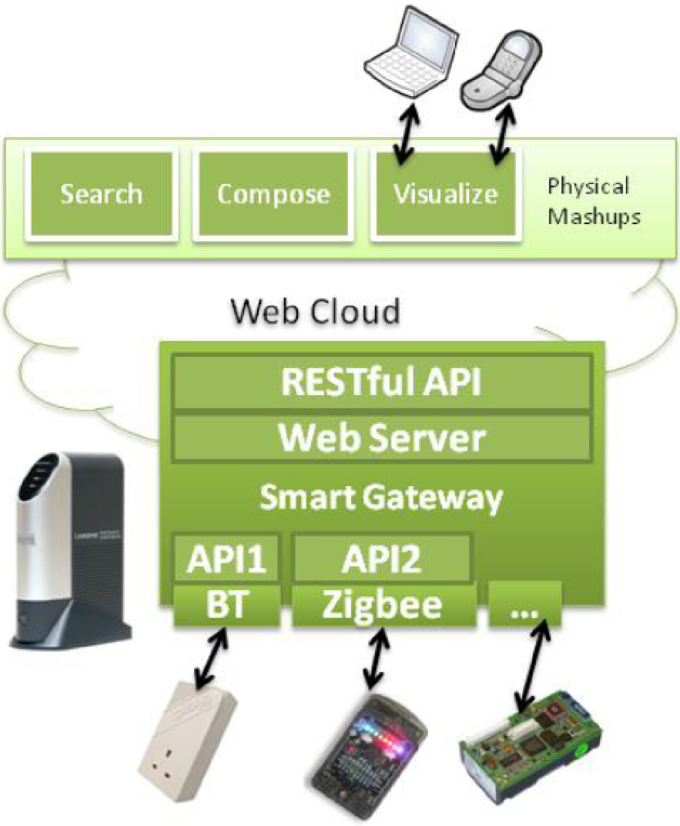

Figure 3.3: RESTFul architecture connecting with real world systems[87]

HTTP complement each other perfectly to cover the overall spectrum of Home Energy Management Systems. MQTT may look redundant, however its advantages in performance make it a tech to look for the future, if it goes more mainstream than it is presently.

Hence, on the long term it makes sense to use all the three in the right places, in order to build a true web enabled open (via HTTP REST) and hardware agnostic (via DLMS or MQTT) platform. However, to implement all this protocols and infrastructure would be a huge task for a Master Thesis, so prioritization is in order.

HTTP RESTful API emerges as the main focus for now. It enables access to most of open Power Meters (like Current Cost and TED), and provides a good infrastructure to build value to the user with mobile apps and mashups with other web applications or as a door to the Web of Things. In a more strategic point of view, the frontend web and mobile interaction where a HTTP RESTful API stands out is the less crowded spaced in the

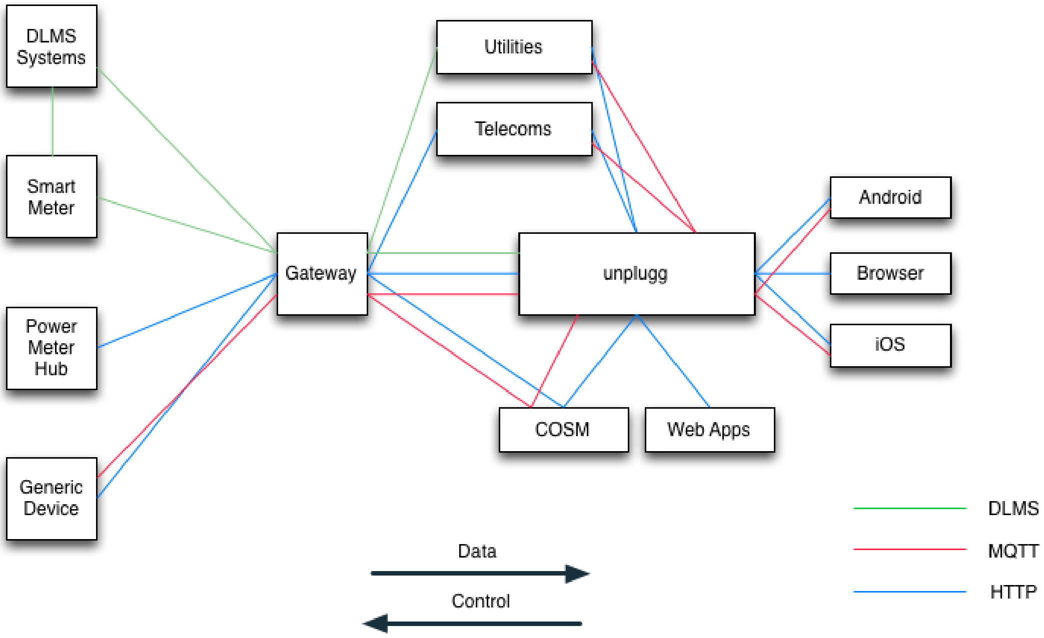

Figure 3.4: Role of each protocol to integrate unplugg platform as the enabler of the Internet of Things for Energy

energy management market, and the one who offers the most potential for innovation, as can be understood through the energy management offering presented in section 2.3.

## 3.2 Development tools

### 3.2.1 Programming Languages and frameworks

For this work, many programming languages could have been used. The main criteria used for selection was development speed and support to a reliable, agile, well supported web framework. It should be taken into account that being the objective to provide a market-ready solution, a language that naturally focus on the value for the user and web interface.

The languages that stand out are Ruby with Ruby on Rails and Python with Django. After some analysis of strengths and weaknesses, it was decided to use Ruby on Rails due to the vibrant community and knowledge available. Since it would be necessary to learn this language almost from scratch, the availability of tutorials and online courses presented a serious advantage in a otherwise quite even comparison.

This choice came naturally with some tradeoffs. Django offers an administration solution right from the start, yet Ruby on Rails requires for it to be added later with a third-party solution. In other hand, Ruby on Rails is very focused on a RESTful architecture, and allows to create scaffolds which accelerate greatly the development speed. This makes it very simple to deploy a RESTful API following the web app models.

It should also be mentioned that to achieve short-term development speed, some level o efficiency and even scalability can become compromised, as can be seen in the following section. However, more than to develop a perfect solution, the focus was to implement a effective one, avoiding early optimization.

## 3.3 Implementation

### 3.3.1 Architecture

In this subsection the platform architecture is presented. It should be recalled the goal: create a cloud based energy management solution, while integrating with the Internet of Things. This requires easy integration with third-party systems and modularity to facilitate its scalability.

A Ruby on Rails web app was developed. It currently runs on two server instances in Heroku. One (web process) focuses on all browser interaction and API requests. The other (worker process) executes jobs in background that keep data in sync and execute all the analysis and simulation jobs.

The web application is currently deployed in heroku[3], a PaaS cloud hosting service, which stands above the infrastructure of Amazon EC2[4]. The cloud enables a quick response to performance demand, scaling up and down the server instances with a simple command, making it easier to adapt the service to user demand.

The default database system was Postgresql, but it was proven that mongodb[5] could offer a better performance in the long term. In this case, since the migration was necessary, and it would save development time immediately, the database technology was changed while the small database made it easy.

An overview of the architecture and how it connects with other services can be seen in Figure 3.3.1

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[3] http://heroku.com

[4] http://aws.amazon.com/pt/ec2/

[5] http://www.mongodb.org/

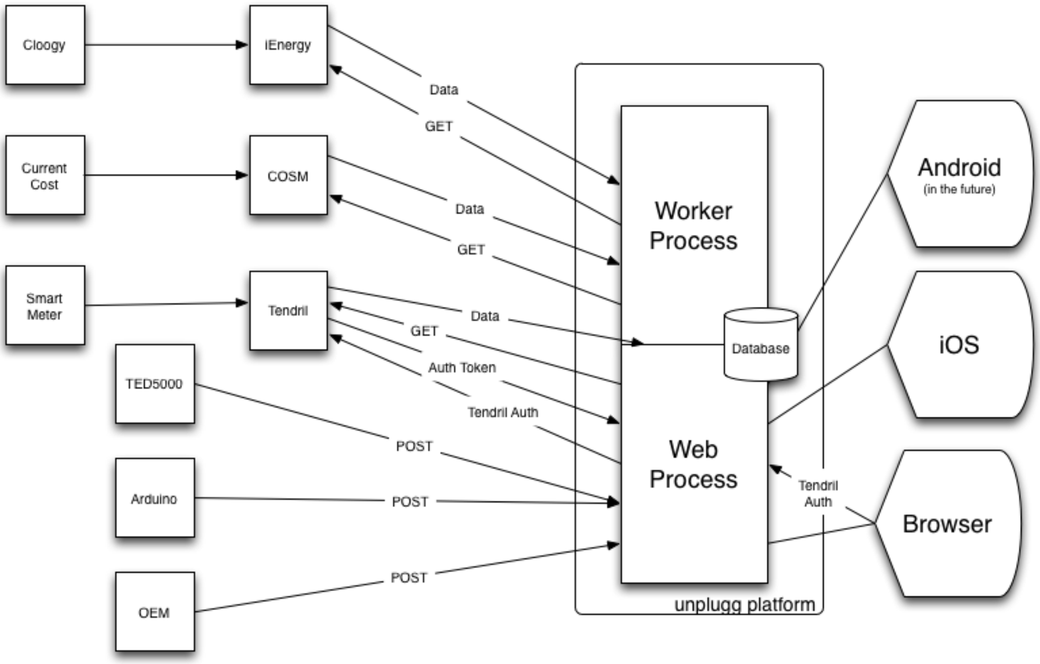

Figure 3.5: Unplugg Platform architecture

As can been seen in the figure, the integration occurs in several levels.

Some independent systems can be connected directly, while delivering data in regular manner through HTTP POST requests, like TED5000 or the open hardware solutions. This POST is delivered in the web process.

Off the shelf power meters like Current Cost Envi or Cloogy serve data to some type of backend, an the worker process executes regular HTTP GET Requests to keep data up to date.

In the case of Tendril, it is a more high-level, and smart backend, providing much more than raw data, so it may be more correct to designate it middleware.

For Tendril, it isn't possible for the user to provide a long-term authentication token. So data can only be requested immediately after user authentication in Tendril via Oauth. This likely translates in a less transparent interaction for the user, and limits the capability to analyze and compare data before the user logs in.

### Future Work

After present work, Ruby on Rails fits perfectly in the role of web application, allowing to iterate quickly and deliver a great user experience. However, in the medium term two main bottlenecks can be envisioned. These are not exactly limitations to scalability, however they result in a suboptimal solution which in large scale use will lead to a less than ideal use of server instances, growing unnecessarily the server costs.

**Data crunching** is inefficient in Ruby. Although it is a trade off that is currently positive, in the future the worker process role should be replaced by a complementary web app developed in a language with better performance when it comes to processing raw, and mostly numerical, data. The present modularity should make this transition simple.

**I/O** may become an issue, since this platform requires a lot of message traffic and all its API traffic is now supported on the web process in rails. In times of great API use, this may result in a slow performance in the user experience through the browser. Hence, it should be also considered to remove the API from the web process. This can be done in several ways, being the most promising to make the API access into additional app that shares the database, using more effective technologies for communication.

## 3.3.2 Worker Process

Background jobs are currently managed by Resque[6]. They are ordered by queues that can be assigned to a certain level of priority.

Jobs are added to the queue by two main sources: directly by user interaction, such as the first data import after adding a meter; automatically by Heroku scheduler, an add-on from our hosting provider that allows scheduling of rake tasks. Currently the rake tasks are used simply to organize and add jobs into Resque queues, like the update of stats for every user.

This job queue management offers a great opportunity to increase the platform efficiency, since not only the queues can be managed by priority, but also this system can be configured to launch and close instances to deal with irregular load balancing, taking advantage of the cloud infrastructure offered by Heroku. A much more efficient use of resources occurs, by simply and swiftly responding to application needs.

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[6] https://github.com/defunkt/resque/

### 3.3.3 API

The API offered is a long-term bet in the potential of the Web of Things. It should enable integration of the platform with systems such as utilities and telecoms infrastructure, sensors and actuators or even security systems. Its use is a simple as a RESTful one can be, requiring only the authentication token given to the user in the web app. The underlying data model is presented in figure 3.3.3, which translate into the endpoints of the API. The rest is a simple application of RESTFull architecture and HTTP methods. The format used for data exchange is always json[7], and base URI is `http://www.unplu.gg/`. A more exhaustive summary of API methods is presented in appendix B.

## 3.4 Overview

Using the table 2.1 as reference, this platform offers an innovative approach to the market. It is cloud-based and open, two almost unique characteristics in the current landscape. Only Tendril can claim to have a similar offer, and yet their openness is limited, since one cannot add data from any given monitoring system, while the approach here presented is has open as technology can make it. But even if there a is doubt on its value, we can see that the presented focus on the consumer as user and client makes this platform unique. This is more tangible in the powerful yet simple features offered through the web and mobile applications that this platform naturally enables.

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[7] http://www.json.org/

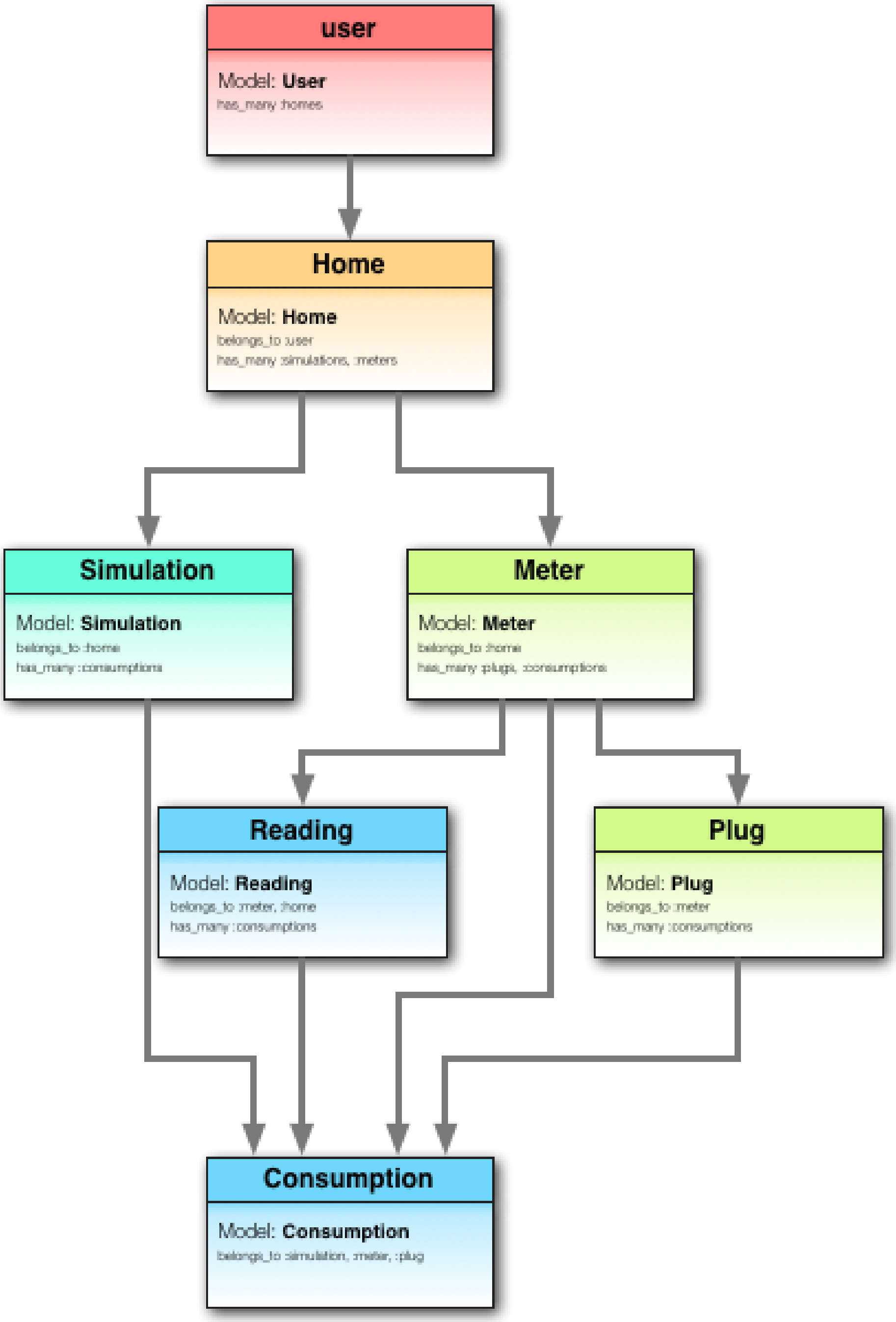

Figure 3.6: Simplified data model of the unplugg platform

# Chapter 4

# Integration of HEM solutions

The first section of this chapter will present the integration possible with Smart Meters. The second section will be focused on the selected power meters for this work.

In the last few years, open hardware solutions started to appear, being the most well known the Arduino open source electronic prototyping platform[1]. This trend led to energy monitoring concepts developed by tech savvy users. In the last section of this chapter, the integration of our platform with such systems is also covered.

## 4.1 Smart Metering

### 4.1.1 Green Button

As presented in section 2.4, The Green button is designed for a more sporadic use, where the consumer occasionally downloads his data, analyzes it and maybe uploads it to a third-party. However, this process has much friction for a platform aiming for real-time feedback. Hence the Green Button data standard is used for now only as the default standard for getting data from Tendril, which also supports it.

Having the ability to parse Green Button already implemented, it will be easy in the future to follow the development of this standard, while hoping for a more broad and frictionless use.

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[1] http://www.arduino.cc/

### 4.1.2 Tendril

Tendril is a service focused on the middleware between the Home Area Network, where the data is collected and communicated to the cloud, and a marketplace of apps in the making. Our platform can hence use Tendril as a link to tens of millions homes[2].

Tendril offers a REST API[3], where data is requested with OAuth[4]. In this case the Green Button standard was selected as the preferred data format, mostly to enable future use. After the OAuth authentication, a security token is generated, which currently lasts no more than two hours. This means that we can only access data when the user signs in the system. More enduring tokens are mentioned by Tendril, however its implementation this proves to be difficult to find in the documentation.

Presently, data import is provided taking into account the ephemerality of the token. Due to this, the user needs to login in Tendril to get new data, every time. This is a suboptimal solution, yet at least requires a much simpler interaction than the Green Button most simple use case: login in utility site; download data; upload data to app; repeat to update data.

## 4.2 Power Meters

These devices can be consider the first interaction of many consumers with energy management, preceding the arrival of smart grid and its potential. They are mostly bought by tech savvy and/or environment friendly people. This context makes the power meters users very prone to try new services and get to know their energy data better, because contrary to the smart meters, they have it because they bought it. They are already interested. This context made them a priority in terms of integration, an as such were their support was implemented first.

### 4.2.1 Current Cost

As presented in section 2.3.2 all that collected by Current Cost Monitors can be accessed[89] through Cosm (ex-Pachube) API[5]. All it is necessary is for the user to provide the Feed ID and the API Key that gives access to such feed. It is common for users to have the feed public, requiring no API Key,

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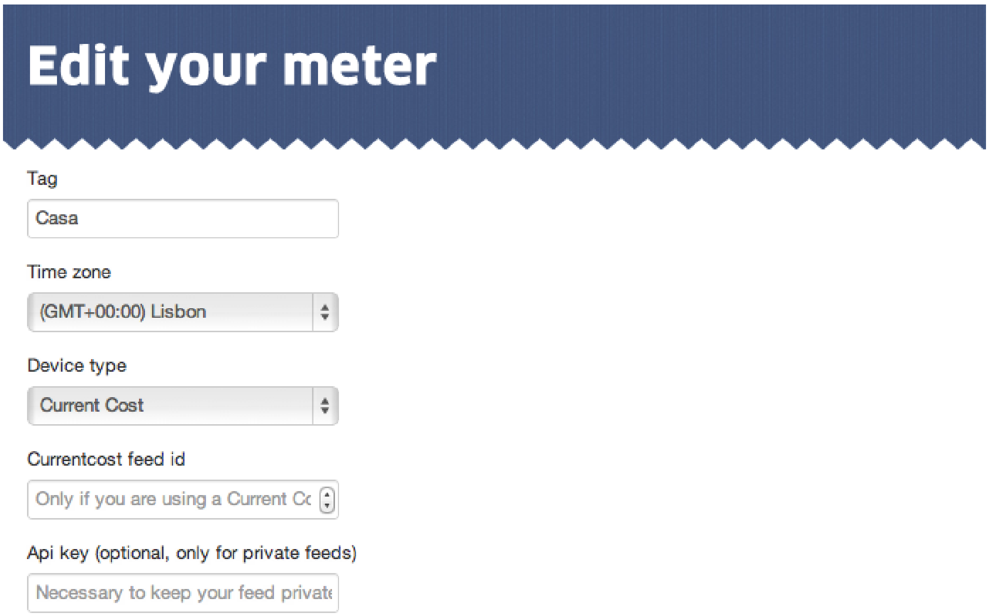
[2] http://www.greentechmedia.com/articles/read/SDGEs-Massive-Smart-Grid-to-Consumer-Playbook/

[3] http://dev.tendrilinc.com/

[4] http://oauth.net/

[5] https://cosm.com/docs/

yet this procedure is naturally discouraged. A snapshot of the add meter form is presented in figure 4.2.1



Tag
Casa

Time zone
(GMT+00:00) Lisbon

Device type
Current Cost

Currentcost feed id
Only if you are using a Current Cc

Api key (optional, only for private feeds)
Necessary to keep your feed privat

Figure 4.1: Snapshot of Current Cost configuration form

Having the credentials, it is only necessary to execute a GET request for the *history*[6] method such as is presented in listing 4.1. The response is then parsed and saved in our database.

Listing 4.1: Example of a GET Request

```
GET http://api.cosm.com/v2/feeds/504.json?start
    =2010-08-02T14:01:46Z&end=2010-08-02T17:01:46Z&
    interval=0
```

---

[6] https://cosm.com/docs/v2/history.html

| Value | Description | Maximum range in one query |
|---|---|---|
| 0 | Every snapshot stored | 6 hours |
| 30 | 30 second interval data | 12 hours |
| 60 | One snapshot every minute | 24 hours |
| 300 | One snapshot every 5 minutes | 5 days |
| 900 | One snapshot every 15 minutes | 14 days |
| 1800 | One snapshot per 30 minutes | 31 days |
| 3600 | One snapshot per hour | 31 days |
| 10800 | One snapshot per three hours | 90 days |
| 21600 | One snapshot per six hours | 180 days |
| 43200 | One snapshot per twelve hours | 1 year |
| 86400 | One snapshot per day | 1 year |

Table 4.1: Relation between the data interval and the maximum query range

As presented in section 3.3.1, the import of data is made on background jobs managed on a queue system [7]. In this case the data import occurs for a time span selected by the script in order to get the latest new data. On the first import all data from the last six hours is requested, in order to keep maximum resolution. Afterwards, the data is requested since the last data point until now, for efficiency sake.

The time zone is also taken into account, since the data comes attached with the time on the meter location timezone. This requires considering the time difference when selecting the period of data to request.

This background job is run in a periodic fashion of one hour and also more intensively if the user is using the platform.

### 4.2.2 Cloogy

Cloogy provides a backend server with an REST API called iEnergy. This allows for a data import workflow very similar to Current Cost case, where we need simply to run a regular background job that makes the necessary requests to get the data. This background job is run in a periodic fashion of one hour and also more intensively if the user is using the platform.

Eventually the interested on Cloogy shifted from the main load monitoring to the potential of its smart plugs. Although its support is relevant, the smart plugs presented an almost unique offer to install reasonably cheap sensors and actuators at home. The other known similar system is Wemo[8] from Belkin which as just been launched.

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[7] https://github.com/defunkt/resque

[8] http://www.belkin.com/wemo/

These systems can be enablers of an Internet of Things focused on improving energy efficiency, due to its simplicity, low cost and connectivity. Beyond the initial scope of this thesis and this section, some work was done to explore the potential of such systems. A high-level description of such can be found on section 4.4

Currently, just the monitoring features of the plugs were implemented in the market ready solution, in order to measure effectively each appliance power consumption.

### 4.2.3 The Energy Detective - 5000

This system has no default backend server to get data from. Yet, it is possible to configure TED5000 to post data into a pre-determined endpoint[52]. It offers another API, more complete API[90], however it only is available if the client is in the same network as of the TED5000. In this case, instead of running a background job to request data, it was necessary to prepare the platform to respond effectively in two situations: TED energy posting activation and the energy posting on itself.

The energy posting is activated through the local TED5000 web interface, supplying an activation link and a unique id. A screenshot can be ssen in figure 4.2.3

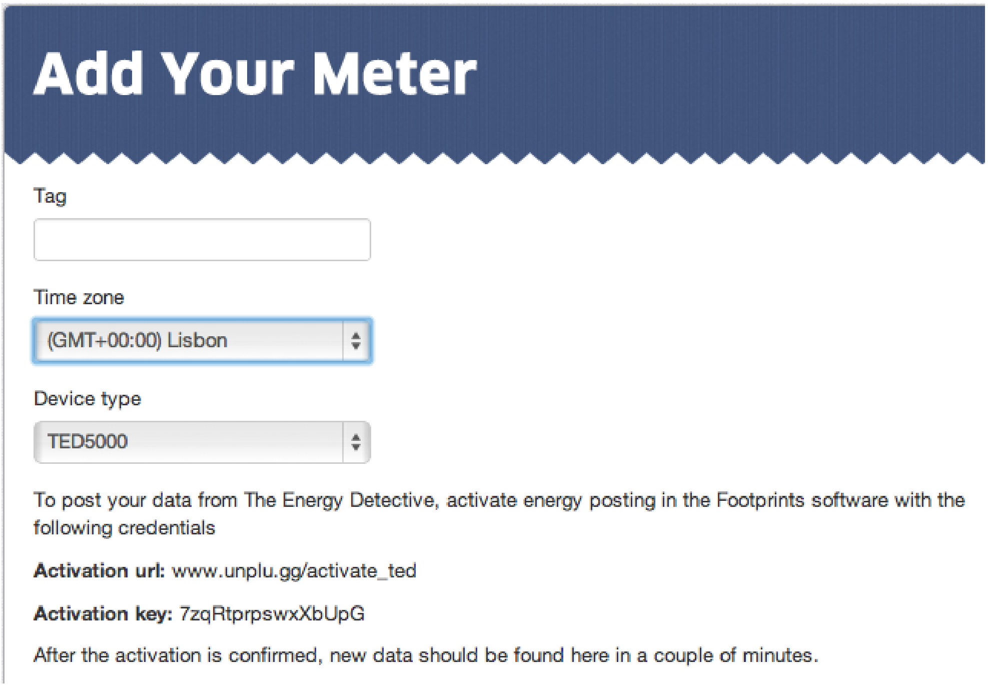
The TED5000 will then make a POST Request with the unique id supplied and the gateway id to the selected URL. Such URL then responds with configuration instructions in a TED5000 predefined template.

After this, if the activation is successful, TED50000 starts posting cumulative consumption data to the defined server. This also requires that the server and selected endpoint are able to authenticate and receive the data to save it in the database.

Several issues arisen in this process, such as many activation and connection errors.

The first problem was regarding the activation step, which didn't seem to make a reliable test case. It randomly gave different error (or successful activation) messages while the request didn't make into the server. After methodic search on the web, many people presented the same issues, without being apparently possible to isolate the problem to a network or browser issue. Finally by insistence, it was understood that in some way the activation form saved states in cache, so it was necessary to clean the browser cache before each activation.

Other issues arisen in the energy posting, which returned frequently a s̈ocket error.̈ This was eventually solved by a manual firmware update. It should be said that the TED5000 is the most unreliable system integrated in



Add Your Meter

Tag

Time zone: (GMT+00:00) Lisbon

Device type: TED5000

To post your data from The Energy Detective, activate energy posting in the Footprints software with the following credentials

**Activation url:** www.unplu.gg/activate_ted

**Activation key:** 7zqRtprpswxXbUpG

After the activation is confirmed, new data should be found here in a couple of minutes.

Figure 4.2: Snapshot of TED5000 configuration credentials

this work, and yet it provides a greater accuracy than most configuring the data posting rate up to 1 data point per minute.

## 4.3 Open Hardware

### 4.3.1 Open Energy Monitor

A test kit of the system presented in subsection 2.3.2 was ordered with the goal to create firmware for the open hardware system that sends the data to our platform with the provided API presented at 3.3.3.

The system sold requires assembling, and the hardware evolved greatly during the time of this thesis. The kit order isn't functional, being impossible to test it presently. However, the open energy monitor is based on Arduino[9]. Hence, all the integration to use Open Energy Monitor as a data source to our platform comes down to adapt and deploy an Arduino firmware code to collect the data gathered by the gateway and send it through the Ethernet port as an HTTP POST.

---

[9] http://www.arduino.cc/

So it should be only necessary to deploy the sketch presented in the following subsection and test to use the Open Energy Monitor as data source.

### 4.3.2 Arduino based energy monitoring

This open hardware system has become common in projects globally. Power monitoring is no exception, with several projects developed independently and presented through the web[10][11][12][13][14]. This kind of autonomous effort is of great importance to great a vibrant community of developers around a platform, as it has been proven in other fields. Hence it was developed a basic Arduino sketch to collect data in one of its analog pins and post it to our platform through an Ethernet shield and HTTP Post.

The resulting code can be found as open source in github[15]. The goal is simple, yet it wasn't easy to achieve effectively. The algorithm for the POST request ends up being quite low level, and as such, requires precise instructions to make the POST request exactly as required by the standard and our server.

It also should be noted that the network connection is unstable, creating an unreliable system. For that it was added a simple version of a watchdog which improved reliability, and yet it the communication failed always after a couple of days at most. This instability is a known issue, yet it is possible to improve it's performance[16]. However, that wasn't the goal of this project, so after proving that the read and post features worked effectively facilitating integration with other sketches, it was decided to move on to other issues in this thesis.

Other approaches may be used configure these Arduino based solutions to send data. For theses cases, the API documentation will allow for users to develop such systems. A snapshot of the instructions to send data is presented in figure 4.3.2

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[10] http://jarv.org/2009/07/home-power-monitoring/

[11] http://www.secretbatcave.co.uk/arduino/arduino-house-monitor/

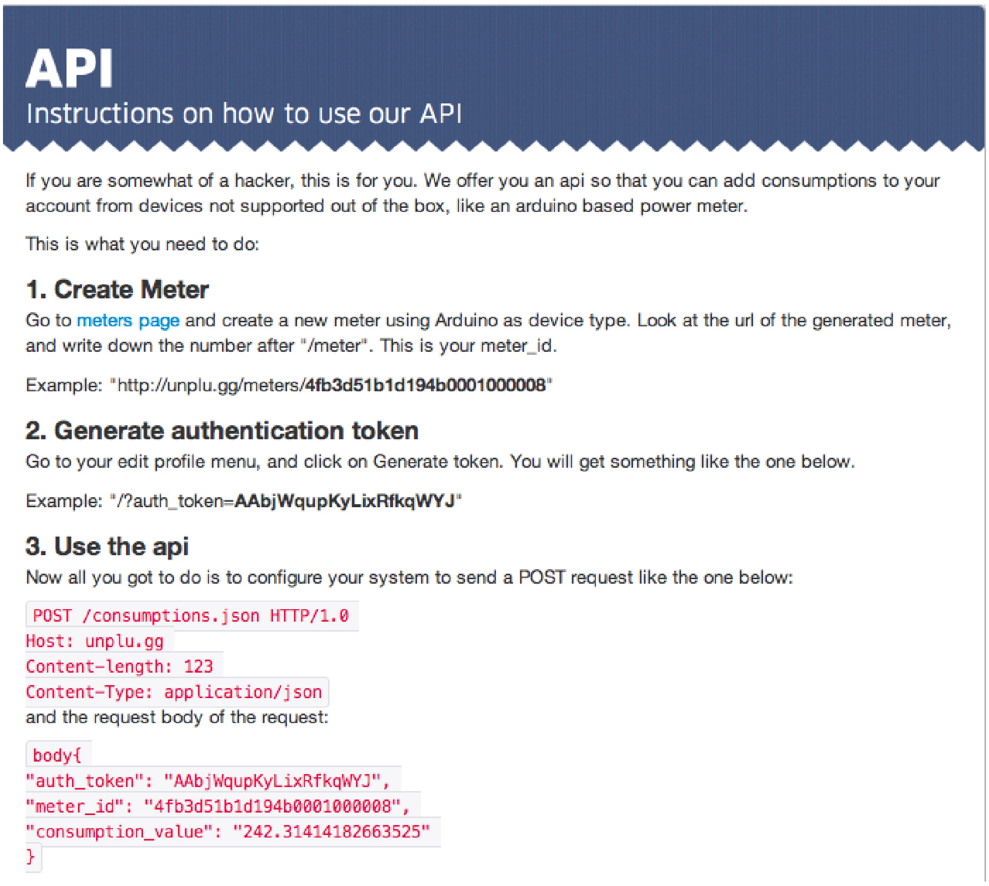
[12] http://www.open-electronics.org/real-time-energy-monitor-with-arduino-and-labview/

[13] http://blog.blakecrosby.com/2011/05/08/arduino-electricity-monitor.html

[14] http://matt.colyer.name/projects/power-meter/

[15] https://github.com/unplugg/Arduino-energy-monitor

[16] http://arduino.cc/forum/index.php/topic,85342.45.html



**API**

Instructions on how to use our API

If you are somewhat of a hacker, this is for you. We offer you an api so that you can add consumptions to your account from devices not supported out of the box, like an arduino based power meter.

This is what you need to do:

**1. Create Meter**

Go to meters page and create a new meter using Arduino as device type. Look at the url of the generated meter, and write down the number after "/meter". This is your meter_id.

Example: "http://unplu.gg/meters/**4fb3d51b1d194b0001000008**"

**2. Generate authentication token**

Go to your edit profile menu, and click on Generate token. You will get something like the one below.

Example: "/?auth_token=**AAbjWqupKyLixRfkqWYJ**"

**3. Use the api**

Now all you got to do is to configure your system to send a POST request like the one below:

```
POST /consumptions.json HTTP/1.0
Host: unplu.gg
Content-length: 123
Content-Type: application/json
```

and the request body of the request:

```
body{
"auth_token": "AAbjWqupKyLixRfkqWYJ",
"meter_id": "4fb3d51b1d194b0001000008",
"consumption_value": "242.31414182663525"
}
```

Figure 4.3: Snapshot of API documentation for data input

## 4.4 Automating Energy with the Internet of Things

Cloogy smart plugs can monitor consumption and also turn on/off equipments remotely. While developing the work of this thesis, the potential of the Internet of Things emerged as an enabler for the future, which also takes advantage of the cloud as the pivot point where most of the intelligent resides. This also might allow for a lower cost to deploy HEM solutions, making them more available for the mass-market.

This vision, and the role in it of a platform such as unplugg, is specially covered in the submitted paper that can be found in appendix A. In more concrete terms, in this thesis development, the access to Cloogy smart plugs allowed to explore the potential of using the cloud to manage such systems.

The initial idea was to install such plugs in position to monitor and control systems of regular, discrete use, such as the TV set and all the gadgets that usually accompany it. After some weeks of monitoring, the hypothesis was that a repetable padron would emerge, and one could use such padron to turn off the appliances in the periods of the day where these were not usually in use. This would allow to reduce greatly the vampire power that is wasted. Using real data and the likely price of each plug, it would be possible to recover their cost in less than two years.

After adding plug support to collect their data, a simple algorithm was developed to find such padrons of use. However the data required to make it meaningful would take much time to gather, and the goals initially set for this thesis took precedence, making it impossible to conclude such work and test its potential.

Some usability issues were also found. There was a great risk that this automation creates friction for the user, if he decides to use such devices beyond what would be expected. This would require fallback features on the web and mobile app to quickly turn on the system.

**In the future** it would be interesting to get back to this concept and try to validate it with some sort of beta feature restricted to Cloogy users. This would require to collect enough data for an improved version of the algorithm be able to supply with confidence a padron of idle time for such appliances. Then it would only be a matter of integrating with the Cloogy API to implement such control and iterate. A more vague but interesting challenge was to develop a similar concept while taking advantage of the complementary motion sensoring feature of Wemo[17].

## 4.5 Overview

Concluding, the platform developed is presently ready to collect data from the following sources

- Tendril, using the Green Button data Standard
- Current Cost Envi
- Cloogy
- The Energy Detective 5000
- Arduino and similar solutions

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[17] http://www.belkin.com/wemo/

Open Energy Monitor should also be compatible, yet it was impossible to test it. Overall, a broad support was achieved, covering several systems that stand out in the present HEM landscape. This data source options are even broader than previous multi-system solutions such as Plotwatt, and the potential of the API as displayed by the Arduino integration proves that this platform has the potential to get data easily from any system.

The potential of the simple control solutions such as the smart plugs provided by Cloogy was also lightly explored, however due to lack of time and data, this challenge was left on hold to focus on the goals set of this thesis. However this topic showed great potential to be revisited in the future.

# Chapter 5

# Data analysis and Modeling

Data is a very valued asset, yet there's little one can do if it is presented in an ineffective way. For this project to succeed it was necessary to also translate the consumption data in actionable metrics. The work developed towards this goal is presented in the next section.

On a broader vision, the ability to predict future consumption in a precise manner is a more disperse but very interesting proposal. The possibility to use predictions as goals to achieve for users or as a way to demonstrate the impact of changes in the home energy ecosystem may be an effective catalyzer to rally the consumer motivation to change habits and invest in his home energy efficiency. In this context, a simulation model was developed that allows to make predictions on the energy consumption using the home main characteristics as a kick-starter. This work is presented in section 5.2

## 5.1 Consumption metrics

The metrics used to inform the user effectively on his energy performance are based in simple math. Still, it is necessary to make it work in a production environment, transforming the consumption data streams we have access to in valid, meaningful data.

### 5.1.1 Power consumption measurement

The data collected and sent to the project platform is the consumption value for a given instant. However, the magnitude of power consumption is measured in $kW \times hour$. This means that one can't simply make averages and sums of the received data points, but instead to divide the power by the number of points per hour, arriving this way to the average of the consumption values.

Hence, if calculating the power consumed in a certain period, the result is translated by the following expression,

$$Power\ consumed = \frac{1}{n}\sum Power_{ins}, \tag{5.1}$$

where $n$ is the average number of consumption data points per hour gathered and $Power_{ins}$ each instant power measurement collected in the period. Following this, and average translates to the following expression

$$Average\ power\ consumed = \frac{1}{t \times n}\sum Power_{ins}, \tag{5.2}$$

Where $n$ is the number of periods in days, months or years we are calculating the average for. After this, it is now trivial to calculate the metrics presented in the following subsections.

### 5.1.2 Averages

The first and most obvious group of metrics is the average consumption by month, week and day, which can be trivially achieved with equation 5.2.

### 5.1.3 Energy Consumed

The energy consumed is viewed in two different periods: today, which gives a almost real time feedback of how one is performing, and a monthly view, to get a grip on how this month can compare with the average and usual invoiced value. This is a simple implementation of the equation 5.1

### 5.1.4 Comparisons

To provide an easier benchmark for the user, some direct comparisons with homologous periods are also calculated. These are:

- Between the present day consumed power and the consumption from the day before in the same time frame.
- Between the present day consumed power and the consumption from the last equal week day.
- Between the current month consumption and the consumed power in the last month

- Between the current week consumption and the consumed power in the last week

All historic values used on reference are naturally restricted in a equal time frame inside each comparison period.

This allows for the user to better compare is current performance with the past, and get a quick understanding if progress is being made in the present.

### 5.1.5 Trends

On a more complex view, some performance trends are also evaluated, regarding the overall performance in the context of all existing data, and the trend of last month. These are simply calculated through the variation rate between the data points of each period in a consecutive way, such as presented in the following expression

$$Trend = \sum_{t} \frac{Reading_{t+\Delta t} - Reading_{t}}{\Delta t} \tag{5.3}$$

Where $Reading_t$ is the consumption value at the instant t, and $Reading_{t+\Delta t}$ the value measured immediately after.

### 5.1.6 Expected Monthly consumption

The expected monthly consumption is a key metric for users which commonly really on it for managing expectations of future bills. Considering the metrics presented before, the more simplistic way to calculate the expected value is to extrapolate it from the known power spent in such month, as follows

$$Expected = \frac{Spent \times D}{\delta}, \tag{5.4}$$

where $D$ is the number of days contained in the month being considered and $\delta$ the number of elapsed days, for which the *Spent* metric was calculated.

However this value can be improved if we take into account the measured monthly consumption average. Hence the value currently presented to the user is the result of the average between the extrapolation presented in the equation 5.4 and the monthly average calculated as presented in subsection 5.1.2.

$$Expected = \frac{\frac{Spent \times D}{\delta} + Monthly_{avg}}{2} \tag{5.5}$$

The future work on this section is to bridge the simulations engine presented in the following section 5.2 with this extrapolation, to create a unique and dramatically more effective estimation of the expected value.

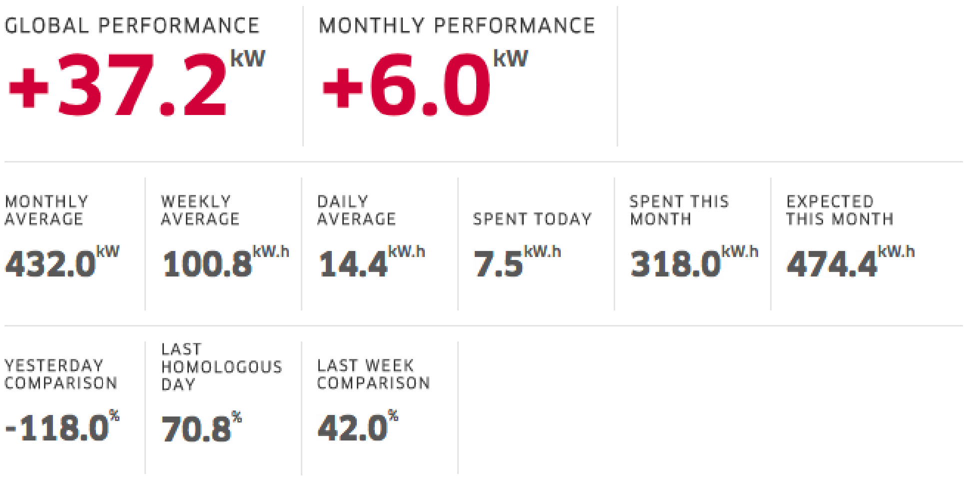
### 5.1.7 Implementation

These metrics are divided in the implementation in two groups:

- Real time metrics, which demand real-time computing
  - today consumption
  - comparison with yesterday
  - comparison with last homologous day
- More long term metrics, which can be calculated each few hours without losing effectiveness
  - monthly trend
  - overall trend
  - month average
  - week average
  - day average
  - spent this month
  - expected this month
  - week comparison
  - month comparison

The first group is calculated each time the user requests the pages were this data is presented. This allows to have truly real-time metrics, always up to date. It naturally may affect performance, however given that this metrics have the simplest calculus, it has not been noticed any clear change in the web application responsiveness.

A script that runs daily calculates the second group, updating all values with that frequency. Most of these metrics are still quite quick to calculate since that most of the operations are made through database queries. However the trends are a clear exception, requiring a *for* loop that treats each point one by one. Currently to get the trend of one month of data for a user, one of our workers requires 3 minutes. On the long term, this should be revisited to guaranty that it will not restrain the scalability of the platform.



GLOBAL PERFORMANCE +37.2 kW

MONTHLY PERFORMANCE +6.0 kW

MONTHLY AVERAGE 432.0 kW

WEEKLY AVERAGE 100.8 kW.h

DAILY AVERAGE 14.4 kW.h

SPENT TODAY 7.5 kW.h

SPENT THIS MONTH 318.0 kW.h

EXPECTED THIS MONTH 474.4 kW.h

YESTERDAY COMPARISON -118.0 %

LAST HOMOLOGOUS DAY 70.8 %

LAST WEEK COMPARISON 42.0 %

Figure 5.1: Snapshot of metrics presented in the web application

A snapshot of the main stats display in the platform can be seen in figure 5.1.7

In the future, for bigger data sets, it should be implemented an improved version to calculate the trends. Presently, the most simple and effective approaches seem to be:

- on medium size data sets, use data sampling to calculate the trend. This could improve performance by half or even a tenth if we got enough data to keep the method statistically credible.
- on big size data sets, we can simply ignore the data in the middle, comparing the earliest data points (representing the first couple of months) with the latest (representing the latest data points). However this should only be used when data is available for well more than a year.

## 5.2 Consumption Simulation

Predicting future energy consumption is a much bigger, complex challenge than simple consumption metrics. Energy consumption depends on many factors, such as

- Weather in the region, which is a huge challenge to predict on it self.
- House building materials and type of architecture, that vary through decade of construction and region.

- The overall group of electric appliances used in such house, including many that are easily forgotten or are wrongly despised in a inventory procedure
- The people and its habits that live in such house, which gives an extra chaos to any hope of simulation, since people habits naturally evolve, and many times change quickly in response to life events.

All this factors make it very hard to forecast energy consumption. In this section it is presented a first approach for such a model.

### 5.2.1 State of the art

Reviewing the literature, it was impossible to find any article that mentions a simulations model to predict the consumption of a single home. There are although several references to simulation models for bigger sets, of a few houses or small communities[91]. In these articles it is mentioned that the simulation for a single house was avoided due to inaccuracy[92]. However, these simulations were generally implemented with macro inputs. Hence, this can be seen as an opportunity to validate the feasibility of such simulation and its accuracy with custom data for each particular house, or at least have a clear notion of the deviation between simulation and reality.

There is a recent cloud-based commercial solution though, directed at and enterprise level which offers a similar value proposition, named Grid Navigator [93]. The information about such forecasting algorithm is naturally scarce, but seems to be more focused on extrapolating consumption data, while taking into account the weather forecast[94]. However it should also be said that the habits of a typical company should be more reliable and coherent than the ones of a normal home.

It is also possible to find more basic simulators, as offered by EDP, the main utility of Portugal to help users select the most appropriate charge plan [95] or to understand how much one can save turning off appliances normally in standby[96]. These simulations however are more of a simplistic model, developed with some simple presets, and no apparent random factor.

However, as it was shown in the beginning of this section, most of the energy consumption of a home is due to more random events. Hence, instead of a model that extrapolates from historic data consumption such as the forecast offered by Grid Navigator [94] or the table based model offered by EDP [95] [96], there is clear scientific value and likely interest from the users to understand an visualize how all the factors presented in the beginning of this section impact energy consumption. This may help drive user behavior and decisions for a more efficient energy performance on his home.

### 5.2.2 Monte Carlo

This method developed initially by Nick Metropolis, Stan Ulam and John von Neumann at the Los Alamos Laboratory as a method for dealing with problems in mathematical physics[97] allowed to tackle problems between classical mechanics and statistical mechanics such as the behavior of a system composed by three mutually attractive bodies[98]. Hence, it was proposed this method that consists of a mixture of deterministic and stochastic processes, giving a powerful tool for solving many problems.

Its impact evolved and growth in great magnitude. Currently, the Monte Carlo Method is considered one of the top ten algorithms of the 20th century [99] [100], being used in fields so disperse as finance [101]. Hence, this method proves itself as a good base to build the required energy forecast simulator.

In a more practical view, Monte Carlo method starts with a set of known characteristics and a statistical sampling of its occurrence. Random scenarios based on this sampling are generated leading to a new system state. Usually this process is repeated a reasonable number of times until the new system state converges for a solution.

### 5.2.3 Implementation

For this work, a simulation algorithm was implemented. It uses as input:

- Weather data
- Basic house characteristics
- Number of inhabitants

Starting from these, many other elements are assumed, such as the presence and power consumption of a wide range of electrical appliances. All these factors are adjusted with the probabilistic likelihood of each translate in a given appliance consumption on a giving time. For improved statistical meaning this is repeated dozens of times.

One simulation for the following 7 days is generated each hour, and then only the average is presented to the user and for correlation measurement. This allows for a good balance between number of iterations for convergence and data size.

It should also be mention that this implementation is the result of a compromise between accuracy, reasonable processing requirements, data warehouse demands and the friction for the user to add their home characteristics. This is a complicated balance, and yet necessary to effectively make this model useful. It also offers much room to improvement, not only because it is a first approach to this problem, but also the accuracy can only improve with constant tuning and comparison with real data.

### 5.2.4 Results

With the developed simulation model, we can get simulated energy consumption as presented in Figure 5.2.4. As we can visually see while comparing with Figure 5.2.4, there is still room to improve, mostly due to the accuracy of people habits. However, it was expected some level of inaccuracy on the hourly consumption. A more reasonable objective is to evaluate if the simulations can predict effectively daily and monthly simulation, so they can be used to benchmarking and set medium-term goals. A snapshot of the comparison between real and simulated data, as presented to the user, can be seen in figure 5.2.4

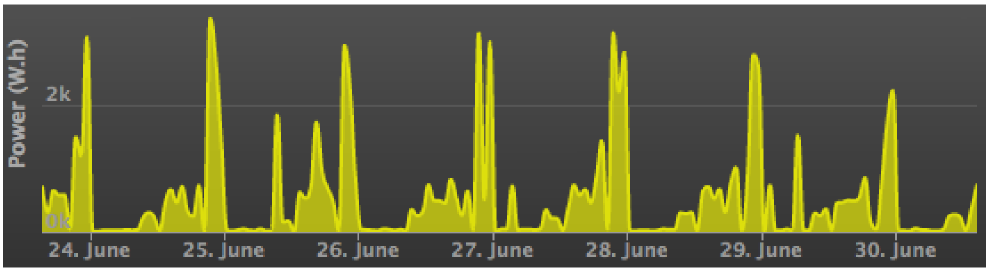


Figure 5.2: Simulated energy consumption for a week.

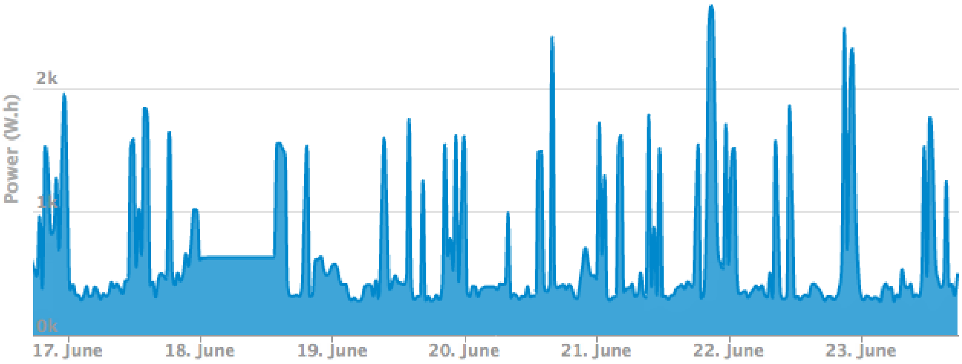
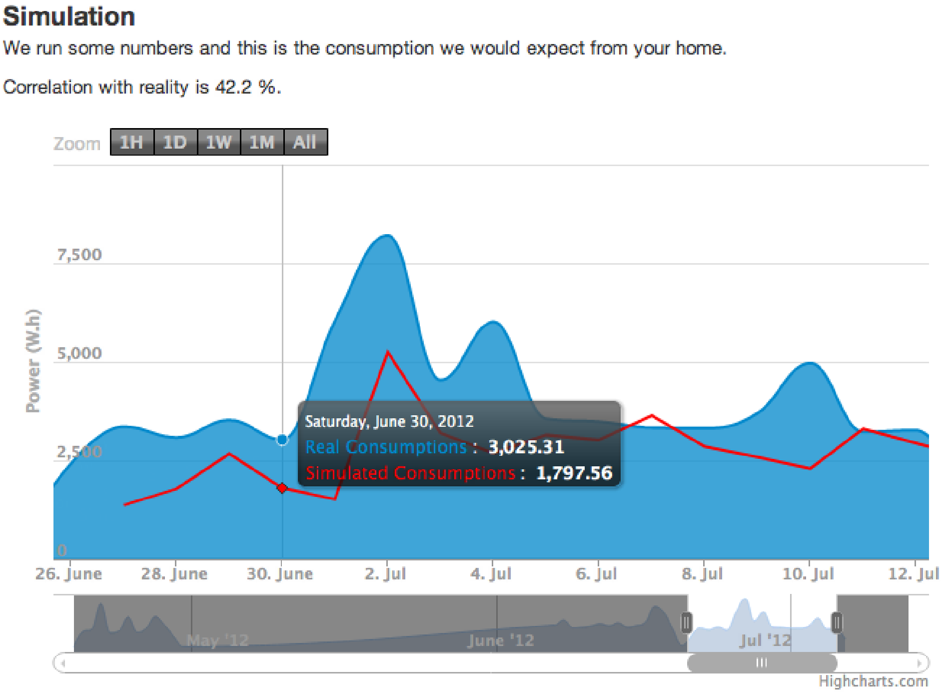


Figure 5.3: Real energy consumption for a week.

The success of this simulation method can only be measured effectively by comparing the results with a generous and diverse data set. Data is never



**Simulation**

We run some numbers and this is the consumption we would expect from your home.

Correlation with reality is 42.2 %.

Figure 5.4: Comparision chart between real and simulated data, clustered.

enough, however the data gathered on the platform enables a reasonable comparison of correlation between simulations and real data in different settings. The Table 5.2.4 presents the correlation for several data sets.

| Sample size | Location | House Type | AC | Heaters | Correlation |
|---|---|---|---|---|---|
| 1 | United Kingdom | T0 | no | no | 34,86% |
| 1 | Portugal | T3 | no | yes | 27,67% |
| 1 | Portugal | T2 | no | no | 50,13% |
| 1 | Portugal | T3 | no | yes | 48,93% |
| 1 | Portugal | T6 | no | yes | 8,57% |
| 1 | Netherlands | T1 | no | no | 30,29% |

Table 5.1: Correlation between real and simulated data. Average correlation is 33,41%

Overall, the average correlation is of 33,41%. It is not a great result, yet it was known since the start that this would be a great challenge, due to the various different, chaotic factors involved.

We can see that the correlation is better for smaller houses. This is coherent with the charts presented above, where one can see clearly that the simulation baseline is lower than the real measured values. From this it can be understood that a dramatic part of overall consumption is due to the baseline consumption, which in turn, varies immensely between different homes, depending on the quantity and type of appliances on standby and similar.

Access to up to date, real time data was also necessary to validate continuously this model, and hence its improvement ended up being limited by the data availability, or in other words, the presence of real users in the developed platform.

Being true that these results are not what one would like, this is still a good base to build upon on what was known as a difficult problem. Now the basic algorithm is ready to be improved and the developed platform, which is now in production, in the future will provide the wealth of data required to tune this simulation engine.

# Chapter 6

# Conclusion

The work of this thesis is divided on several sectors. From a scientific point of view, it could be seen as more valuable to focus on just one and push the state of the art forward. However, from a more engineering point of view, it was preferred to bring the state of the art to the market, while solving interesting challenges. In this context, it can be considered that the goals outlined were attained successfully, with different levels of effectiveness. For all this, the conclusion will be divided by analyzing the work developed from different points of view: the absolute results obtain; the relation to the state of the art and academic world and the market value validated through the business model potential. In the last section, a vision of the future for this platform is discussed.

## 6.1 Final result

This work ends delivering an open platform that can be found publicly at `http://unplu.gg`, although it is currently an invite only beta. This platform is based on the scope of the present thesis, which was outlined in the introduction:

**An architecture that enables cloud-based home energy management** The architecture implemented shows much potential. The API enables integration with virtually any kind of system, and being based on the cloud, this platform is on a pivotal position to manage the internet of energy things, while providing opportunities to make all this scale effectively.

**Integration with monitoring solutions** was implemented for a broad set of data sources, that together cover the main geographies and markets in this sector: Tendril (via Green Button), The Energy Detective, Current Cost, Cloogy and Arduino.

**Data Analysis** through twelve actionable metrics were implemented and are recalculated permanently, some even in real-time. These offer the necessary indicators to monitor change on a more high-level.

**Simulations** were made possible through the development of a simulation engine, which using weather forecast, basic supplied house characteristics and a group of presets, predicts recurrently the consumption for the following seven days. Present simulations, when compared with a small data set, present a correlation of 33,41%, which indicates inaccuracy of the model, however it was known that this type of energy system is to chaotic to predict effectively with limited time and data.

All this was done while deploying the developed solutions in a market-ready platform, which in term increased the quality required to consider it done, in order to guaranty a great user experience for the final user. Hence, overall it can be said that the scope of this thesis was achieved as expected. A screenshot of the main screen of the platform can be seen in figure 6.1

Going beyond the goals set, the potential of using smart plugs to manage energy more effectively was also lightly explored, although without time to achieve meaningful results. Still, the potential of the Internet of Things to improve energy efficiency shows great promess for the future, making this a vector worth pursuing further in the future.

## 6.2 Academic validation

A positioning paper was submitted to it4energy[1], in order to subject the vision of an open platform for the HEM to peer review, while hoping to improve and gain sight from the discussion. It can be found in appendix A

## 6.3 Market validation

The ability of selling a service is probably the ultimate proof of its value. While it is not a much relevant topic to be deeply covered in an engineering master thesis, much effort was made through out this work to explore the market potential of this project. The team assembled eventually evolved

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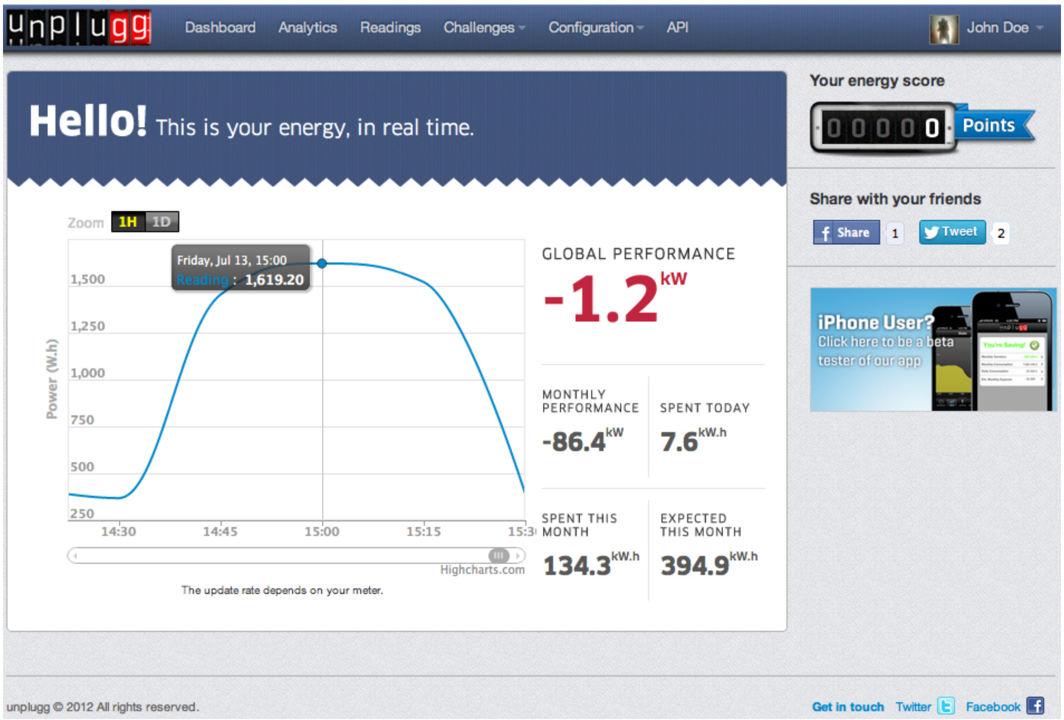
[1] http://it4energy.org/



**Hello!** This is your energy, in real time.

The update rate depends on your meter.

iPhone User? Click here to be a beta tester of our app

Figure 6.1: Unplugg web application

into a startup that iterated the business model and has been executing the strategy to implement it.

It was proven that, as can be understood on this thesis, that a void exist in the intersection between HEM, Internet of Things and open platforms, where we can perfectly position. This platform hence was converted in a service that users can take advantage through a web and mobile app, which as been developed until the current state, evolving with user feedback and the market change.

Presently, in an invite-only beta, a couple of dozens of users are registered, and almost two hundred shown interest, without meaningful marketing effort. The project was present and competed in several events, which inclusively led to a prize as best value proposition of University of Coimbra in the Tech Base Entrepreneurship Course. Presently, our project is at the second stage of EDP Inovação[2] and is semifinalist for the Energy and Transports track of MIT Portugal IEI[3].

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[2] http://www.premioedpinovacao.edp.pt/

[3] http://mitportugal-iei.org/

In the future we hope to provide this offering in a SaaS model, targeting the final costumer. A QREN project to further develop this project was also approved recently with a classification of 3.95 in a scale of 5, which proves the market potential and innovation of the proposed solution and gives hope to the evolution of this project.

This thesis work consists in the main intellectual property of this platform and hence it is being licensed to the established spin-off, in order to pursue effectively in the future the business potential of this project.

## 6.4 Future Work

After this work it is hoped to continue evolving this service, enlarging the user base through broader hardware integration, scaling the platform and exploring the potential of Internet of Things on the years to come. Open standards offer a great support to achieve this, and making the platform open seems to be the best way to enable this ecosystem around it.

Data analysis has still room to evolve by incorporating the lessons learned in behavior science for this field, while the simulations can be tuned iteratively in the short-term. For the long-term, different approaches can build upon this work to make the simulations more accurate and effective, using tools such as Markov Chains or Neural Networks.

The architecture will need to evolve organically in response of user growth and adapt to the requirements, while dividing it in smaller models to maximize the performance of each tool and allowing it to scale effectively.

This effort will also require further market validation, using the users feedback to improve the platform and maximize its value for the consumer.

And being a global effort, all this will be achieved while bringing down the geographical, technological and business frontiers that fragment and weaken the HEM space.

# Bibliography

[1] Steven Goldman, Lowell Ungar, Steve Capanna, and Tom Simchak. Energy Efficiency : A Tool for Climate Change Adaptation. Technical Report February, Alliance to save energy, 2012.

[2] Eurostat. Final Energy Consumption - Residential, 2010.

[3] Eurostat. Final energy consumption, 2010.

[4] Bill Marsh. Wasted energy. *The New York Times*, 2008.

[5] Aneesh Chopra, Vivek Kundra, and Phil Weiser. A POLICY FRAMEWORK FOR THE 21st CENTURY GRID: Enabling our scure energy future.

[6] European Commission. Citizens' summary-EU climate and energy package. 2020:0–1, 2008.

[7] S Darby. Literature review for the energy demand research project. *Change*, pages 1–30, 2010.

[8] Derek Foster, Shaun Lawson, Mark Blythe, Paul Cairns, and Brayford Pool. Wattsup ?: Motivating reductions in domestic energy consumption using social networks. *Statistics*, 2010.

[9] Actionable Insights for the New Energy Consumer Contents. Technical report, Accenture, 2012.

[10] Neil Strother and Charul Vyas. Social Media in the Utility Industry Consumer Survey. Technical report, 2012.

[11] S. S. van Dam, C. a. Bakker, and J. D. M. van Hal. Home energy monitors: impact over the medium-term. *Building Research & Information*, 38(5):458–469, October 2010.

[12] Ashley Brown and Raya Salter. Can Smart Grid Technology Fix the Disconnect Between Wholesale and Retail Pricing? *The Electricity Journal*, 24(1):7–13, January 2011.

[13] European Commission. Vision and Strategy for Europe's Electricity Networks of the Future. *Smart Grids European Technology Platform*, 2006.

[14] Microsoft Introduces, Home Energy, Management Software, Efficient Incandescent Bulbs, May Be, and Possible After. Microsoft Introduces Home Energy Management Software. *Energy Design Update*, 14(5):6, 2009.

[15] João Lopes, António Messias, and Rui Gonçalves. Redes de energia inteligentes como contributo da engenharia portuguesa para o desenvolvimento sustentável.

[16] Harvey Michaels and Kat Donnelly. Architecting the Smart Grid for Energy Efficiency Information-Driven Efficiency and Demand Response Mechanisms. *ACEEE Summer Study on Energy Efficiency in Buildings 11-163*, 11(October 2009):163–173, 2010.

[17] Task Force Smart Grids. EXPERT GROUP 2: REGULATORY RECOMMENDATIONS FOR DATA SAFETY, DATA HANDLING AND DATA PROTECTION. Technical report, European Comission, 2011.

[18] Task Force Smart Grids Expert Group 2. Essential Regulatory Requirements and Recommendations for Data Handling , Data Safety , and Consumer Protection - Final Draft. Technical Report April, European Comission, 2011.

[19] US Gov. Apps for Energy. \url{http://appsforenergy.challenge.gov/rules}, 2012.

[20] Intel Planning Home Energy Use Display and Smart Monitor System. *Energy Design Update*, (November):7, 2010.

[21] Best Buy Introduces Home Energy Monitoring Devices to Store Lineup. (December), 2011.

[22] E Carroll and E Hatton. Residential Energy Use Behavior Change Pilot. *Franklin Energy*, 2009.

[23] Hunt Allcott. Behavior and energy policy. *Science*, 2010.

[24] Alexandra-Gwyn Paetz, Elisabeth Dütschke, and Wolf Fichtner. Smart Homes as a Means to Sustainable Energy Consumption: A Study of Consumer Perceptions. *Journal of Consumer Policy*, 35(1):23–41, October 2011.

[25] GE. Home Energy Manager, Energy Monitor GE Nucleus. \url{http://www.geappliances.com/home-energy-manager/}.

[26] Cassie Peterson. The Green Bottom Line. (April):82–87, 2012.

[27] Home Energy Management Eragy Announces New Family of Energy Management Applications for Control4 Systems. \url{http://www.eragy.com/news/news-releases-6/}.

[28] Pengwei Du. Appliance commitment for household load scheduling. *Smart Grid, IEEE Transactions on*, 2(2):411–419, 2011.

[29] RP Singh and S Keshav. HITS: A Cloud-Based Flexible Architecture for Home Energy Management. *blizzard.cs.uwaterloo.ca*.

[30] Home Energy Is Managed With Mobile Phone. *Microwaves & RF*, (July), 2010.

[31] Dae-Man Han and Jae-Hyun Lim. Design and implementation of smart home energy management systems based on zigbee. *IEEE Transactions on Consumer Electronics*, 56(3):1417–1425, August 2010.

[32] Jinsoo Han, Chang-sic Choi, and Ilwoo Lee. More efficient home energy management system based on ZigBee communication and infrared remote controls. *IEEE Transactions on Consumer Electronics*, 57(1):85–89, February 2011.

[33] G W Hart. Nonintrusive appliance load monitoring. *Proceedings of the IEEE*, 80(12):1870–1891, 1992.

[34] Marisa Figueiredo and Ana De Almeida. Non-intrusive Residential Electrical Consumption Traces. *Ambient Intelligence-Software*, 2011.

[35] DA Kelly. Disaggregating Smart Meter Readings using Device Signatures. (September), 2011.

[36] K. CARRIE ARMEL, ABHAY GUPTA, GIREESH SHRIMALI, and ADRIAN ALBERT. DISAGGREGATION: THE HOLY GRAIL OF ENERGY EFFICIENCY? 2012.

[37] Sarah Darby. The Effectiveness of Feedback on Energy Consumption: A REview for DEFRA of the Liternature on Metering, Billing and Direct Displays. *Review for DEFRA of the Literature on Metering Billing*, (April), 2006.

[38] S Afsah and Kendyl Salcito. Energy Efficiency is for Real, Energy Rebound a Distraction. *Energy*, page 15, 2012.

[39] Energy Emergence - Rebound & backfire as emergent phenomena. Technical report, 2011.

[40] Nick Hanley, Peter G. McGregor, J. Kim Swales, and Karen Turner. Do increases in energy efficiency improve environmental quality and sustainability? *Ecological Economics*, 68(3):692–709, January 2009.

[41] Rui Neves Madeira, André Silva, Catarina Santos, Bárbara Teixeira, Teresa Romão, Eduardo Dias, and Nuno Correia. LEY ! Persuasive Pervasive Gaming on Domestic Energy. pages 1–2, 2011.

[42] Magnus Bang and Anton Gustafsson. Promoting new patterns in household energy consumption with pervasive learning games. *Persuasive Technology*, pages 55–63, 2007.

[43] Matt Davis. Behavior and Energy Savings.

[44] Shawn Fitzpatrick and Matt Murray. Home Energy Monitor Report. Technical Report 6, Advanced Energy, Raleigh, June 2011.

[45] Current Cost. CC128 ENVI Manual.

[46] Usman Haque. OnBoard enabling a world of open data devices. \url{http://blog.cosm.com/2011/11/onboard-helping-device-makers-open-data.html#more}, 2011.

[47] Usman Haque. Pachube is now Cosm! \url{http://blog.cosm.com/2012/05/pachube-is-now-cosm.html}, 2012.

[48] Cosm. Socket Server - Cosm API Documentation. \url{https://cosm.com/docs/beta/socket_server/}, 2011.

[49] Harri Hämäläinen. HTML5: WebSockets. *noppa.aalto.fi*, pages 1–9.

[50] Peter (Kaazing Corporation) Lubbers and Frank (Kaazing Corporation) Greco. HTML5 Web Sockets: A Quantum Leap in Scalability for the Web. \url{http://www.websocket.org/quantum.html}.

[51] Cosm. Historical queries - Cosm API Documentation. \url{http://cosm.com/docs/v2/history.html}, 2012.

[52] TED 5000 Third Party Posting API. Technical report, The Energy Detective, 2010.

[53] Open Energy Monitor. \url{http://openenergymonitor.org/}.

[54] The Global Market for Embedded Connectivity in the Utilities Sector 2010-20. Technical report, 2011.

[55] Energy Design Update - July 2011. (July):10–12, 2011.

[56] CNET. Opower monthly report - Home energy displays show you the juice (photos). \url{http://news.cnet.com/2300-11128_3-10001909-8.html}, 2011.

[57] Opower. Honeywell and Opower Develop Next-Generation Tools to Reduce Energy Use and Costs in Homes Opower. \url{http://opower.com/company/news-press/press_releases/37}, 2011.

[58] Katrina Leni-konig. Honeywell Opower Thermostat Laboratory Testing. 2012.

[59] Opower. Facebook, NRDC and Opower Join with 16 Utilities to Drive Energy Efficiency Through Social Media Opower. \url{http://opower.com/company/news-press/press_releases/50}, 2012.

[60] Janelle Lamarche, Katherine Cheney, Sheila Christian, and Kurt Roth. Home Energy Management Products & Trends. Technical report, Fraunhofer Center for Sustainable Energy Systems, Cambridge, MA, 2011.

[61] Jennifer Snook and Elizabeth Boomgard. *Driving Sustainable Behavior in the Mainstream Consumer: Leveraging Behavioral Economics to Minimize Household Energy Consumption.* PhD thesis, Duke University, 2011.

[62] Karla Conn Welch and Cindy K. Harnett. A review of electricity monitoring and feedback systems. *2011 Proceedings of IEEE Southeastcon*, 1:321–326, March 2011.

[63] Bob Parks. Home Energy Dashboards. *Make, Volume 18*, 18:50, 2009.

[64] Lawrence Han. Green Button Program. Technical report, Erb Institute for Global Sustainable Enterprise, 2012.

[65] Cambridge Cambridgeshire CB5 8DZ GB) James Laura B (62 South RoadImpington Cambridgeshire CB24 9PN GB) Phillips Amyas Edward Wykes (c/o CARET1st Floor16 Mill Lane Cambridge CB2 1SB GB) Beart Pilgrim Giles William (AlertMe.comCompass House80 Newmarket Road. ELECTRICAL APPLIANCE MONITORING SYSTEMS, 2011.

[66] Gael Scott. Safe as houses. *Mental health today (Brighton, England)*, (September):12–3, 2010.

[67] Nick Sinai. Empowering Customers With a Green Button. \url{http://www.whitehouse.gov/blog/2011/11/21/empowering-customers-green-button}, 2011.

[68] Aneesh Chopra. Modeling a Green Energy Challenge after a Blue Button. *The White House*, 2011.

[69] Tom White. Powering the People. \url{http://homeenergypros.lbl.gov/video/green-button-initiative-nick-sinai-on-the-white-house-green?xg_source=msg_mes_network}, 2012.

[70] Utility-scale smart meter deployments, plans, & proposals. Technical Report May, Institute for Electric Efficiency, 2012.

[71] New Industry Commitments to Give 15 Million Households Tools to Shrink Their Energy Bills. \url{http://www.whitehouse.gov/administration/eop/ostp/pressroom/03222012}, 2012.

[72] Smart Grid Priority Actions. \url{http://www.nist.gov/smartgrid/priority-actions.cfm}.

[73] Fatemeh Nikayin. Governance of smart living service platforms: state-of-the-art and the need for collective action. In *Third International Engineering Systems Symposium CESUN 2012, Delft University of Technology*, number June, pages 18–20, 2012.

[74] Dave Locke. MQ Telemetry Transport (MQTT) V3.1 Protocol Specification. Technical report, IBM, 2010.

[75] A Stanford-Clark. MQTT For Sensor Networks (MQTT-S) Protocol Specification Version 1.1. pages 1–28, 2008.

[76] Urs Hunkeler and HL Truong. MQTT-S – A Publish / Subscribe Protocol For Wireless Sensor Networks. *Systems Software and*, 2008.

[77] Andy Stanford-clark. The importance of Internet standards and other topics. *-The Importance of Industrial Standards*, 2004.

[78] Klaas De Craemer. Analysis of state-of-the-art smart metering communication standards. pages 1–6, 2010.

[79] Tarek Khalifa, Kshirasagar Naik, and Amiya Nayak. A Survey of Communication Protocols for Automatic Meter Reading Applications. *IEEE Communications Surveys & Tutorials*, 13(2):168–182, 2011.

[80] DLMS User Association. Green Book DLMS/COSEM - Architecture and Protocols. Technical report, DLMS User Association, 2009.

[81] Stefan Feuerhahn, Michael Zillgith, Christof Wittwer, and Christian Wietfeld. Comparison of the communication protocols DLMS/COSEM, SML and IEC 61850 for smart metering applications. *2011 IEEE International Conference on Smart Grid Communications (SmartGridComm)*, (c):410–415, October 2011.

[82] Zhong Fan, Georgios Kalogridis, and Costas Efthymiou. The new frontier of communications research: smart grid and smart metering. *Proceedings of the 1st*, pages 115–118, 2010.

[83] P. Bredillet, Eric Lambert, and Eric Schultz. CIM, 61850, COSEM Standards Used in a Model Driven Integration Approach to Build the Smart Grid Service Oriented Architecture. *2010 First IEEE International Conference on Smart Grid Communications*, pages 467–471, October 2010.

[84] UC Irvine. Hypertext Transfer Protocol-HTTP/1.0. (May), 1996.

[85] Robert Battle and Edward Benson. Bridging the semantic Web and Web 2.0 with Representational State Transfer (REST). *Web Semantics: Science, Services and Agents on the World Wide Web*, 6(1):61–69, February 2008.

[86] Roy T. Fielding and Richard N. Taylor. Principled design of the modern Web architecture. *ACM Transactions on Internet Technology*, 2(2):115–150, May 2002.

[87] Dominique Guinard. Towards the web of things: Web mashups for embedded devices. *Workshop on Mashups, Enterprise Mashups and*, 2009.

[88] Vlad Stirbu. Towards a RESTful Plug and Play Experience in the Web of Things. *2008 IEEE International Conference on Semantic Computing*, pages 512–517, August 2008.

[89] Bridge API Pull Options.

[90] TED. Ted 5000 API. Technical report, The Energy Detective, 2010.

[91] Omid Ardakanian, Srinivasan Keshav, and Catherine Rosenberg. Markovian models for home electricity consumption. *Proceedings of the 2nd ACM SIGCOMM workshop on Green networking - GreenNets '11*, page 31, 2011.

[92] KM Svehla. *A Specification for Measuring Domestic Energy Demand Profiles*. Master thesis, University of Strathclyde, 2011.

[93] Gigaom. GridNavigator crunches data to forecast energy use, 2012.

[94] Gridnavigator. Grid Navigator - Forecast Energy, 2012.

[95] EDP. Simulador de Potência, Tarifas e Consumos, 2012.

[96] ECO EDP. ECO EDP - Homepage - Homepage - simular - Standby, 2012.

[97] HL Anderson. Metropolis, Monte Carlo, and the MANIAC. *Los Alamos Science*, 1986.

[98] N Metropolis. The monte carlo method. *Journal of the American statistical association*, 1949.

[99] BA Cipra. The Best of the 20th Century : Editors Name Top 10 Algorithms. *SIAM news*, 2000.

[100] Jack Dongarra and Francis Sullivan. The top 10 Algorithms. *COMPUTING IN SCIENCE & ENGINEERING*, pages 22–23, 2000.

[101] P Glasserman. *Monte Carlo methods in financial engineering*, volume 53. Springer verlag, 2004.

# Appendix A

# Submited paper

The position paper submited to it4energy can be found in the following 4 pages.

# Unplugg: a cloud-based home energy management platform

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**Abstract.** The residential market is responsible for an important part of the global energy consumption, representing 26,65%[1] in Europe, where 20%[2] of all energy is wasted. Being a fragmented market[3], and highly dependent on individuals convictions and circumstances, it presents a great challenge for energy efficiency increase. There is a crucial effort of evangelization and innovation to be made, in order to effectively execute current energy policies[4][5] and achieve objective thus concrete results. Some concepts appear in this context as important enablers, such as the Smart Grid, Cleantech, Open Data and even the potential of Internet of Things. All these will have a key role in providing the consumers, utilities and governments, tools to drive change and improve efficiency. A consumer centric, cloud-based Home Energy Management (HEM) platform is presented. Its challenges are: to build the foundations of a hardware agnostic solution, supporting the main open data sources available and enlarging the potential interested consumer base; provide actionable metrics and consumption simulations that give insight to the user and help understand the impact of habits and choices; explore the potential of internet of things and cloud based energy management. And achieve all this in a market-ready solution that can be sustainable and effectively drive change.

**Keywords:** home energy management, cloud, internet, internet of things, open data

## 1 Introduction

Many concepts and market solutions have been developed in the HEM field. Yet the market reality has failed to comply with expectations[3]. This can be justified by several issues such as the global economic crises standing out in the last two years. A more subtle but relevant issue is the reasonably high cost of energy management systems for the consumer, which creates a natural entry barrier. Most of these systems deliver a home-based solution where the intelligence of the systems is located in-site. This has its advantages from a technological stand point, providing a quicker and more effective response. However it has its drawbacks from a efficiency and business point of view. The up front cost is high, and quickly loses its novelty for smarter solutions. The updates are irregular and the technology loses its novelty quickly due to the difficulty of upgrading hardware.

An interesting alternative is to move the intelligence to the cloud where it can be iterated and updated quickly, while leaving just the sensors and actuators in home. This enables lighter business models with lower costs for the costumers up front. In this way the user can take advantage from the bleeding edge of HEM technology and pay by what is effectively used. This results in a more efficient solution from a business but also data processing point of view since the cloud based management enables relevant economies of scale[6].

## 2 Unplugg Platform

The cloud potential as base for innovation through open data and communication has been until now reasonably overlooked where the possible exceptions are the deprecated Google Power Meter[3] and the HITS concept[7]. Here we explore a consumer oriented vision of this while making a market-ready solution.

The developed platform was designated as unplugg. Its goal is to provide a base for exploring and make good use of data collected by sensors such as power monitoring solutions to maximize the saving potential of global actuation solutions that start to appear in the market.

### 2.1 Architecture

The effectiveness of such platform depends on its capability of integrating most of the main sensoring and actuation solutions. This presents a challenge to support a broad set of communication protocols. Looking into the power monitoring systems today, which is more a mature market than the control and actuation, one can understand that most data can be acquired simply trough HTTP which simplifies its implementation. The exception are the smart meters that use standards like DLMS[8] which are a lot more powerfull, but also much more complex to interact with.

In this case, HTTP was selected as a priority in order to support immediately the market represented by power meters such as Current Cost[4] and The Energy Detective[5]. Another key element that make this selection obvious is that the integration with this systems through HTTP is based on open APIs, unlike the use of DLMS by utilities which is naturally closed to their infrastructure. The communication with this systems can also be made through brokers such as Cosm[6], or in the future the middleware solutions from utilities for which Tendril can be seen as a possible example. A simplified vision of the integration architecture can be seen in figure 2.1. This platform is currently deployed in heroku[7], a PaaS hosting solution built upon Amazon EC2[8] that simplifies the administration while keeping the advantages of the cloud.

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[3] http://www.google.com/powermeter/about/

[4] http://www.currentcost.com/

[5] http://www.theenergydetective.com/

[6] http://cosm.com

[7] http://heroku.com

[8] http://aws.amazon.com/pt/ec2/

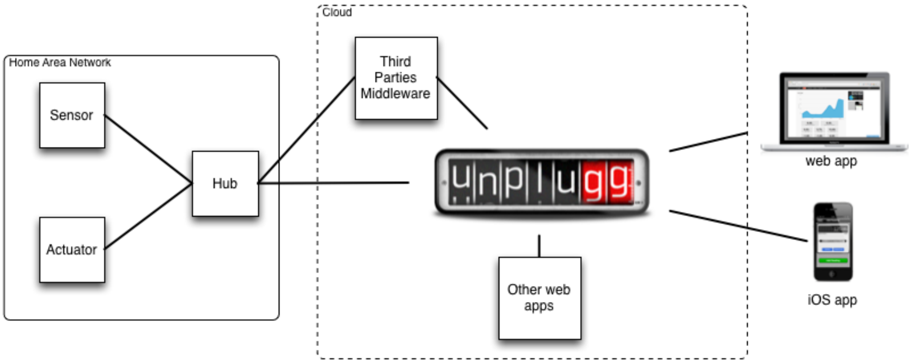

**Fig. 1.** Unplugg Platform architecture

Present systems integrated to the platform are: Cloogy[9], Current Cost Envi, The Energy Detective and the Tendril API[10].

### 2.2 Internet of Things

The ultimate goal of this platform is to enable an Internet of Things focused on energy management, building upon the many interesting concepts on this field[9]. In order to achieve that, beyond data sources which are already present, it is necessary to enable innovation and explore the integration potential through an open platform[3].

Control solutions with low price points start to appear in the market. Examples of this are Cloogy which offers smart plugs that can be remotely controlled through and API and the just launched Wemo[11] from Belkin that provide control and movement sensing, while indicating that an API will be provided in the near future. This type of integrations are already present in more early adopter segments where the the IFTTT[12] association with Wemo stands out. In this field exciting times are coming and cloud based solutions are a natural enabler due to its ubiquity and quick evolution potential.

However this trend will only evolve organically when the more tech enabled consumers start experimenting and creating mashups between the internet of things, HEM solutions and even other web applications. This makes the offer of an open, powerful and well documented API a crucial step for the effectiveness of a platform in this context.

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[9] http://cloogy.com
[10] http://dev.tendrilinc.com/
[11] http://www.belkin.com/wemo/
[12] http://ifttt.com/recipes/search?utf8=%E2%9C%93q=wemo

### 2.3 Data Analysis and Presentation

Web and mobile apps are also a driver for smart energy solutions adoption, by enabling rich, frequently real-time energy management through already omnipresent devices. But these apps require access to actionable, meaningful data that can be easily crunched in the cloud. For unplugg, an iOS app was developed that provide actionable metrics which allow users to track progress, and complements the view offered by the main platform interface.

## 3 Conclusion

Cloud based energy management presents several advantages comparing with home based control systems, such as efficiency, low entry barrier, increased ease of adoption, global and ubiquitous potential of integration. It can hence be a technological solution to tackle the slow adoption of HEM systems. In this paper a global platform named unplugg was presented which stands out by enabling the support of multiple data sources and empower the innovation through the internet of things while keeping the user as the main focus of development.

## References

1. Final energy consumption. Eurostat (2010)
2. Marsh B.: Wasted energy. The New York Times (2008)
3. Fatemeh Nikayin. Governance of smart living service platforms: state- of-the-art and the need for collective action. Third International Engineering Systems Symposium CESUN 2012, Delft University of Technology, 18-20 June 2012
4. European Commission. Citizens summary. EU climate and energy package (2008)
5. Chopra A., Kundra V., and Weiser P.: A POLICY FRAMEWORK FOR THE 21st CENTURY GRID: Enabling our secure energy future.
6. Birman K., Ganesh L.: Running Smart Grid Control Software on Cloud Computing Architectures Next Generation Electric Grid (2011)
7. RP Singh and S Keshav.: HITS: A Cloud-Based Flexible Architecture for Home Energy Management blizzard.cs.uwaterloo.ca
8. Bredillet P., Lambert E., and Schultz E.: COSEM Standards Used in a Model Driven Integration Approach to Build the Smart Grid Service Oriented Architecture. First IEEE International Conference on Smart Grid Communications, October 2010
9. Dominique Guinard.: Towards the web of things: Web mashups for embedded devices. Workshop on Mashups, Enterprise Mashups (2009)

# Appendix B

# API endpoints complete list

Here, the API is listed in a more exhaustive manner, following the data model as presented in figure 3.3.3 and expanding to other models that are present in the platform but go beyond this thesis work. most of present

**GET challenges.json** Read all challenges.

**GET challenges/id.json** Read challenge with sent id.

**PUT challenges/id** Update the challenge with sent id.

**GET consumptions.json/?period=timeframe** Read energy consumption data points from *meter_id* (string) or *plug_id* (string) or *simulation_id* (string) of the time-frame sent on the parameter period. Period options are

- ”today”
- ”yesterday”
- ”last_week”
- ”last_month”
- ”last_semester”
- ”all_time” (default).

**GET consumptions/id.json** Read consumption with sent id.

**POST consumptions** Create consumption with sent parameters: *consumption_value* (float), *meter_id* (string) and *date* (datetime). If no date is supplied, it defaults to the instant the consumption was saved.

**PUT consumptions/id** Update consumption with sent id.

**DELETE consumptions/id** Delete consumption with sent id.

**GET homes.json** Read all homes.

**GET homes/id.json** Read home with sent id.

**POST homes** Create home with sent parameters: *address* (string), *has_ac* (boolean), *has_heater* (boolean), *people* (integer) and *typo* (string).

**PUT homes/id** Update home with sent id.

**DELETE homes/id** Delete home with sent id.

**GET meters.json** Read all meters.

**GET meters/id.json** Read meter with sent id.

**POST meters** Create meter with sent parameters: *home_id* (string), *tag* (string), *time_zone* (string) and *device_type* (string) with options

- ”API”
- ”Cloogy”
    - *cloogy_username* (string)
    - *cloogy_password* (string)
- ”COSM”
    - *currentCost_feedID* (integer)
    - *api_key* (string)
- ”Current Cost”
    - *currentCost_feedID* (integer)

  - *api_key* (string)
- "Manual".

**PUT meters/id** Update meter with sent id.

**DELETE meters/id** Delete meter with sent id.

**GET readings.json** Read all readings.

**GET readings/id.json** Read reading with sent id.

**POST readings** Create reading with sent parameters: *meter_id* (string), *value* (integer)and *date* (datetime).

**PUT readings/id** Update reading with sent id.

**DELETE readings/id** Delete reading with sent id.

**GET simulations.json** Read all simulations.

**GET simulations/id.json** Read simulation with sent id.

**DELETE simulations/id** Delete simulation

# Appendix C

# Business Model

In the following figure, the business model developed and in implementation is presented in simplified manner, using the business model canvas[1].

Figure C.1: The unplugg business model canvas

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[1] http://www.businessmodelgeneration.com/canvas/