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## Contents

<b>DOCUMENT</b> .....	<b>2</b>
<b>DISTRIBUTION OF THE RELEASE</b> .....	<b>2</b>
<b>HISTORY OF CHANGES</b> .....	<b>2</b>
<b>1 EXECUTIVE SUMMARY</b> .....	<b>5</b>
<b>2 INTRODUCTION</b> .....	<b>6</b>
<b>3 PILOT SITES DEPLOYMENT AT MID-2017</b> .....	<b>7</b>
3.1 TURIN PILOT: CURRENT STATE.....	7
3.2 HYLIE PILOT: CURRENT STATE .....	7
<b>4 PRELIMINARY ANALYSIS</b> .....	<b>8</b>
4.1 EXISTING DATA PRE-FLEXMETER .....	8
4.2 PRELIMINARY DATA ANALYSIS FROM PILOT INSTALLATIONS .....	9
<b>REFERENCES</b> .....	<b>15</b>

## List of figures

Figure 1. Electrical energy consumption from 2 users in Turin pilot. ....	8
Figure 2. Aggregated curve for the Turin pilot consumption. ....	9
Figure 3. NED consumption traces (1Hz measuring and reporting rate). ....	10
Figure 4. Active power of one day of sampling from Hyllie pilot meters. ....	12
Figure 5. Voltage values of one day of sampling from Hyllie pilot meters. ....	13
Figure 6. Energy values of one day of sampling from Hyllie pilot meters ....	13

## **1 Executive Summary**

This deliverable aims at presenting the state of implementation of the pilot sites installations and services. It contains preliminary report about meters installed and data processing performed with this data. A typo in the DoW set the deadline of this deliverable at M22, while the intended data was M30. Because of delays in pilot installations, this deliverable has been rescheduled to M33. A description of final pilot installations is found in D6.3.

## 2 Introduction

In FLEXMETER project a number of algorithms for energy vector data analysis have been developed. These have been summarized in D1.4 and metrics for their evaluation can be found in D6.2. These algorithms have to be applied either to real data from pilots either on the simulation infrastructure developed in the project to evaluate DSO services (presented in D6.1). In this report, we present some preliminary data coming from the installations, while data used for evaluation in the simulator are presented in D6.1.

A detailed analysis of all data coming from the pilot site installations and data generated by the simulator infrastructure will be presented in the final project deliverable D6.4, dealing with data processing performed in the context of all use cases defined in the project.

Currently, we are able to report only preliminary data coming from installations in pilots, which is delaying the evaluation of algorithms applied to real data (while algorithms tested on the simulator are on track). The delays in site installations were due to technical and integration/testing problems on the smart meter prototypes developed during the project.

In the rest of the document, Chapter 3 reports the deployment state of the two pilots in Turin and Malmo at mid-2017. Problems occurred at different level of implementation will be reported in this section. Chapter 4 deals with the preliminary analysis of available data at the 2 pilot sites. In both cases the analysis have been done on available data prior to the installations of smart meters defined in FLEXMETER and on first sets of data coming from the new infrastructures developed in the project. Regarding NIALM disaggregation at residential user level, some statistics based on what available at the pilot state will be also presented.

### 3 Pilot sites deployment at mid-2017

The objectives of this chapter is to present the state of the art of the two pilot sites in Hyllie and Turin. Delays occurred in both pilots but recovery plans have been put in place to try to respect FLXMETER main objectives and test all functionalities.

#### 3.1 Turin pilot: current state

Based on the preliminary figures in D1.4 about all the different types of installations in Turin pilot and the revised final figures envisaged in D 6.3, this is the current status of deployment at mid-September 2017:

- ST Mono-phase smart meters: because of delays in the production of the ST boards and, once arrived in IREN premises, installation problems due to lack of correct communication between prototype boards (meter and receivers) and electrical problems causing electricity cut once connected, strong delays occurred. Electrical problems have been solved beginning of September 2017 and now (20<sup>th</sup> of September, 2017) 30 meters and 1 concentrator/gateway have been installed in Environment Park. Communication tests (meter-gateway and gateway-middlewere) are being conducted and the finalization of installations are envisaged in 2 weeks (80 meters + 8/10 gateways depending of installation topology in Environment Park).
- ST Three-phase smart meters: because of the same production delays stated in the point above, tests started only beginning of summer 2017. A problem related to current transformer to be coupled with the meter caused the failure of the first test in one of the 6 MV/LV substations chosen for the pilot. Functionalities tests both in IREN and ST made it possible to detect a current transformer working properly. Installations in all substations will continue in the following weeks.
- Home meters for NIALM and blink detectors: problems related to the recruitment of residential users wanting to participate to the test, even if for free, caused strong delays and a redrafting of the final number of participants. IREN will continue to look for possible users. Currently 7 meters for NIALM disaggregation and 10 blink detectors have been installed and are communicating data.
- Water meters: 15 commercial water meters, based on wireless meter bus 868 MHz communication, will be installed in Environment Park premises. They have been purchased and they will be installed in the following weeks.
- District Heating meters: 7 district heating meters already providing data to IREN and installed in the same buildings in which the residential meters have been installed and started pushing data to Sitewhere.

#### 3.2 Hyllie pilot: current state

Data about the Hyllie pilot site are reported in D6.3. This is because this pilots has already completed all the installations. D6.3 reports final installations plan, which for the case of Hyllie corresponds to the actual status.

## 4 Preliminary analysis

### 4.1 Existing data pre-FLEXMETER

In FLEXMETER we analyse both data collected with pre-existing metering system and data collected by newly installed meters. Historical data from pre-existing meters refers to the same users where new meters have been installed. In this section we briefly outline existing data, specifically monthly consumption data from old meters/bills for the users of the pilots:

- Turin (Italy) – residential
- Hyllie (Sweden) – residential/substation

Monthly data from the 28 selected residential users of the Turin pilot are analysed. These data refers to consumption information for the months passed already in 2017 (January to august) and is separated in two categories that correspond to the two different tariffs. As such, the M1 data refers to consumption between hours 8 and 19 and M23 to the consumption from 19 to 8. Consequently, M\_total refers to the overall consumption.

In Figure 1, the time variation of the active energy consumed by 2 out of the 28 users is presented, while in Figure F2 the aggregated (mediated) load curve based on available data. Also, in Tables T1, T2 and T3 statistical information for the three levels of consumption is presented. Based on these data, it can be easily seen that the highest consumption (for the overall studied population, the user with the highest consumption and the one with the lowest) is registered in January and the lowest in August. Taking into account that the August low consumption for residential users is easily explained by the vacation season, the next month with a minimum level is April, a month where, in normal conditions, there is no need for heating but also no need for air conditioning.

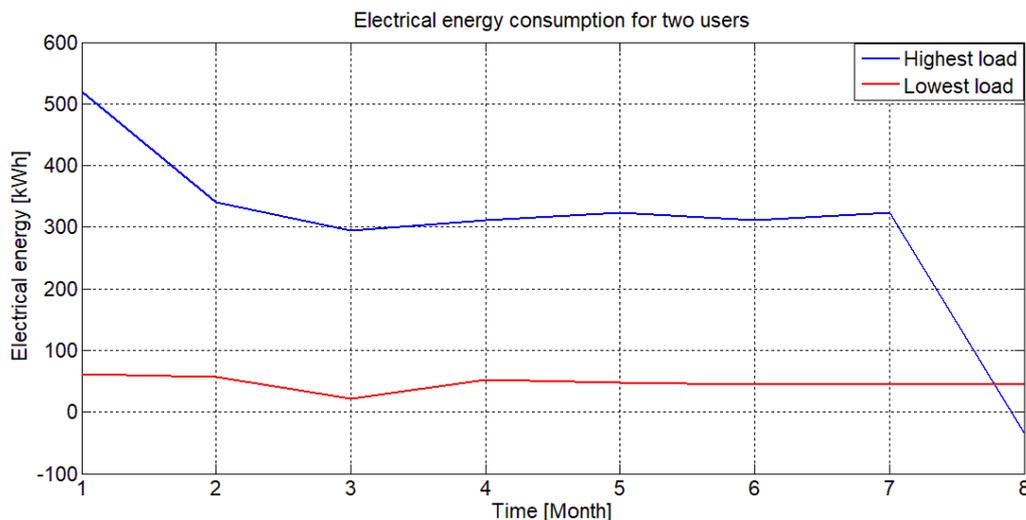


Figure 1. Electrical energy consumption from 2 users in Turin pilot.

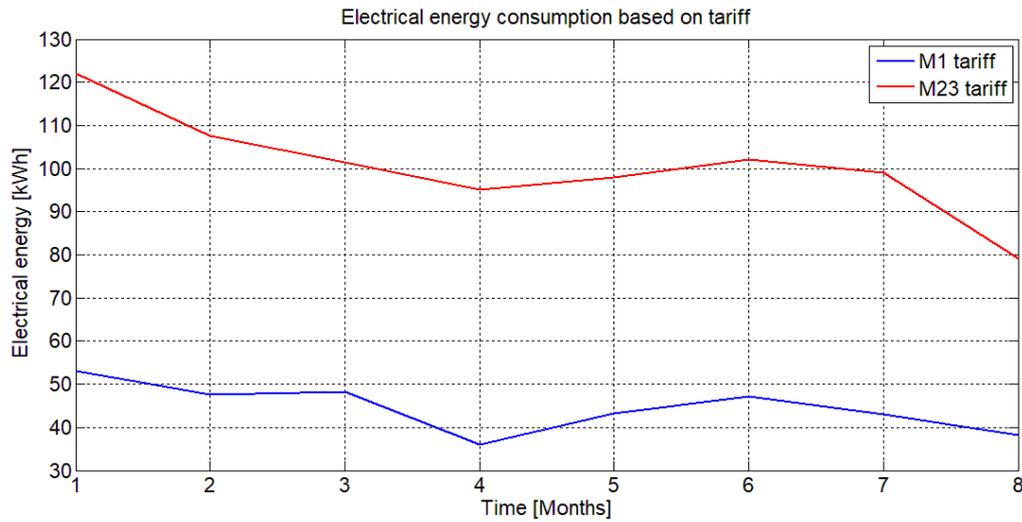


Figure 2. Aggregated curve for the Turin pilot consumption.

Table 1. Data for 28 users and M1 tariff

	January	February	March	April	May	June	July	August
Total energy [kWh]	1484	1336	1353	1007	1208	1323	1203	1071
Mean energy [kWh]	53.00	47.71	48.32	35.96	43.14	47.25	42.96	38.25
Maxim energy [kWh]	190	142	129	108	112	108	112	94
Minim energy [kWh]	15	13	-18	9	5	13	12	-2

Table 2. Data for 28 users and M23 tariff

	January	February	March	April	May	June	July	August
Total energy [kWh]	3415	3013	2840	2662	2742	2858	2770	2215
Mean energy [kWh]	121.96	107.60	101.42	95.07	97.92	102.07	98.92	79.10
Maxim energy [kWh]	330	198	190	204	211	204	211	175
Minim energy [kWh]	43	40	40	41	5	31	34	-33

Table 3. Data for 28 users and total consumed energy

	January	February	March	April	May	June	July	August
Total energy [kWh]	4698	4133	3977	3464	3748	3947	3770	3070
Mean energy [kWh]	180.69	158.96	152.96	133.23	144.15	151.80	145.00	118.07
Maxim energy [kWh]	520	340	294	312	323	312	323	257
Minim energy [kWh]	61	57	22	52	10	44	46	-35

## 4.2 Preliminary Data analysis from pilot installations

In this section we report some statistics about power consumption in two pilot installations where meters are deployed. In Turin, NED meters are installed in residential houses. On the

other side, in Malmoe commercial meters with 0.1Hz reporting rate were installed. Meters in Envipark, as mentioned in the Chapter 2, are not yet installed.

**Data collected through the platform from NED meters for disaggregation (NIALM)**

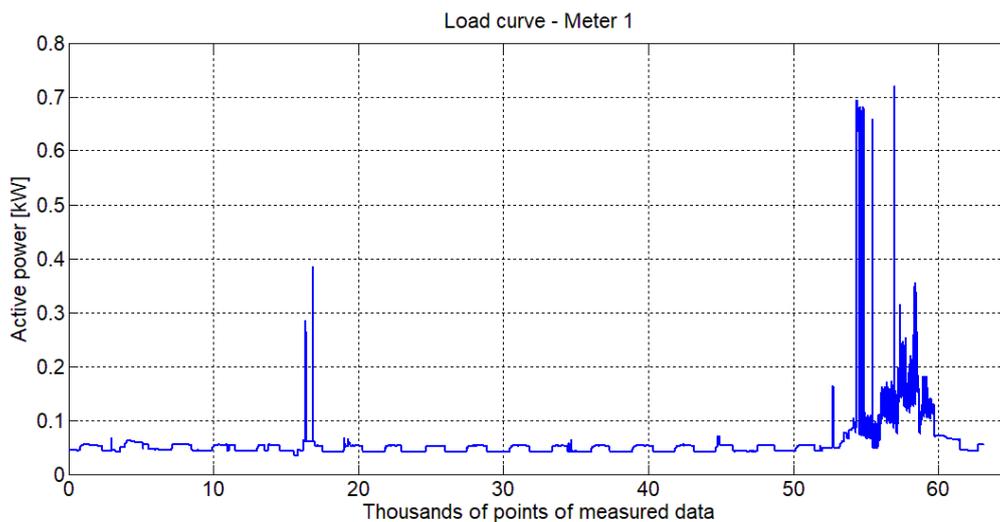
NED meters are prototyping meters with 1Hz measuring and reporting capabilities. The reported results refer to a 2 days of consumption. We used these values to make a preliminary check about the meter connections and data communication with the FLEXMETER IoT platform.

In table T4, data about consumed active power for one example meter are reported. This represents the more relevant type of data for NED meters, that is used for further NIALM operations. It is to be noted that there is a percentage of around 30% of data lost in the reported period for the reported meter. The reason is mostly due to the unreliable WIFI connection with the home gateway (AP). In general, up to now, the data communication from the meters is still a to be completely fixed, because not all meters communicate with 100% of success. Of course, this challenge was expected due to the requirement of continuous reporting of these types of meters. The work we are currently doing is about making this communication more solid.

*Table 4. Electricity consumption data from one NED meters in Turin pilot.*

Date	Meter	Number of points	Percentage of data successfully transmitted [%]	Total energy per day [kWh]	Maximum of measured power [W]	Average of measured energy [kWh] per second
27-Jul	1	58964	68.25	6.5273	4.091	0.1107
26-Jul	1	63109	73.04	3.7255	2.592	0.0590

Also, in Figure 3 an example of consumption traces generated from the NED meter is presented. A maximum active power of 0.7 kW per sample is recorded for this site.



*Figure 3. NED consumption traces (1Hz measuring and reporting rate).*

To do this, we consider that for the NIALM algorithm to be working, a number of 84000 samples out of a total of 86400 is necessary. Table T5 reports some statistical analysis concerning the data provided as input to the NIALM algorithm.

Table 5. Statistical data for the information used as input for the NIALM algorithm. IDs refer to selected user IDs in the FLEXMETER system.

	<b>ID21</b>	<b>ID41</b>	<b>ID44</b>	<b>ID45</b>	<b>ID46</b>	<b>ID56</b>
<i>Days with sent measurements</i>	80	78	62	29	32	26
<i>Days with at least 84000 measurements sent</i>	<b>53</b>	38	33	0	25	20
<i>Days in which data was analyzed</i>	37	38	33	0	25	19
<i>No of identifications of washing machine</i>	13	3	29	0	0	9
<i>Instances of detections of Fridge</i>	36	38	32	0	25	19
<i>Instances of detection of Dishwasher</i>	11	8	8	0	0	0
<i>Instances of detection of Microwaves</i>	27	31	10	0	13	16
<i>Total energy (Wh)</i>	111106	136754	193157	0	116293	164222
<i>Estimated energy (Wh) - using NILM</i>	46192	44171	35656	0	17583	22056
<i>Stand-by (Wh)</i>	15228	12828	21115	0	27707	31849
<i>Percentage of identified energy (reported)</i>	55	42	30	0	39	33
<i>Percentage of useful info days</i>	66.25	48.72	53.23	0	<b>78.13</b>	76.92
<i>Percentage of estimated energy</i>	41.57	32.3	18.46	N/A	15.12	13.43
<i>Identified loads percentage (calculated)</i>	55.28	41.68	29.39	N/A	38.94	32.82
<i>Percentage of analyzed days out of all</i>	46.25	48.72	53.23	0	78.13	73.08
<i>Percentage of analyzed days out of days with useful information</i>	69.81	100	100	N/A	100	95

It can be noted that for one meter we have heavy problems (ID45), because there are not data for disaggregation in the observation window (80 days). From the other side, there is one meter (ID21) sending more information (first row - 53 days out of 80 -> 66%) and for this meter we find the highest percentage of identified energy 55%). Another meter (ID46) that in absolute terms shows less days with sent measurements (first row – 26 days) shows a percentage of useful info days (78%). This is one of the 3 meters that had data analyzed in all days in which it sent enough info.

Also, for one meter (ID41) with 38 days with enough data sent, all of them were analyzed and in all of them at least one instance of the “fridge” was correctly identified.

### **Data collected through the platform from Hyllie meters**

Data reported in this deliverable refer to the period from 20 to 30 of July, 2017. In the figures below, data from Hyllie test site is presented through the FLEXMETER platform with a highlight on consumption data and statistical information on a day of data from one meter. It is to be mentioned, that if the meters from the Turin pilot have a reporting rate (demand time) of 1s, for the Hyllie test site, the same parameter is 10s. As such, the number of expected samples is 8640.

Also, for these meters, information on the RMS phase voltage is presented and analysed. For the reported day, all samples were successfully transmitted and analysed. In Figures 4, 5 and 6, the following recorded quantities are plotted (and then statistically analysed): Active power consumed, RMS phase voltage and electrical energy.

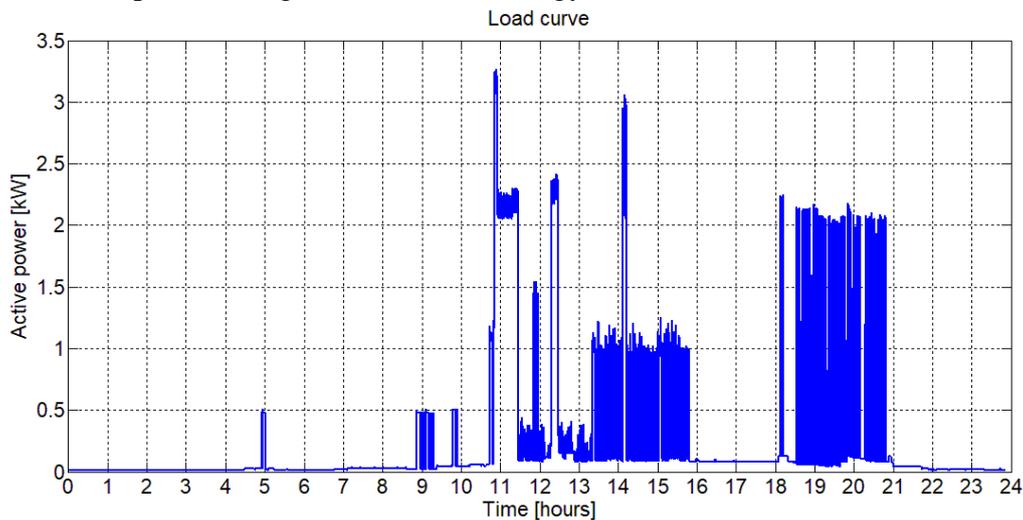


Figure 4. Active power of one day of sampling from Hyllie pilot meters.

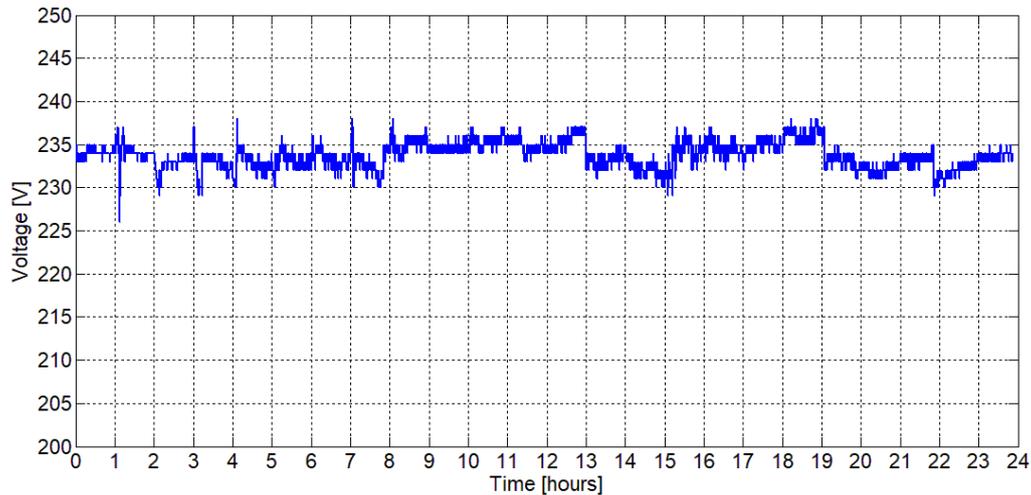


Figure 5. Voltage values of one day of sampling from Hyllie pilot meters.

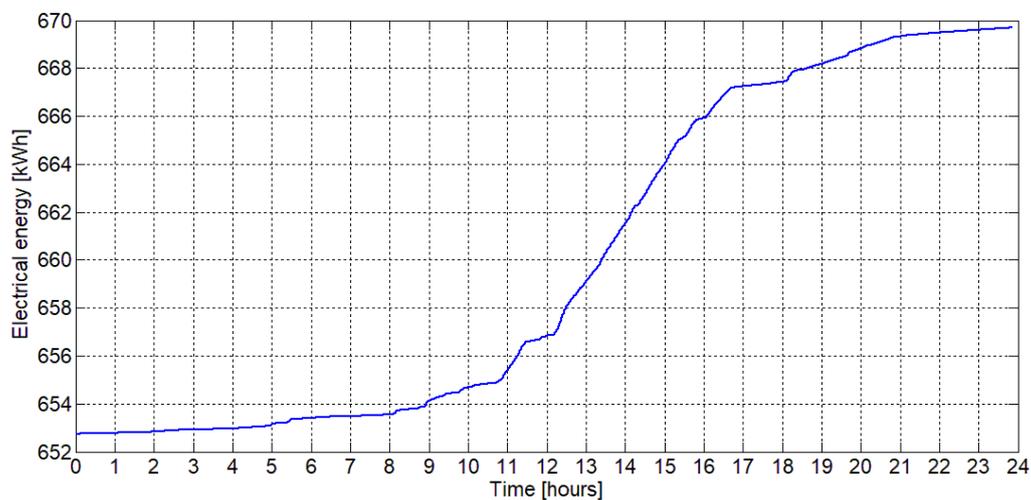


Figure 6. Energy values of one day of sampling from Hyllie pilot meters

Here are some details about measurement data from one installed meter (one day time period):

- Minimum voltage: 226V
- Maximum voltage: 238 V
- Recorded consumed energy: 16.958 kWh
- Maximum energy recorded between two measurements (10s): 0.022 kWh
- Maximum power consumed: 3.27 kW

It can be seen that the consumed energy has a value that is expected from a household in Sweden, that the voltage is in the power quality limits ( $\pm 10\%$  of the rated value, in this case 230V) and that there was an instantaneous power of more than 3 kW.

## 5 Conclusion

In this deliverable we reported preliminary results about data collected from the demonstration pilots, Turin and Malmoe. Data are related to meters deployed up to mid 2017. Some statistics about residential data analysis is also reported.

The target of this deliverable is mainly to report about the implementation of a complete chain for data analysis, from meter HW to communication protocols, IoT infrastructure and applications for data processing. Additional results about data processing will be presented in D6.4 and in the final report.

## References

- [1] J. Jin, J. Gubbi, S. Marusic, M. Palaniswami, An information framework for creating a smart city through internet of things, *IEEE Internet of Things Journal* 1 (2) (2014) 112–121. doi:10.1109/JIOT.2013.2296516.
- [2] A. A. Khan, M. H. Rehmani, M. Reisslein, Cognitive radio for smart grids: Survey of architectures, spectrum sensing mechanisms, and networking protocols, *IEEE Communications Surveys & Tutorials* 18 (1) (2016) 860–898.
- [3] T. Strasser, F. Andr en, J. Kathan, C. Cecati, C. Buccella, P. Siano, P. Leita˜o, G. Zhabelova, V. Vyatkin, P. Vrba, et al., A review of architectures and concepts for intelligence in future electric energy systems, *IEEE Transactions on Industrial Electronics* 62 (4) (2015) 2424–2438.
- [4] P. McKeever, A. Monti, Bottom-up approach to energy services platform, in: *Energy Conference (ENERGYCON), 2016 IEEE International*, IEEE, 2016, pp. 1–6.
- [5] M. Simonov, G. Dalto`e, G. Zanetto, R. Conti, Smart meters using the architecture of future internet, in: *PowerTech, 2015 IEEE Eindhoven*, IEEE, 2015, pp. 1–6.
- [6] E. Patti, A. L. A. Syrri, M. Jahn, P. Mancarella, A. Acquaviva, E. Macii, Distributed software infrastructure for general purpose services in smart grid, *IEEE Transactions on Smart Grid* 7 (2) (2016) 1156–1163. doi: 10.1109/TSG.2014.2375197.
- [7] R. T. Fielding, *Architectural styles and the design of network-based software architectures*, Irvine: University of California.
- [8] P. T. Eugster, P. A. Felber, R. Guerraoui, A.-M. Kermarrec, The many faces of publish/subscribe, *ACM CSUR*.
- [9] M. Fowler, J. Lewis, *Microservices* (2014). URL <http://martinfowler.com/articles/microservices.html>
- [10] S. Newman, *Building Microservices*, O'Reilly Media, Inc., 2015.
- [11] E. Patti, A. Acquaviva, E. Macii, Enable sensor networks interoperability in smart public spaces through a service oriented approach, 2013. doi: 10.1109/IWASI.2013.6576081.
- [12] Message Queue Telemetry Transport (MQTT). URL <http://mqtt.org/>
- [13] L. Ardito, G. Procaccianti, G. Menga, M. Morisio, Smart grid technologies in europe: An overview, *Energies* 6 (1) (2013) 251–281.
- [14] T. Dierks, *The transport layer security (tls) protocol version 1.2*.

- [15] P. F. Velleman, D. C. Hoaglin, Applications, basics, and computing of exploratory data analysis, Duxbury Press, 1981.
- [16] E. Langford, Quartiles in elementary statistics, Journal of Statistics Education 14 (3) (2006) 1–27.
- [17] IEC 61850-5 Edition, Communication networks and systems in substations - part 5: Communication requirements for functions and device models.