Energy Consumption of Smart Meters

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ABSTRACT
The project `SMART METERING consumption` focuses on the energy consumption needed for the operation of smart metering infrastructure - an issue not widely discussed until now. An analysis of state of the art smart metering solutions have been performed to provide a technology-based mapping of technical properties that are relevant for energy consumption. A flexible methodology was developed to enable comparability for differently organized smart metering solutions. Field and laboratory consumption measurements have been carried out to estimate total annual energy consumptions of the whole smart metering infrastructure of a country. The measured data has been combined to build representative real operation cases which were then used for extrapolation, according to underlying national scenarios for Switzerland and Austria.

Keywords
Smart meter, data concentrator, own energy consumption, technical scenarios, roll out.

1. INTRODUCTION
The European Union as well as many countries in the world decided to implement smart metering infrastructure, and have defined timelines for roll out plans. Main efforts in the area of smart metering are targeting improvements in the efficiency of the energy supply. A comprehensive estimate of efficiency has to include, aside from the energy changes in the supply and end-use, the power that the infrastructure itself demands for its operation. This led to the central idea of the binational `SMART METERING consumption` (`SMc`) project, which was started on behalf of the Swiss Federal Office of Energy and the Austrian Federal Ministry of Transport, Innovation, and Technology in September 2010. After a two-year project period results had been delivered in May 2012.

2. RELATED WORK
There is no related work that could be considered as directly related background for the `SMc` project. It is known that meter manufacturers and some utilities perform energy consumption measurements, but the resulting data is not publicly available. Furthermore, there are so far no research or applied studies covering assessments of smart meter's own energy consumption. Some available references are cost-benefit analyses, which partly deal with the topic of costs to run metering infrastructure and indirectly with own energy consumption.

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3. PROBLEM STATEMENT
The transfer of data from metering point to the head-end system of a utility requires suitable hardware. These are smart meters at the metering point, optionally additional gateways, but also devices at other locations such as data concentrators, bridges, and servers throughout the whole network. For the proper operation of all of these components within the communication system, electric energy has to be steadily provided at distributed places. The central idea for the `SMc` project was to conduct an assessment of the corresponding total energy consumption of smart metering hardware.

Following this idea the key questions were:

- Which device and system characteristics are responsible for the energy consumption of the smart meters?
- What is the best available technology with regard to own energy consumption (of smart meters)?
- How high is the estimated energy consumption of the likely smart metering systems for Austria and Switzerland, also in comparison to the yet installed technology?

4. DERIVED METHODOLOGY
4.1 Analysis of Products
In collaboration with key stakeholders, mainly manufacturers and power utilities, different available state-of-the-art smart metering solutions have been identified and analyzed. In the first period of the project an experts workshop with five different smart meter manufacturers was organized to help identify, aggregate, and categorize main influencing parameters of the performance of smart meters (see figure 1). Some of the more important aspects are listed as follows:

- Measurement: refers to the physical principle in the current path, the sampling frequency and the

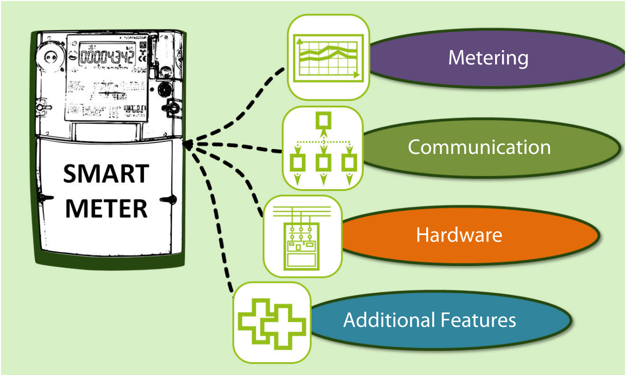

Figure 1: Main categories for parameters influencing consumption for smart meters.

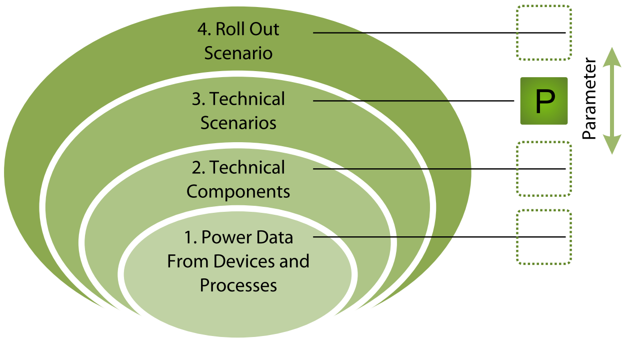

Figure 2: Onion model that explains the layerwise modeling process used to calculate system-wide own consumption of metering infrastructure.

calculation processes, to also provide monitoring functions for power quality (e.g., total harmonic distortion).

- Communication: refers to the mode of data transmission to the wide area network (e.g., PLC, GPRS), the mode of data transmission to the local area network (e.g., Ethernet, M-Bus), the availability and organization (push vs. pull mode), and the modularity of the smart meter.
- Hardware: refers to the number of phases, the power supply unit, and the breaker.
- Additional Features: multi utility control, gateways, and in-home displays.

Most of these aspects refer to the smart meter itself, but some of them are also related to the implementation of the whole metering system, or are strongly influenced by it.

4.2 Solution Approach and Set-up

To keep the chance for adaption and different adjustments to specific roll out scenarios, a well structured modeling path to describe system-wide own consumptions had to be prepared. Averaging over different fluctuations of the source data plays an important role here. A big variety of potentially significant influences should be considered such as different load situations due to the end-user, varying traffic emergence via the communication system, and different operation modes over time. In addition there could also be significant differences in the energy demand according to the position of the meter in the network and the changing network properties (e.g., voltage level, and network impedance).

Figure 2 illustrates the layered modeling process for system-wide consumption per metering point, which only needs to be multiplied by a number of metering points to extrapolate results. In this way the structure is similar to an object-oriented organisation of classes, which is already foreseen to possibly be adapted for an automated calculation by a computer script. The following description explains how the four layers shown in figure 2 are separated:

1. The first inner layer ("Power Data From Devices and Processes") contains all raw data that is necessary to form a solid basis for all calculations. The data is unsorted, yet it must be complete and can cover different operation modes of devices, and/or different use situations like countryside vs. urban region. Self-measured data shall be preferred over values from product specification datasheets values, at least if the percentual contribution to the total system consumption is high. This, to make sure robustness and independent data in the modeling.
2. The second layer combines the data from the first layer to form representative power values (Watt), which may correspond to items that shall be accounted for a certain electric energy consumption and are definitely part of the metering system. More concrete, these are appliances (e.g., smart meters, data concentrators) and processes (e.g., contributions occurring at a telecommunication operator which cannot be allocated to single physical devices). In the project these are called `Technical Components` (`TCs`), and are considered to run under realistic operation conditions. E.g., for a smart meter this means a load spectrum should be considered, which is built from time spans and corresponding input powers over a suitable monitoring period (e.g., one day if daily data readouts are considered[1]).
3. In the third layer combinations of compatible `Technical Components` are assembled to form `Technical Scenarios` (`TSCs`). A `TSC` is understood as a complete working smart metering solution. The description covers the needed system-wide active power, assigned to the single metering point. In this way, the third layer already provides a common basis to enable comparisons of power requirements of different technologies or special solutions. The main

[1]Another approach could be to monitor an entire week/month/year. This depends on the schedule for requests from the head-end, on the modelers estimate for load-dependency, or even the analysis of more sophisticated (future) systems where the smart metering communication also transfers data for the remote control of a HVAC system of a building. In the `SMc` project one typical work day has been used as reference.

property for differentiation is the technology used to connect the smart meters along the so called "last mile"[2].

4. Finally at the fourth layer the results from the third layer are put together in linear combinations to derive realistic and/or interesting `Roll Out Scenarios` (`ROSs`). For the `ROSs` for Switzerland and Austria, exemplary `TSCs` addressing the current most popular technologies such as PLC, GPRS, Radio Transmission and M-Bus have been created. Figure 3 gives an overview of how these are organized.

Key remark for figure 2: On the right side a parameter P is shown which stands for any influencing parameter. This shall provide more flexibility at the very outer modeling layer than achievable through the only combination of `Technical Scenarios`. A good example is the mandatory separation between 1- and 3-phase meters when the region to be modeled happens to include a certain amount of 1-phase connected households. This parameter would be situated as shown in layer 3, if a 1-phase and a 3-phase version of the `TSC` have been prepared. This is the case in the modeling process undertaken for Austria.

Key remark for figure 3, on categories for `Technical Scenarios`:

- `TSC A` covers systems that carry data on a conductor that is also used for electric power transmission in the distribution network. These systems are organized as meshed networks, which means the nodes (smart meters) communicate all with each other, and also act as repeaters to bridge higher distances to the data concentrator. The data concentrator then sends accumulated data over only one connection to the head-end system. PLC systems are currently the most popular cable-based technology, as they use existing infrastructure. Moreover, PLC systems comprise about 70% of both in Swiss and Austrian running smart metering pilot projects.
- `TSC B` describes systems that make use of services provided by a telecommunication operator. Similar as for mobile communication systems, the technologies and protocols are the same.
- `TSC C` stands for proprietary radio transmission systems developed by meter manufacturers. These are also organized as networks using repeating functions. In this case, some selected meters act as data concentrators (in parallel).
- `TSC D` has been introduced to evaluate special solutions adjusted for congested areas. The standardized wireless M-Bus protocol is used to gather meter data from e.g., one building complex with several appartments. A gateway transmits the bundled data packages to the head-end system.

4.3 Laboratory Stand Setup and Measurements

Measurements of the active energy consumptions in the laboratory as well as in field tests have been carried out to support all the following work with reliable data. The test series was set to cover a representative variety of smart metering solutions available on the market. `TCs` which have the greatest occurrence in the metering system were given priority. These are the smart meters and their corresponding modules, and on second place, the data concentrators. The metrological work has been performed by a competent project partner, the Institute of Electrical Power Systems of the Graz University of Technology. The measurements were addressing the main drivers for energy consumption listed in figure 1, and have been completed in four blocks:

1. Approval of the measurement equipment and arrangement: Figure 4 shows the test circuit used to measure without any load. This means only the voltage and current signals located at the net side of the meter have to be registered. As the current is low a simple shunt test circuit is sufficient. This arrangement allows measurements with high accuracy, but can only be used without the presence of load on the user side of the meter. Figure 5 shows the circuit for measurements with load of up to 16 A. This circuit was used to analyze the sensitivity in the laboratory, and also for live measurements in the field.

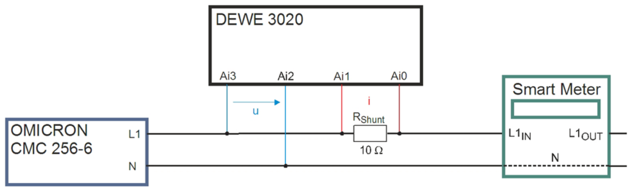

Figure 4: Test circuit using shunts - for power measurements at the meter when it is operated without load.

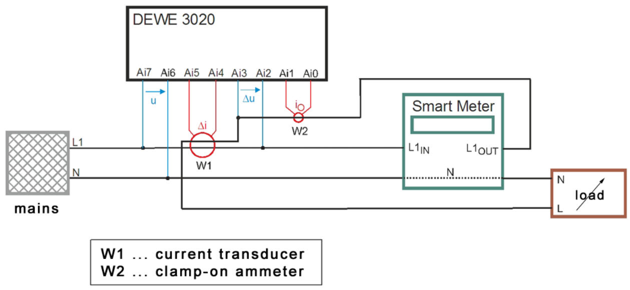

Figure 5: Test circuit using current transducers - for power measurements at the meter in real use cases, when there is a certain load, caused by the end-user.

[2]This is the distance between an end node and the next higher level node of the network (data concentrator). It is small in relation to the distances in the data transfer network, nevertheless high technical challenges are associated to reaching every end node in reasonable time and for the high number of connections. As a consequence the overhead to operate this `data collection network` is often higher than for the `data transfer network`.

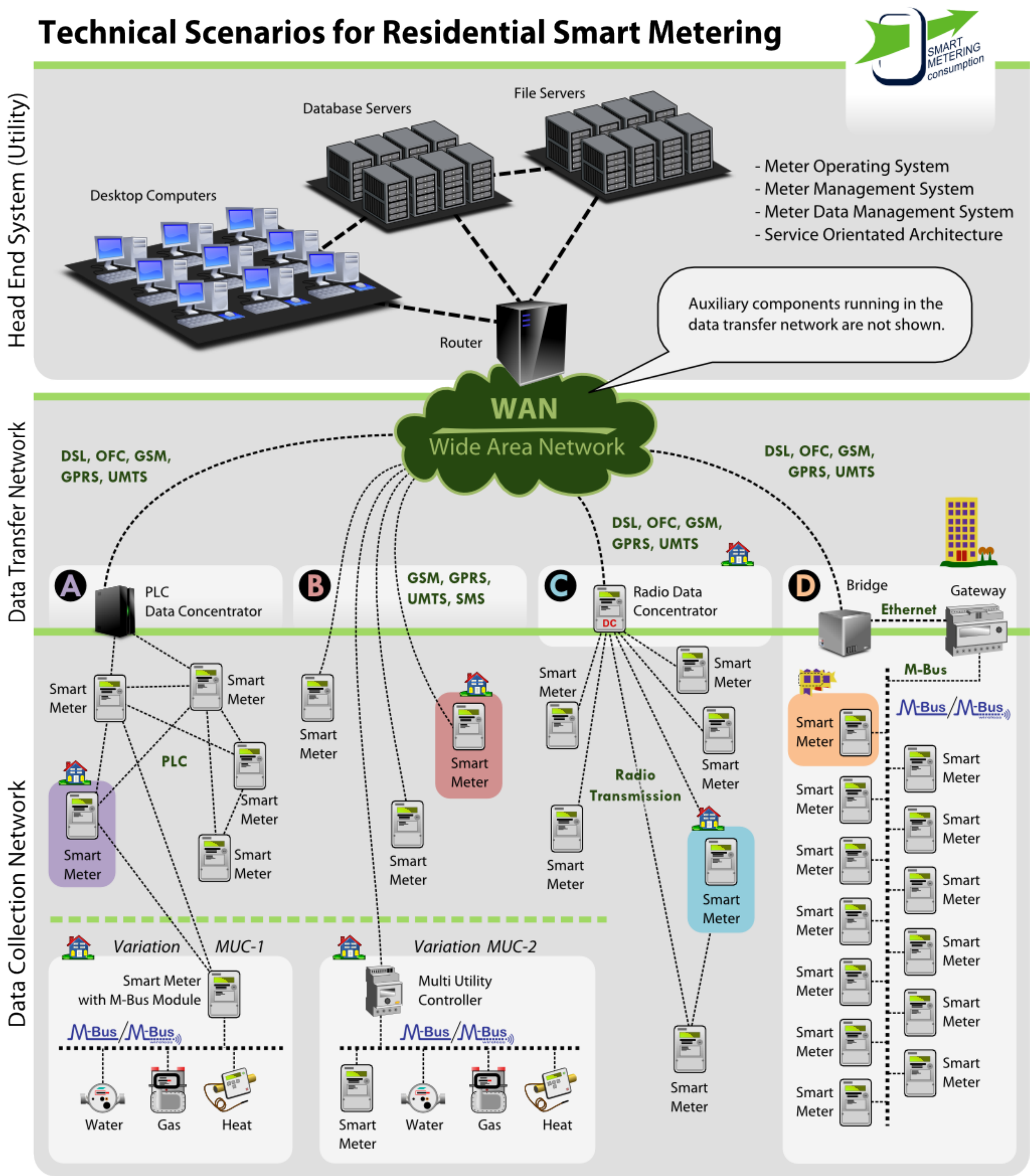

Figure 3: Network model showing the differences between the categories A, B, C, and D for the Technical Scenarios used in the SMc project. The main distinction between different data collection technologies is derived from the priorities a power utility sets for making decisions about its investments, and it is not based on their contribution to the total energy consumption.

2. Sensitivity analysis at two 3-phase smart meter products that are well represented in the Swiss-Austrian market for: mains voltage, total harmonic distortion (both coming from the net source), load current, and power factor (both caused by different types of loads). As an example figure 6 shows the relative change of own consumption as a function of load, for smart meter products from different manufacturers. The circuits used for measuring under different circumstances (that is without or under load) were evaluated in parallel.

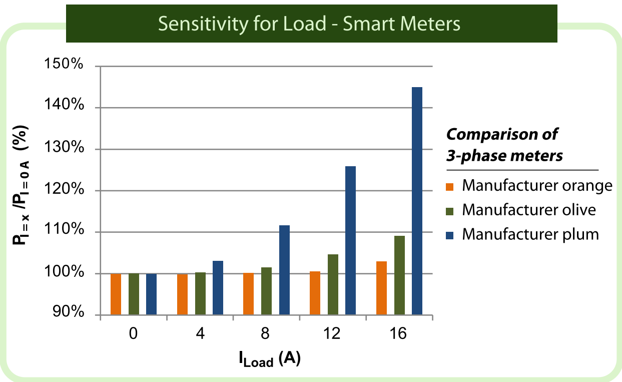

Figure 6: Anonymized comparison of sensitivity for load of different manufacturer-specific smart meter products, normalized to state without load.

3. Performing measurements of own energy consumption of different smart meter products without load and under load, in laboratory conditions.

4. Capturing live measurement data over 24 hrs: Real households situated in regions of power utilities cooperating in the SMc project facilitated this work. The most important additional data coming from these real application cases was the consumption profile over time, in connection to the remote controlled data requests to the meters.

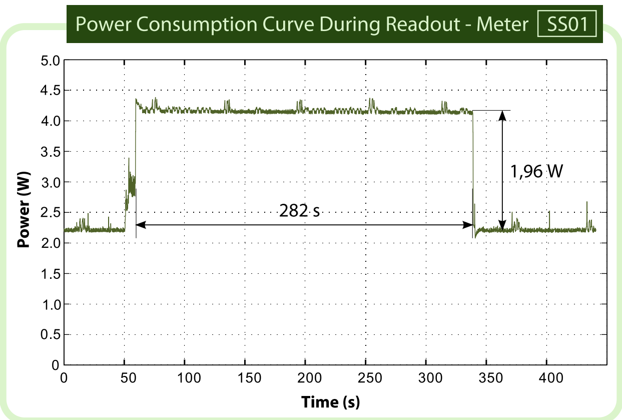

Figure 7: Input power curve of a 3-phase GPRS-connected smart meter - extract of a data transfer event (whole data log lasted for 24 hrs).

Figure 7 shows that the readout of data over the tested GPRS system (as described for TSC B) showed an input power increase during a timespan of about five minutes. The readout process over the tested PLC system lasted for 6 hrs, as shown in figure 8.

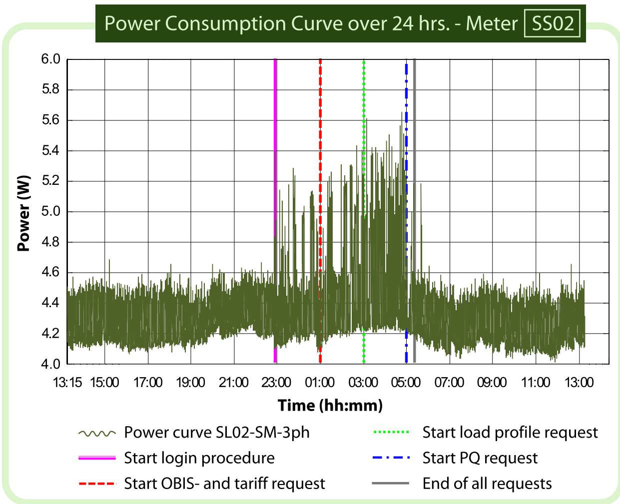

Figure 8: Input power curve of a 3-phase PLC-connected smart meter - during 24 hrs.

5. DISCUSSION OF RESULTS

5.1 Comparison of Smart Meters and Metering Systems

The project results show a large bandwith of possible own energy consumption for the smart meter types used in Austrian and Swiss pilot projects so far.

The measured (and derived) energy consumption ranged from 1.41 W to 4.64 W for a 3-phase smart meter compared to the energy consumption of a 3-phase Ferraris meter of 3.92 W, and respectively from 4.16 W to 4.65 W for a 3-phase electronic meter without communication.

For the SMc project TCs based on seven different technical solutions have been compiled. Not all of the previously determined input power values are presented in a way that they could be directly assigned to a single metering point. The necessary calculations are performed in an extra step. To give an example, for TSC B_2[3] the result is:

- 1-phase metering point ... 1.83 W
- 3-phase metering point ... 2.38 W

As described above, the number of phases is kept as a variable. In the TSCs B there are no data concentrators involved (see figure 3). For TSCs A the average ratio of meters connected to one data concentrator is also used for the different subcases. For example the abbreviation "100MP" means that hundred metering points are managed by one data concentrator. To provide a quick

[3]The index _2 stands for a special solution that is member of category B.

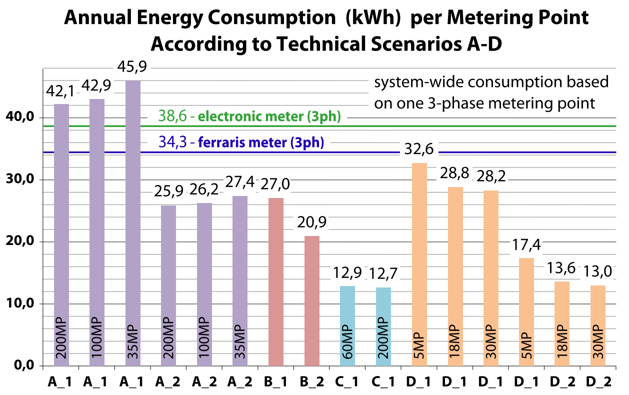

Figure 9: Comparison of system-wide occurring annual energy consumptions to operate smart metering systems which were analyzed in the `SMc` project.

overview, figure 9 shows the system-wide modeled annual consumptions based on one 3-phase metering point. From this graphic it can be seen a tendency to have higher consumptions for the PLC systems. The best performance is shown by the proprietary radio transmission system C_1. Nevertheless, it would be wrong to derive the consumption only from the kind of communication technology in use. Some other influencing aspects are mentioned in section 5.3.

5.2 Nation-wide Projections for Roll Outs in Austria and Switzerland

All previous results have been brought together to estimate energy consumptions for smart meter `Roll Out Scenarios` for Austria and Switzerland.

On November 1st, 2011 the Austrian government released the legislative requirements for smart metering systems operated in Austria. Switzerland was conducting a large impact assessment study on smart metering systems and no policy was derived at that time. Important mandatory requirements (for Austria) are:

- Measurement and logging of average values for active power at a 15 minutes interval; possibility to save this data for 60 days.
- Bi-directional communication between utility and smart meter to enable transmission of the consumption data once per day (allowed time slot for transmission is 12 hrs).
- Connectivity to minimum four external meters (e.g., water, heat, gas).
- Breaker - possibility for a remote controlled disconnection from the mains.
- Data encryption according to the "state of the art".
- Possibility for remote firmware updates.

The projections have been performed considering these requirements. The data has been assembled using assumptions for the most likely smart meter roll out, according to the method described above, to estimate the overall energy consumptions for smart meters in Austria (AT) and Switzerland (CH). The nation-wide results for one year of normal operation are shown in figures 10 and 11. The assumptions for the `Roll Out Scenarios` are described as follows:

- **AT - Status quo**: Projection of the actual Austrian state without smart meters. This scenario is based on 1.7 mio. 1-phase and 4.1 mio. 3-phase metering points, where 97% Ferraris, and 3% electronic meters are installed.
- **AT-1**: This is considered to be the most likely `ROS` based on smart metering technology available in 2011. It is based on 73% `TSC` A (PLC), 11% `TSC` B (GPRS), and 16% `TSC` C (radio transmission) solutions. For every `TSC` category, uniformly distributed mixes of the assessed solutions have been assumed.
- **AT-2 (>10)**: Derived from AT-1, it has been evaluated, if the application of `TSC` D solutions pays off in terms of efficiency. It has been assumed that only buildings with more than ten appartments are connected through a common gateway.
- **AT-2 (>1)**: Similar to AT-2 (>10), but every building with more than one household is assumed to have a common gateway. Whereas AT-2 (>10) enables a certain reduction in the own consumption, AT-2 (>1) turns out to be more energy consuming in operation than AT-1.

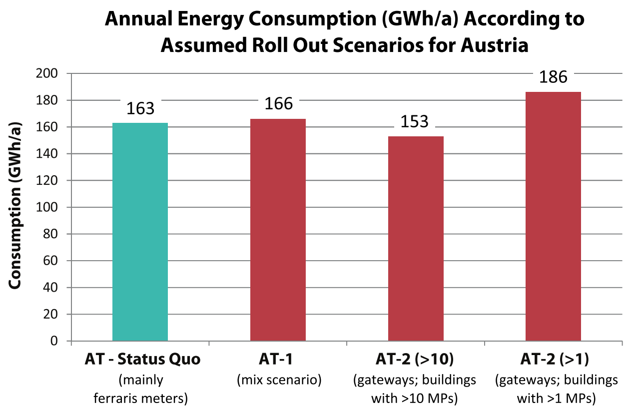

Figure 10: Comparison of annual energy consumptions according to different assumed `Roll Out Scenarios` for Austria.

- **CH - Status quo**: Projection of the actual Swiss state without smart meters. This scenario is based on 5.0 mio. 3-phase metering points, where 60% Ferraris and 40% electronic meters are installed.
- **CH-1**: For this `ROS` the use of 100% `TSC` A_2 solutions has been assumed. The total consumption is lower

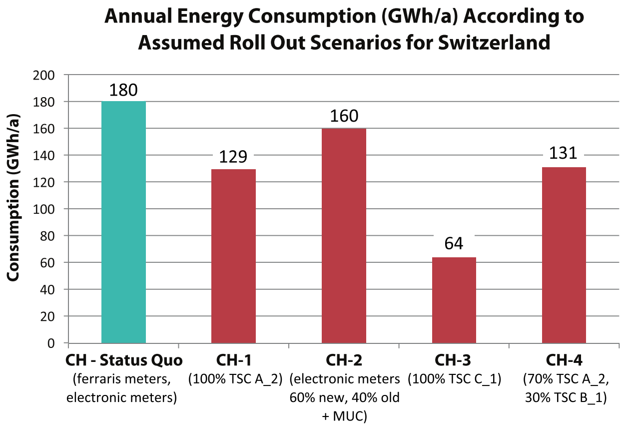

Figure 11: Comparison of annual energy consumptions according to different assumed `Roll Out` Scenarios for Switzerland.

than in `ROS` AT-1, although there are more 3-phase metering points in Switzerland than in Austria.

- **CH-2**: Here it is assumed that only the Ferraris meters are exchanged by modern electronic meters. Both, the old installed and the new electronic meters do not directly communicate to the wide area network. This is realized through an auxiliary device, a gateway (see variation MUC-2 in figure 3). In comparison with CH-1 this causes an increase in the consumption.
- **CH-3**: In this scenario 100% metering solutions from `TSC` C_1 are installed. The comparison above showed that this is the most efficient `TSC`, therefore an energy saving of nearly two thirds with reference to the status quo could be achieved.
- **CH-4**: With reference to the Austrian scenario AT-1, a mix of 70% `TSC` A (PLC) and 30% `TSC` B (GPRS) has been projected here. Again, like for CH-1, -2, and -3, the homogeneous application of only one solution per category has been assumed (`TSC` A_2 and `TSC` B_1).

The calculated scenarios show that the roll out could lead to an overall reduction in the energy consumption for the metering hardware, provided that the most efficient technical solutions would be rolled out, respectively, would stay in the range of the energy consumption of the currently implemented solutions, namely, Ferraris meters and electronic meters without communication system.
The comparisons in the `SMc` project show, that the energy efficient smart metering technologies seem not to been prevalently chosen in the Austrian implementation plans so far. This refers to the currently represented and evaluated smart metering systems in Austrian pilot projects. Moreover, there are no specific policy measures limiting consumption per metering point, although a reduction by nearly two thirds could be achieved.
Although not all possible or imaginable smart metering technologies have been analyzed in the `SMc` project, there are indications that higher potential for low consumption exists, when considering technologies already established for meters of the gas or water sector (battery driven).

5.3 Identification of Aspects Causing Energy Consumption

Within the entire smart metering infrastructure the smart meter itself shows the highest energy consumption (76% - 98% contribution to the system-wide consumption; according to the Swiss `ROS`s). The main driver for the energy performance of a smart meter is the technology used to carry out the communication of the data. Among other technical aspects this can be explained with the permanent execution of “keep-alive functions” in PLC systems which are necessary to keep the network stable. The corresponding overhead in radio transmission systems is much lower. Other than electromechanical meters which only measure and display an accumulated consumption value, the smart meters have to provide a couple of functionalities in parallel. This following list shows some aspects which are related to these.

- **Number of phases**: The ratio of 3-phase meter to 1-phase meter consumptions is for the analyzed solutions ranging from 1,13 to 1,69.
- **Measurement principle of the meter**: There are different principles in use like shunts, hall sensors, or rogowski coils which may cause different energy consumptions.
- **Integration of single functions**: As the meters may even use additional sensors (like for anti-fraud protection) it is a question of the integration level, with how much energy consumption every single function can be associated. For the signal processing in modems this is also an issue.
- **Breaker**: Some manufacturers use relays that permanently need energy to hold the current switching state. On the other hand bi-stable relays only need a negligible portion of energy in the moment the state is being alternated.
- **Power quality features**: Many meters measure not only the basic energy consumption but are also capable of analysing the shape of the voltage signal using fast fourier transformation algorithms. This helps utilities understand in which actual condition the net at different locations is. These and other computations taking place in the smart meter could cause significant additional energy consumption.

Referring only to these few examples described above, it is already clear that the technical requirements for smart meters, especially with focus on detailed solutions, play an important role when aiming at roll outs using efficient hardware.

Sensitivity for influencing electrical parameters from the network and the user side
Other than for older generations of electronic meters the two evaluated state of the art smart meters only showed minor sensitivity to load current, mains voltage, total harmonic distortion, or power factor of the load. Therefore, these effects have been neglected in the modeling approach of the `SMc` project.

6. CONCLUSIONS AND OUTLOOK

The SMc project results presented system-wide modeled energy consumptions demanded by different smart metering technologies, based on measurements of currently available solutions. There are big saving potentials of a factor 3 through the choice of technology.

A flexible and broadly applicable assessment methodology for performing energy measurements of Smart Meters has been developed in this project. The modeling path is designed to easily accommodate other scenarios of roll out implementations. Based on this, projections have been carried out on the energy consumption of changing to smart metering infrastructure at the national level for Austria and Switzerland have been carried out. As there is no standardized methodology for assessments nor plans for a harmonized international collaboration, the presented methodology could be the basis for further developments in terms of:

1. **Expanded system boundaries towards the home area of the end-user**. This could include home monitoring and home automation systems which are often discussed in parallel with smart metering systems and smart grids. Energy saving suggestions could be provided to the user by the utility, or even third party companies, when monitoring data would be transferred over the smart metering network[4]. It is assumed that the own consumptions of such systems could exceed by far the smart metering consumption assessed in the SMc project. These home systems are normally purchased and installed by the end-user, therefore the cost due to the accompanying electric energy these systems demand are beared by them. Many different systems are under discussion or already on the market, e.g., in-home displays, applications for smart phones or tablet PCs, web portals (eventually coupled with a monitoring and/or control system consisting of so called "smart plugs" distributed in the home area, connected to an own data server, and running on an own communication system, e.g., ZigBee or broadband PLC). There are projections for 20 to 30 nodes for a one family house, so the energy demand to perform permanent monitoring and communication through this home network becomes potentially relevant.
   Expanded system boundaries could also include alternating current converters of private photovoltaic systems or loading stations for electric vehicles. These are two additional devices which are thought to be somehow integrated in future distributed power generating smart grid systems.

2. **International cooperation** to evaluate and compare roll out plans to be set under different boundary conditions (legal, topographical, in terms of policy, and methodologically). From the experience with the binational SMc project, leverages and synergies for projects between various countries could be explored in the future.
   International standards which define consumption parameters and possible limits per metering point still need to be developed (concerning system-wide occurring consumptions).
   Likewise, collaboration at the international level is needed to develop policies regarding consumption of smart metering.

[4]In the SMc project the focus was strictly kept on the metering system itself, that only has to fulfil the core functionalities measuring, logging, and transferring of data.

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