Bundesministerium
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# SMART METERING consumption

## Own consumption of electricity meters

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Berichte aus Energie- und Umweltforschung

44a/2012

Dynamik mit Verantwortung

**Imprint:**

Owner and Publisher:
Austrian Federal Ministry for Transport, Innovation and Technology
Radetzkystraße 2, A-1030 Vienna, Austria

Responsibility and Coordination:
Division for Energy and Environmental Technologies
Head: Michael Paula

http://www.nachhaltigwirtschaften.at

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Vienna, September 2012
english translation: October 2013

**Within the programme „Energy of the Future“**

ENERGY SYSTEMS of Tomorrow

Supported by the Austrian Federal Ministry for Transport, Innovation and Technology

**Co-financed by:**
Swiss Federal Office for Energy (SFOE).
Research programme: "Elektrizitätstechnologien und -anwendungen"
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SWITZERLAND
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This is the English translation of the original report (2012) in German. Translation by the ECODESIGN company GmbH, October 2013.

# Glossary and list of abbreviations

The following glossary defines some of the technical words used throughout this publication. In addition to the generally accepted terminology, the words indicated in **bold** have a specific meaning in the context of the methodology developed in this project.

- **1ph: single phase**. Refers to a type of meter. Single phase meters are connected to one phase of the distribution grid (Alternating current meter).
- **3ph: three phase**. Refers to a type of meter. Three phase meters are connected to three phases of the distribution grid (Poly-phase meter).
- Anti-fraud protection: The term refers to protection mechanisms which aim to prevent electricity theft or the manipulation of devices. Usually, these are based on the detection of magnetic fields as well as on the detection, if the terminal cover has been opened. Further preventive measures are the use of current measurement principles, which are insensitive to magnetic fields (Magnetic immune).
- AT: Austria
- **Basic meter**: Refers to a modular meter, meaning the meter alone, without any modules.
- BMVIT: Bundesministerium für Verkehr, Innovation und Technologie
  (Austrian Federal Ministry for Transport, Innovation, and Technology)
- **Bridge**: A general definition for a device, which allows converting and forwarding data from a specific transfer method to another.
- CH: Switzerland
- CPE → Customer Premises Equipment:
- Customer Premises Equipment: Any terminal and associated equipment of a telephone or other service provider, which is located on the customer's premises (not at the provider's premises or in between). In the case of transmission over optical fiber, this would be a device that converts optical signals from the optical fiber cable to the Ethernet (see: Bridge).
- **Breaker**: A device that allows the separation (cut-off) of the metered area from the grid at the metering point. Technically this is carried out in each phase with a relay, and initiated from the control center of the energy utility. This is necessary when customers change the electricity supplier or when it comes to debt collection.
- **Data collection network:** Infrastructure for data communication between meters and data concentrators.
- Data communication: Data communication in the smart metering system includes all processes, starting from the metrological part of the meter at the metering point, to the control center at the head-end (Generally in both directions). If data concentrators are installed, the network is divided into the data collection network and the data transmission network.
- **Data transmission network**: Infrastructure for data communication between the data concentrators (or directly from individual meters) and the head-end.
- **DC:** Data Concentrator. The data concentrator collects data from the local metering points and transmits it in aggregated form to the head-end system (HES). Depending on the transmission method, the DCs are installed in transformer stations (usually applies to PLC) or at selected metering points (usually applies to radio transmission). Some data concentrators provide a data interface to connect a separate modem to them. Other types

operate with an integrated modem. Systems which use mobile technology, such as the Global System for Mobile Communication (GSM), General Packet Radio Service (GPRS) and the Short Message Service (SMS), have a direct connection to the meter and do not need a data concentrator.

- DLC → PLC
- DSL: Digital Subscriber Line. A family of technologies that provide digital data transmission over the wires of a local telephone network.
- DSP: Digital Signal Processing. Calculations performed with digital technology for signal processing.
- FTTB: Fiber To The Building. Name for a fiber optic infrastructure (see OFC), which reaches individual buildings. In the case of FTTH, it reaches individual households.
- FTTH: Fiber To The Home → FTTB
- **GPRS**: General Packet Radio Service. This is a mobile phone technology.
  Within this project, GPRS is a category of TSCs that use mobile communication technology as a solution for data transmission. The communication is based on services of a telecom operator.
- GSM: Global System for Mobile Communications. It is a mobile phone technology.
- HAN → Home Area Network. Network inside or within the close vicinity of a home (Household).
- **HES** → Head-end system
- Head-end / Head-end system. There are different interpretations of this term. In principle, it is the control center of a grid. Within the SMc project it means the control center of the smart meter infrastructure. In other words, it is the node where all energy consumption data is collected for monitoring. The head-end system is usually part of the network operator. Small utilities may outsource this IT-service to other companies.
- ICT → Information and communication technology
- IHD → In-home display
- In-home display: In this report an in-home display is understood as an independent device that provides end customers with feedback about their energy consumption as its primary functionality. It differs from other feedback solutions such as web portals, which need multifunctional facilities like a computer or a smartphone (multi-functional handheld devices). In-home displays are installed in the household area and communicate via wireless M-Bus.
- **IT**: Information technology. In the SMc project, information technology refers to all activities within the HES (control center of the energy utility), needed for data processing. In particular the meter operating system, meter management, and meter data management. From case to case IT-services are outsourced.
- LAN: Local Area Network. A Network within a building or a complex of buildings.
- Last Mile: A term that is often used to describe the distance between the metering point in the household and the nearest node. Different data transmission processes might be used as those used in the data transmission network.
- Lines: When describing the topology of the low voltage distribution grid, lines are defined as star-shaped cables coming from a distribution node. These cables are installed along a group of buildings, generally along a road, until the service drop. Each service drop serves

a housing area, and redistributes the electricity to each household. In rural areas, where overhead lines rather than underground cables are common, the delivery takes place over the roofs.

– Load-free condition → Off-load condition.

– **M-Bus:** *Meter-Bus.* This is a European norm for the remote readout of electricity meters. Furthermore, M-Bus can also be used for other types of utility meters, as well as for diverse sensors and actuators. Moreover, there are specific IEC standards for Wireless M-Bus technology, which is the more common technology nowadays. These are used for the connection of different meters to the electricity smart meter, or to connect to a gateway, to a MUC, or to connect to facilities within the metered area. In most cases the M-Bus is only used for internal communication within buildings. Within the SMc project "M-Bus connection to gateway" is the term used in technical scenarios, in which M-Bus linked smart meters transmit data via a common gateway to the control center.

– MFM: Multifunctional Meter

– **MUC** → Multi Utility Control

– Multi Utility Control: A Multi Utility Control is a system that transmits data from various devices which measure (electricity, gas, water and heat) consumption, by aggregating the data at the metering point and delivering it to the head end system. In some cases a MUC-gateway collects the data via M-Bus, and transfers it to the control center. In other cases, the electricity meter itself can operate as M-Bus master device, and do both procedures. MUC-C refers to Multi-Utility-Communication Controller.

– **Metered area**: This is the part of the distribution network in which the energy consumption is measured and invoiced to the end costumer. This area is not part of the smart metering system. The metering point defines the border between the metered area and the non-metered area (See → Non-metered area). Home monitoring systems and home automation systems, which are not considered within the SMc project, are mainly installed in the metered area (in broader terms, in the household area).

– **MFM** → Multifunctional meter

– **Network Level 7:** In Austria the electricity grid is classified by different network levels to facilitate the definition of tariffing. The voltage is used to distinguish the different levels. Network level 7 is the one which is operated at 230V/400V to serve the end consumers.

– **Non-metered area:** Refers to the area in the distribution grid where the energy consumptions are neither registered by meters nor charged to end consumers. Referring to smart metering this is the data collection network including the meters. The boundary between non-metered and metered area goes through the metering point (See → Metered area).

– OFC: Optical Fiber Cable. Medium for the transmission of optical signals.

– **Off-load condition**: This means testing conditions where the output power at the metering point is zero. As the voltage ranges within its normal boundaries this means, the current is zero.

– **PLC:** Power Line Carrier or Power Line Communication. In the SMc project, this refers to a category of TSC, which uses the power line carrier as transmission medium within the data collection network.

– Power Line Carrier: The communication within the data collection network is often carried out with PLC. In this case, the lines of the low voltage distribution grid are used as medium for data transmission. This is achieved by modulation of the voltage signal by use of a special modem.

- Radio connection → radio transmission
- **Radio transmission**: In the SMc project, radio transmission is defined as a category of TSC, which consider the use of proprietary radio transmission solutions within the data transmission network. Roughly described, the organization of such networks works in a similar way to PLC data collection networks. Repeaters send out signals repeatedly and data concentrators transmit bundled data from several meters to the control center. In this study, the terms “radio connection” and “radio transmission” do not refer to telecommunication services and systems (such as GSM, GPRS, SMS, etc.). Neither do these terms refer to wireless M-Bus solutions, which use gateways for data collection within buildings. From a technical perspective, also within these systems “radio” corresponds to the physical transfer medium. However, the arrangement of the data transfer differs substantially for “GPRS”, “radio transmission” and “M-Bus to gateway”.
- Repeating*:* Referring to network technology, repeating is generally defined as a technique through which an incoming signal is received on a node (where the repeater is located) and transmitted again with defined signal strength. The purpose is overcoming distances where signal attenuation and interferences occur, and keeping the defined signal quality, so that the communication from end-node to end-node works without loss of information. Repeating is implemented for the communication in the data collection network with radio transmission, as well as in PLC system. Instead of using independent physical repeaters the meter itself provides this functionality, which is selectively used, depending on the location of the metering point within the grid.
- **Rollout scenario:** In a rollout scenario the needed combination of technical scenarios is defined to build up an extrapolation for a whole region.
- SFOE: Swiss Federal Office for Energy
- SIM: Subscriber identity module. This is an integrated circuit that securely stores the international mobile subscriber identity (IMSI) and the related key used to identify and authenticate subscribers on mobile telephony devices (such as mobile phones and computers).
- **SM**: Smart meter.
- SMc: SMART METERING consumption.
- **SS**: Specific solution. Manufacturer-specific implementation for the meters and the infrastructure in the data collection network.
- **Status quo**: Regardless of the fact that some energy utilities already run pilot projects or have smart meters in productive operation, within this project the status quo is defined as a scenario without any smart meters. This includes electronic meters without communication module.
- **Technical components**: In this project, technical components are modules needed for generating a technical scenario. In most cases these technical scenarios include physical components with characteristic power inputs, for example: a meter, a data concentrator, a bridge, etc. In some cases it makes sense to model single processes as technical components. This might be appropriate if, for example, the output device of an end-user only displays the own energy consumption under certain conditions, or if a transmission signal for the meter reading at the mobile network operator is within a specific timeslot and serves, and for the rest of the time, used for the operation of the mobile communication network.
- **Technical scenario**: In the context of this project and for the purpose to retrieve own energy consumption totals, a technical scenario is a complete illustration of a possible system. Technical scenarios are composed of modules which are technically compatible

and can be combined. Each part of the individual modules is standardized to one single metering point. For example, if 50 metering points are served by one data concentrator, for the generation of a technical scenario it is necessary to add one fiftieth of the consumption of the data concentrator to the consumption arising at the metering point.

- **TC** → Technical component
- **THD**: Total harmonic distortion
- **TSC** → Technical scenario
- WiMAX: Worldwide Interoperability for Microwave Access is a wireless communications standard.

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# Zusammenfassung

Das Projekt SMART METERING consumption beschäftigt sich mit dem Energieverbrauch künftiger Smart Metering Infrastruktur – ein bisher wenig betrachteter Bereich.

Sowohl die EU wie auch viele andere Länder und Regionen haben beschlossen eine Smart Metering Infrastruktur einzuführen mit dem Ziel die Energieeffizienz der Energieversorgung zu verbessern. Eine gesamthafte Abschätzung der erreichbaren Effizienz muss aber auch die Verbräuche der neuen Infrastruktur mit einbeziehen.

In Zusammenarbeit mit Smart Meter Herstellern und Energieversorgern wurden verschiedene dzt. verfügbare, dem Stand der Technik entsprechende Smart Meter untersucht. Es wurden vom Institut für Elektrische Anlagen der Technischen Universität Graz Messungen der Eigenenergieverbräuche von Smart Metern, sowohl unter Laborbedingungen wie auch im echten Einsatz in Haushalten durchgeführt.

Im Projekt wurden der gesamten Kommunikationskette Energieverbräuche zugeordnet, beginnend mit den Smart Metern, über die Datenkonzentratoren, sowie den Geräten der Telekommunikationsanbieter bis hin zum Head End Server der Energieversorger.

Die Ergebnisse dieser Analyse wurden in sogenannten technischen Szenarien zusammengefasst. Ziel war es, eine Vergleichbarkeit verschiedener Technologien zu ermöglichen. In Summe wurden so vier technische Szenarien ausgearbeitet, jeweils in Bezug zu den aktuellen Kommunikationstechnologien wie PLC, GPRS/UMTS, Funkübertragung und M-Bus.

Schlussendlich wurden realistische Rollout-Szenarien für Österreich und die Schweiz abgeleitet und entsprechende, zu erwartende Gesamtenergieverbräuche für den Betrieb von Smart Metering Lösungen errechnet.

Das Projekt zeigt folgende Ergebnisse:

– Es wurde eine breit anwendbare Methode für die Bewertung des Eigenenergieverbrauchs von Smart Metern entwickelt. Da es dazu derzeit noch keine international abgestimmte Vorgangsweise gibt, könnte die im Projekt entwickelte Methode als Basis für weitere Entwicklungen genutzt werden - z.B. im Rahmen der IEA oder anderen Organisationen;

– Gemäß der im Projekt durchgeführten Messungen zeigen sich erhebliche Unterschiede im Eigenverbrauch von Smart Metern. Die gemessenen Verbräuche reichen von 1,4 W bis 4,6 W für 3-phasige Smart Meter. Im Vergleich dazu benötigt der 3-phasige Ferrariszähler 3,9 W und der 3-phasige elektronische Multifunktionszähler 4,2 W bis 4,6 W;

– Innerhalb der gesamten Smart Metering Infrastruktur weist der Smart Meter den höchsten Energieverbrauchsanteil auf. Davon wiederum entfällt in vielen Fällen der größte Anteil auf die Einheit für die Datenkommunikation des Smart Meters;

– Die gemessenen Energieverbräuche wurden zusammengeführt und unter den erwartbaren Annahmen für Rollouts wurden Gesamtverbräuche für Österreich und die Schweiz errechnet. Dabei zeigt sich, dass der Rollout ähnliche Energieverbräuche wie die zur Zeit verwendeten Technologien bringen wird oder aber zu einer Reduktion der Gesamtverbräuche führen kann wenn die energieeffizienteste Zähler-Hardware respektive Kommunikationstechnologie zum Einsatz kommen wird.

Die Gültigkeit dieser Aussagen und Ergebnisse beschränkt sich auf die im Projekt untersuchten Technologien und auf die zur Zeit verfügbare Hardware.

# Abstract

The project SMART METERING consumption focused on the energy consumption of the future smart metering infrastructure - an issue not widely discussed until now.

The EU as well as many other countries in the world decided to implement Smart Metering infrastructure. 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.

In collaboration with key stakeholders, especially manufacturers and power utilities, different available state-of-the-art smart metering solutions have been analyzed. Measurements of the actual energy consumption of Smart Meters under laboratory conditions and under real conditions in household have been carried out. The Institute of Electrical Power Systems of the Graz University of Technology has performed these measurements.

Technical components for the entire communication chain using smart meters have been identified and energy consumptions have been assigned to these technical components starting with the smart meter, followed by the data concentrator and devices at the telecommunication operators as well as the head end servers at the power utility.

Results of the analysis where put together in so called technical scenarios. This is providing a common basis to make comparisons of power requirements of different technologies currently available. In total four technical scenarios have been analyzed addressing the main technologies such as PLC, GPRS/UMTS, radio transmission and M-Bus.

The final aim was to derive realistic rollout scenarios for Austria and Switzerland. Accordingly a projection of the energy consumption due to the roll out of Smart Metering solutions has been calculated.

The project showed the following main results:

– A widely applicable and flexible methodology for assessing the energy consumption of smart meters has been developed. Since there is no international standard methodology available, this could serve as a basis for further method development at an international level such as IEA or other forums;

– According to the measurements performed in the project there are significant differences in the energy consumption of smart meters as available today. The measured energy consumption ranged from 1,4W to 4,6W for a 3 phase Smart Meter compared to the energy consumption of a 3 phase Ferraris meter of 3,9W respectively to 4,2W to 4,6W for an 3 phase state-of-the-art electronic meter without communication;

– Within the entire Smart Metering infrastructure the Smart Meter itself shows the highest amount of energy consumption. With regard to this amount in many cases the main driver for the energy performance of a Smart Meter is the technology used to achieve data communication;

– The measured consumptions have been put together using most likely assumptions for the Smart Meter roll out to calculate the overall energy consumptions caused by Smart Meters for Austria and Switzerland. These calculated scenarios show that the roll out may lead to an overall reduction in the energy consumption of the metering hardware – providing that the most efficient Smart Meter hardware solutions and communication technology will be rolled out – or at least that the energy consumption will remain in the range of the currently implemented solutions.

The validity of these results is limited to the specific evaluated technologies and currently available hardware only.

# Résumé

Le projet SMART METERING consumption se focalise sur la consommation d'énergie de la future infrastructure Smart Metering – un sujet peu abordé jusqu'à présent.

L'UE, ainsi que de nombreux autres pays dans le monde, a décidé de mettre en oeuvre l'infrastructure Smart Metering. Les principaux efforts dans le domaine du Smart Metering ont pour objectif des améliorations dans l'efficience de l'approvisionnement en énergie. Une estimation complète de l'efficience doit inclure, à part les changements d'énergie dans l'approvisionnement et l'utilisation finale, la puissance que l'infrastructure même exige pour son opération.

En collaboration avec des parties prenantes clés, en particulier les fabricants et services d'électricité, différentes solutions Smart Metering des plus récentes et disponibles ont été analysées. Des mesures de la consommation d'énergie effective des Smart Meter dans des conditions de laboratoire ainsi que dans des conditions réelles, dans des ménages, ont été réalisées. Ces mesures ont été effectuées par l'Institut des systèmes de puissance électriques de l'Université technologique de Graz.

Les composants techniques pour toute la chaîne de communication utilisant des Smart Meter ont été identifiés et les consommations d'énergie ont été assignées à ces composants techniques, à commencer par le Smart Meter, suivi du concentrateur de données et des dispositifs chez les opérateurs de télécommunication ainsi que les serveurs de tête de réseau chez le fournisseur d'électricité.Les résultats de l'analyse ont été synthétisés dans des scénarios techniques. Ceci offre une base commune pour faire des comparaisons des demandes d'énergie des différentes technologies actuellement disponibles. Quatre scénarios techniques ont été analysés au total, visant les technologies principales comme les PLC, GPRS/UMTS, transmissions radio et M-Bus.

L'objectif final était d'en tirer des scénarios de mise en œuvre réalistes, pour l'Autriche et la Suisse. Ainsi, une projection de la consommation d'énergie due à la mise en œuvre de solutions Smart Metering a été calculée.

Le projet montra les principaux résultats suivants:

– Une méthodologie souple et largement applicable a été développée pour déterminer la consommation d'énergie de Smart Meter. Comme il n'existe pas de méthodologie standard internationale, ceci pourrait servir de base pour un développement de méthode ultérieur au plan international, comme l'AIE ou d'autres organisations.

– D'après les mesures effectuées dans le projet, il existe des différences significatives en matière de consommation d'énergie des Smart Meter disponibles aujourd'hui. La consommation d'énergie mesurée varie de 1,4W à 4,6W pour un Smart Meter triphasé; ceci comparé à la consommation d'énergie d'un compteur Ferraris triphasé de 3,9W respectivement 4,2W à 4,65W pour un compteur électronique triphasé moderne sans communication.

– Dans toute l'infrastructure Smart Metering, c'est le Smart Meter même qui présente la plus grande part de consommation d'énergie. De cette part, l'élément principal influençant la consommation d'énergie d'un Smart Meter est, dans beaucoup de cas, l'unité utilisée pour effectuer la communication des données du Smart Meter.

– Les consommations mesurées ont été regroupées en utilisant des hypothèses les plus vraisemblables pour la mise en œuvre des Smart Meter, pour calculer la consommation d'énergie générale provoquée par les Smart Meter en Autriche et en Suisse. Ces scénarios calculés montrent que la mise en œuvre peut conduire à une diminution générale de la consommation d'énergie des compteurs – pour autant que ce soient les solutions techniques respectivement la technologie de communication les plus efficientes qui sont mises en œuvre – ou qu'au moins, la consommation d'énergie restera au niveau de celle des solutions actuellement utilisées.

La validité de ces résultats est uniquement limitée aux technologies évaluées spécifiquement et au matériel actuellement disponible.

# 1 Background

## 1.1 Introduction

The following final report represents the outcome of the project “SMART METERING consumption” (SMc) undertaken on behalf of the Swiss Federal Office of Energy (SFOE) and the Austrian Federal Ministry for Transport, Innovation and Technology (BMVIT).

The study was coordinated with both project partners and conducted from September 1st, 2010 to April 30th, 2012.

## 1.2 Background and relevance of the project

In the European Union several countries intend to install smart grids on a regional scale. In general the aim is a functional extension for the current energy supply system, by means of which energy consumption can be monitored and supply-relevant data can be exchanged. The rollout of smart grids reaches all levels of the energy supply down to the end customer and therefore the individual households need to be equipped with the corresponding hardware to connect to this infrastructure.

As a consequence, the conventional metering systems will be converted to smart metering systems. This is the reason for governments to be increasingly involved in ambitious rollout programs aimed at a nationwide installation of smart meters in households and industries. In the UK it is already planned to exchange 47 million conventional meters to smart meters by 2020 [DECC 2009]. Energy utilities also plan the adoption of this technology for their supply areas and operations.

The smart metering infrastructure has to fulfill the basic functions “measurement of consumption data”, “data capturing” and “data transmission”; and can include single or multi components per household. The active operation of smart metering systems requires a permanent power supply. The amount of energy consumption of the smart metering infrastructure per household depends on different parameters, which are briefly summarized below:

– The specifications for the performance and features of the smart metering system.

– Manufacturer and system specific technical design to fulfil particular requirements in accordance to present standards

The motivating factors for the installation of small metering infrastructure are:

– New and flexible alternatives for linking different decentralized energy sources. Extending this idea, the integration of various energy sources into “virtual power plants” enhances energy independence

– Increase supply security

– Flexible participation of network users (end-users)

The long-term political and environmental objectives primarily consist of the increase of re-newable energy sources as a portion of the total energy mix, the associated reduction of greenhouse gas emissions, and the improved energy efficiency in the supply chain in gen-eral.

These objectives are also supported by the “20-20-20 targets” of the European Union´s Climate and Energy Package, which aims at achieving the following goals by the year 2020:

– 20% reduction of greenhouse gas emissions from the level of 2005

– 20% (at least) of the total energy consumption of the EU shall come from renewable energy sources.

– 20% increase in energy efficiency

Further influence is due to the Directive on Energy Efficiency and Energy Services 2006/32/EG. This directive states that in order for consumers to be able to make better-informed decisions about their individual energy consumption, it is necessary that they have sufficient information about their (energy) consumption habits. This includes information on available energy sources, energy efficiency measures, comparative end-user profiles, etc. The end-users should also be actively encouraged to review their own meters on a regular basis. Smart meters and energy monitoring systems providing feedback to the user would be therefore ideal.

In Austria smart meters are regulated under the *"Intelligente Messgeräte Anforderungs-verordnung",* which came into force on November 1st, 2011 [IMA-VO, 2011]. This directive sets minimum standards for smart meters installed in Austria, which could have an influence on the energy consumption of different manufacturers´ solutions. Due to the additional product functions there might be increased energy consumption in other nodes of the system, such as for the management and processing of the collected data.

The *"Intelligente Messgeräte-Einführungsverordnung"* came into force on 25 April 2012 (IME-VO, 2012), requiring Austrian network operators amongst other to equip 70% of their own network metering points with smart meters.

Within the study *"Folgeabschätzung einer Einführung von Smart Metering im Zusammenhang mit Smart Grids in der Schweiz,"* carried out by the SFOE for Switzerland, the following preparatory work has been done [BFE1, 2012]:

– Definition of different smart metering scenarios and, based on that, estimation of economic, social and environmental costs and benefits;

– Compilation of conditions for the operation of smart metering;

– Development of recommendations for legislation.

In both Austria and Switzerland many energy utilities have already done some preliminary work, such as pilot projects and internal system evaluations. In few cases, specific decisions for certain smart metering solutions were made. However in most cases, companies are still keeping waiting positions.
Both, companies that have acted and companies that delayed decisions have justifications for their positions. On the one hand, the legal timeframe required for rollouts is limited. On the other hand, pilot projects can help improve the prestige and competitive advantage of a company, due to the gained experience and knowledge on these relatively complex systems, so that companies don't want to miss this opportunity. Furthermore, communicating metering points are essential for some smart grid applications to be deployed in the future. However, companies do not like to invest in new infrastructure, as long as standards (and, going along with that, the meters) are in transition, and there is still uncertainty regarding legal requirements.

Altogether, it makes sense to have flexible tools at one's fingertips, which facilitate the evaluation of the available systems, but also the consideration of the own energy consumption of smart metering is an essential aspect to be assessed.

## 2 Aim of the study

The aim of the SMc project was to develop tools (with the support of on-site measurements and their interpretation) to describe the own energy consumption of smart metering hardware in a transparent and clear way for:

- Political decision-makers dealing with rollouts and possible future scenarios for entire regions;
- Product developers and providers of smart metering solutions, who deal with the energy efficiency of their products;
- Energy utilities who want to have a quick overview of the own energy consumption of the available technologies, which they need for the deployment in their region.

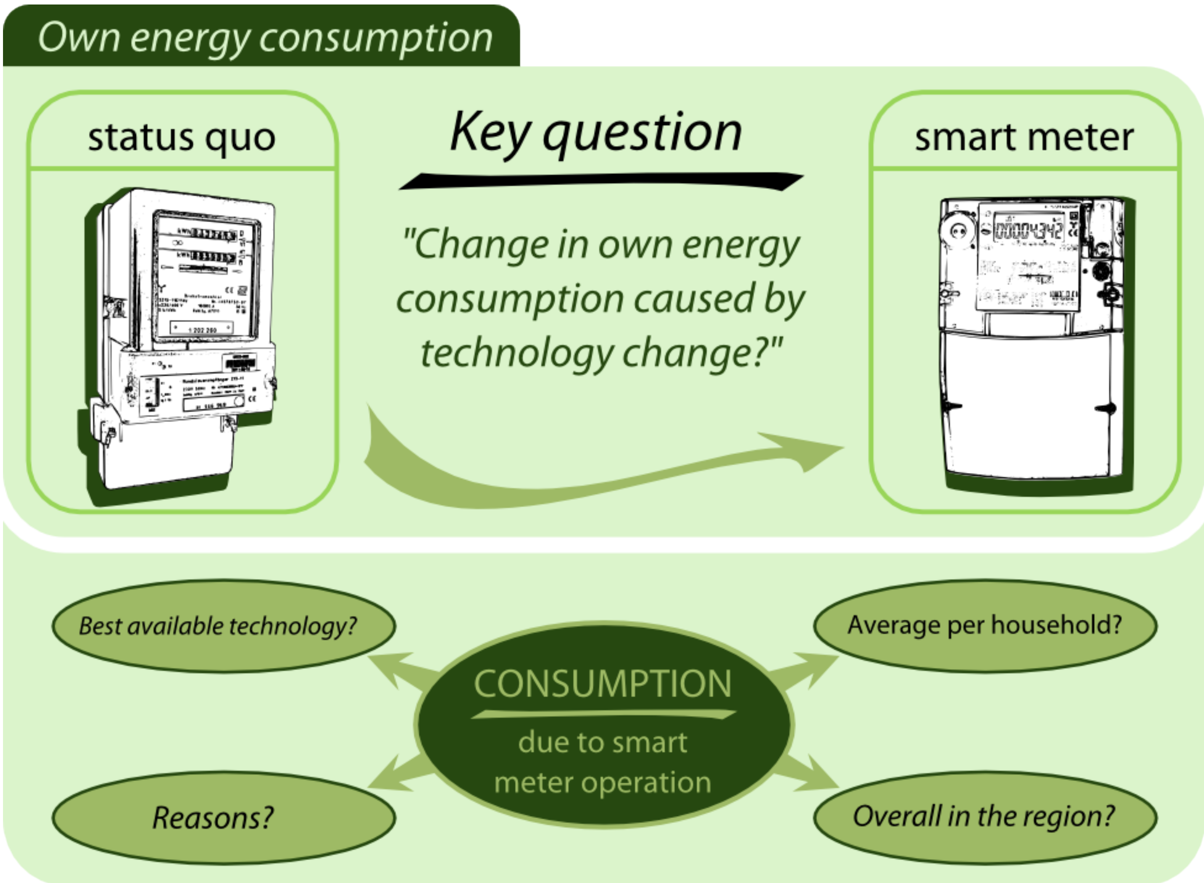


Figure 1: Key question of the SMc project and other related aspects of the study.

For accomplishing this objective step by step, the following research questions were formulated (see Figure 1):

- How can the average value of the own consumption of smart metering equipment per household be identified?
- What are the energy efficiency potentials of the smart metering solutions available on the market with respect to the current state of their technology? What are the average values for the own energy consumption compared to those of the previously used Ferraris meter?
- What are the specific product features of the most energy efficient solutions? Which components or functions of the equipment are functionally or physically exchangeable? Which parts are not essential?

- How can smart meter manufacturers be advised in the development of efficient solutions? (How can the results of the study be prepared and presented to them?)
- How does the change of technology from conventional electricity meters to smart meters influence the own energy consumption of a whole region?
- Which other rebound effects does the whole system design have? Which key system parameters can be identified in terms of energy consumption for smart metering and how can their impact be assessed (functionality, frequency of data transmission, etc.)?
- If all currently installed electricity meters in Austria and Switzerland were replaced by smart meters and their associated infrastructure, what would be the influence on the total power consumption?

The results of this study will be prepared and published with particular consideration to the three stakeholder groups mentioned above.

This publication includes:

- A mapping of the technologies for smart meters available on the market;
- A description of the methodology used for the metrological survey of the energy consumption data as well as for the modeling and extrapolation to overall (network-related) consumption for different technologies;
- A description of rollout scenarios for Austria and Switzerland, and a detailed presentation of individual contributions to the overall consumption.

# 3 Methodology and description of the work

## 3.1 Project Milestones and Time plan

The work within the project was divided chronologically into three main blocks, as shown on the left side of Figure 2. On the right side, the graph illustrates the different levels where incoming data was calculated and analyzed.

– On the *horizontal* level, the focus was on the most representative consumptions, associated with those devices commonly used locally for a metering point. This refers mainly to the smart meter itself (indicated as SMi in the graph), but also to the additional equipment such as in-home displays or MUCs. Research was undertaken to identify the characteristics which have an impact on the own consumption of the meter.

– On the *vertical* level, metering point based calculations were assessed to gain the additional data required for different solutions, so that projections for smart metering systems of entire regions could be completed.

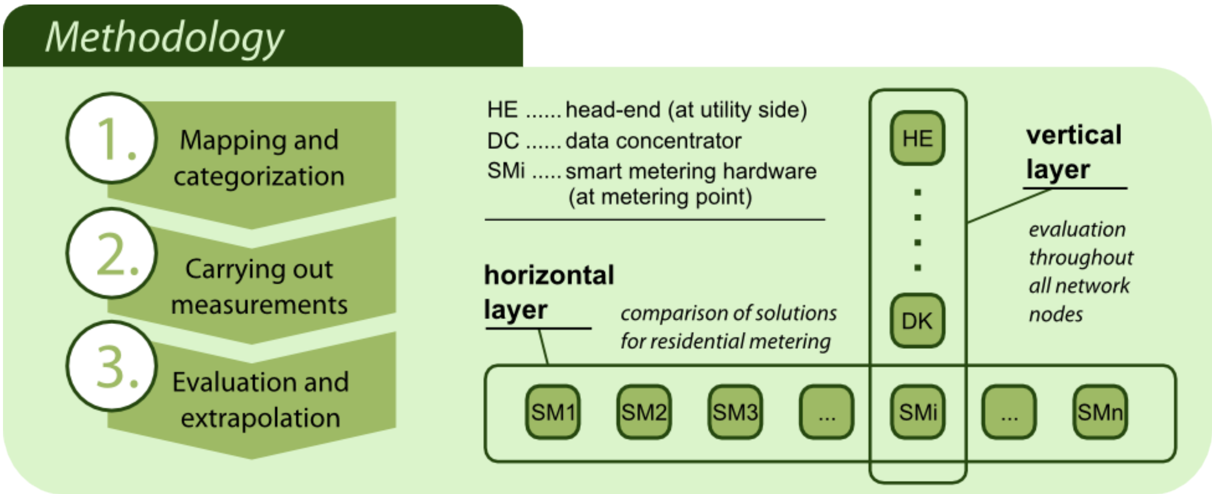


Figure 2: Major working tasks of the SMART METERING consumption project and view of selected levels for the system analysis.

The Gantt chart in Table 1 (below) gives an overview of the time plan of the project, including the most important milestones. The metrological work was completed according to the following steps:

1. Development of a measurement concept in the laboratory, and completion of measurement series for two meters from different manufacturers.

2. Completing a selected portion of the planned measurements in the laboratory.

3. In parallel, in-situ measurements on meters installed in pilot projects were conducted.

4. Finishing of the laboratory measurements.

Table 1: Time plan of the SMART METERING consumption project

| | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| WP1 | Networking | | | | | | | | | | | | | | | | | | | |
| WP2 | Product analysis | | | | | | | 1 | | | Product analysis | | | | | | | | | |
| WP3 | | | Development of method. | | | | | | 2 | | | | | | | | | | | |
| WP4 | | | | | | Laboratory setup | | | | | | 3 | | | | | | | | |
| WP5 | | | | | | | Comparative measurements - verific. | | | | | | | | 5 | | | | | |
| WP6 | | | | | | | | | | | Laboratory measur. | | | | 6 | | | | | |
| WP7 | | | | | | | | | | | | | | Scenarios | | | 7 | | | |
| WP8 | | | | | | | | | | | | | | | | Total cons. | | | 8 | |
| WP9 | | | P. d. | 4 | | | | | | | | | Project documentation (P.d.) | | | | | | | 9 |
| WP1 | | | | | | | | | | | | | | | | | Dissemination | | | |
| WP1 | Project management | | | | | | | | | | | | | | | | | | | |

## Project milestones

| | |
|---|---|
| 1 | All data needed to derive a methodology has been collected from manufacturers. |
| 2 | Planning and preparations for laboratory work completed, laboratory consulted. |
| 3 | Setup and boundary conditions which are relevant for laboratory work are specified. |
| 4 | Documentation of work done in project year 2010 is finished. |
| 5 | All planned in-situ measurements at energy utilities are finished. |
| 6 | All planned laboratory measurements are finished. |
| 7 | All measurements from WP4-WP6 are analyzed, roll out scenarios for AT and CH are defined. |
| 8 | Total consumptions for A and CH are extrapolated. |
| 9 | Documentation including publications finished. |

## 3.2 Involvement of stakeholders from the sector

At the beginning of the project it was essential to gain a good overview about the current situation in the smart metering business, as well as the market for industrial products, and an understanding of the stakeholders in this sector and the relationships between them.

During the project various stakeholders who were currently working with smart meters were contacted. These included providers and energy utilities that were testing or planning to test smart meters in pilot projects, as well as other stakeholders. Thereby an extensive network across Austria and Switzerland was developed.

Afterwards, several communication and outreach steps were needed, including raising interest, revising aspects of the technology behind smart metering, proposing possible forms of cooperation, arranging timetables, and discussing organizational issues for the measuring process. Each of the companies involved received a written non-disclosure agreement regarding the handling of their sensitive data. The agreement also stated that any document intended to be made public would not reveal specific sources, instead these would be treated as anonymous. This is also the approach followed in this project report. There are, however, some exceptions to this agreement.

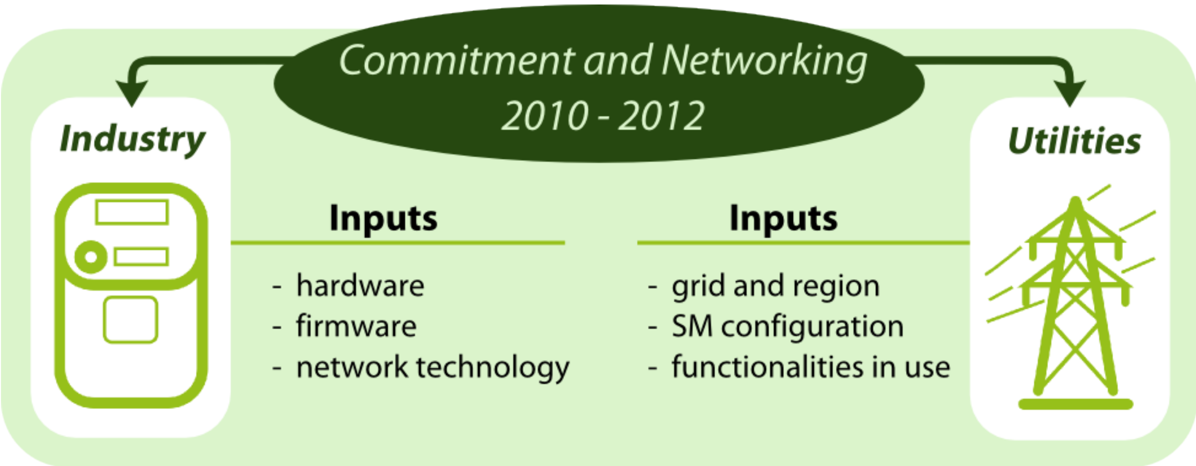


Figure 3: Involvement of different stakeholders to access information and relevant data for the project.

The initiative was taken to get directly in touch with stakeholders, by phone and through personal visits to several system suppliers, energy providers, and network operators. The participation and presentations during the Smart Grid Weeks in Salzburg (2010) and Linz (2011) also helped getting in touch with relevant stakeholders. The project partner ECODESIGN company GmbH was responsible for establishing the contacts to stakeholders in Austria, and Encontrol AG was responsible for this task in Switzerland.

Figure 3 shows the kind of information gained through the involvement and information exchange with these stakeholders.

The following smart meter manufactures were contacted and collaborated in the project:

– ALCATEL-LUCENT (Austria)

– ECHELON (Germany)

– ELSTER (Austria and Germany)

– EMH (Germany)

– GÖRLITZ (Austria)

– ITRON/ACTARIS (Austria)

– KAMSTRUP (Denmark, Austria and Switzerland)

– LANDIS+GYR (Austria and Switzerland)

– SCHRACK TECHNIK (Austria)

– Siemens (Austria and Switzerland)

The following energy utilities were contacted and cooperated with the project:

– AEW – AARGAUISCHES ELEKTRIZITÄTSWERK (Switzerland)

– AGE SA CHIASSO (Switzerland)

– EGS - ELEKTRIZITÄTS-GENOSSENSCHAFT SIGGENTHAL (Switzerland)

– EKZ – ELEKTRIZITÄTSWERKE DES KANTONS ZÜRICH (Switzerland)

– ENERGIE AG OBERÖSTERREICH NETZ GMBH (Austria)

– ENERGIEVERSORGUNG BÜREN AG (Switzerland)

– EVN NETZ GMBH (Lower Austria)

– EWZ – ELEKTRIZITÄTSWERKE ZÜRICH (Switzerland)

– KELAG NETZ GMBH (Austria)

– ROMANDE ENERGIE SA (Switzerland)

– SALZBURG NETZ GMBH (Austria)

– SOCIETÀ ELETTRICA SOPRACENERINA (SES) SA (Switzerland)

– STEWEAG-STEG GMBH (ENERGY STYRIA AG, Austria)

– TIWAG NETZ GMBH (Austria)

– WIEN ENERGIE STROMNETZ GMBH (Austria)

Various companies contacted for the project, who declined to participate, are not included in this list.

During the course of the project information exchange took place between research groups and institutions dealing with relevant projects, regulation, and standardization in Germany, Austria, and Switzerland.

## 3.3 Product analysis

For the description of products towards completing a mapping it is important to have a good overview of aspects such as:

- Product features,
- Product characteristics which are relevant for the energy consumption of the device, and
- System characteristics which are relevant for energy consumption.

Review of different online sources and request of information was conducted during 2010, particularly looking at specifications datasheets for products from different suppliers which are to be installed at metering point, that is, the meter itself and any other additional devices. The corresponding data on such technical solutions were examined in detail and the manufacturers contacted for more information when required.

### 3.3.1 Experts workshop

In November 2010 a workshop with experts from the sector was conducted. The event involved six representatives from well known manufacturers and system providers, and focused on the smart meters themselves. During the workshop the following guiding questions were provided to guide the answers of the experts:

***1. Which technical features and system characteristics are relevant for the energy consumption?***

**Responses on the relevant technical features for consumption included:**

- Sampling frequency at which measurements are performed.
- The implementation of the power supply unit.
- The availability of the smart meter.
- The type of communication (PLC; point to point connection, etc.).
- The quality of the grid.
- The compatibility and future-oriented design.
- The type of meter concept: Modular or compact.
- The presence of a breaker in the meter.
- The area in which the input voltage is located (100-400V).
- The functions (special features) that the meter has and how intensively these are used, for example, the breaker, memory size, etc.
- The energy balance of the components in the core product.

**Responses on the relevant system characteristics regarding consumption included:**

- The possible peak point of power consumption for a maximum level of communication
- The infrastructure (e.g., gateways, displays, etc.).
- The specific architecture which is implemented, e.g., cost-saving features, and configurations, and/or customized solutions.

– The mode of communication being used (PLC, GPR, etc.).
– The user interfaces being used.
– The frequency of communication.
– The types of connections which are available for different systems (in-home, home automation, etc.).
– The reading cycles selected, e.g., the European Directive specifies real time read-out; however, this can be interpreted differently.
– The presence of automatic processes in the smart meter.
– The load distribution.
– The extent of optimized operation.

The following issues were also identified by the majority of respondents as relevant for the consumption:

– The communication system used.
– The implemented functions in use (e.g., displays, updating capabilities, and remote shutdown.)
– The functions used to control the network quality.

***2. Under which conditions are different provider solutions comparable?***

**Responses on the conditions under which solutions are comparable included:**

– The consideration of the requirements set by the calibration authorities.
– The distinction on the use of a breaker (or not).
– Distinction according to the communication features and communication technology.
– The definition of the frequency for the readout.
– The cost of the meters – considering comparative price levels.
– The potential for reducing primary energy consumption needs to be considered.
– The expected lifetime of the devices but also of the technology itself.
– The data volume gathered and transferred.
– The legal requirements to be fulfilled by the devices.

In 2011 several visits to providers and other actors from the sector took place. In addition, a telephone survey was completed and from these sources, a valuable overview of the variety of used and tested solutions was obtained, but also an indication of the technologies most commonly being used.

### 3.3.2 Identified influencing parameters

The various factors which have an influence on the energy consumption of a smart meter have been identified already by April 2011, and are illustrated in Figure 4 and 5 below:

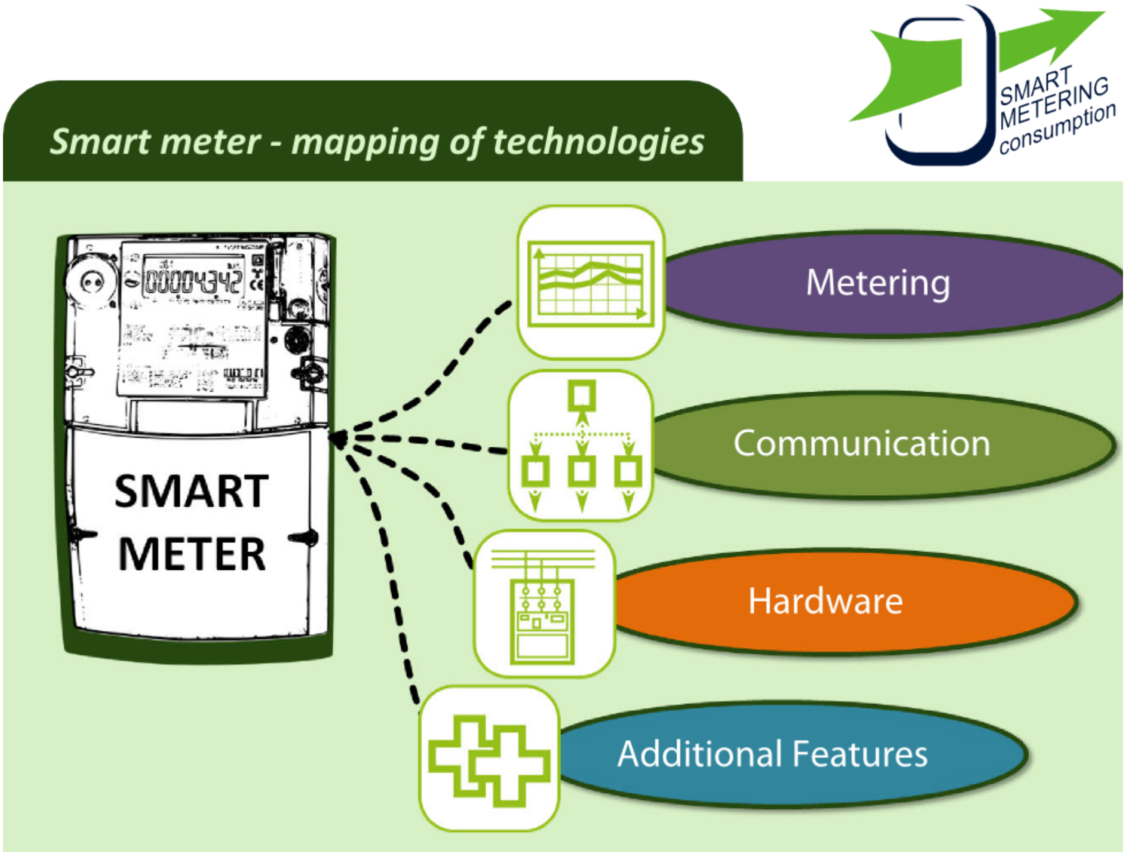


Figure 4: Four main areas to consider for the Mapping of technologies, from the perspective of the metering point.

During the review of the technical details of the smart metering infrastructure for the mapping process, it became clear that the product parameters do not have an isolated effect on the power consumption and therefore can´t be separately compared. For example, this is the case when there are different implementation possibilities of the power supply unit for a specific type of meter, or for the measuring principle for the current path within the meter. During the mapping process the characteristics and potential sources of additional consumption, which could be compared among similar technical solutions, were investigated (e.g., the same type of data transmission, the use of similar local interfaces, and the same amount of transmitted data).

**Influencing parameters identified, from the perspective of a metering point**

Divided into four main areas
- Metering
- Communication
- Hardware
- Additional Features

(Status: April 2011, based on workshop results)

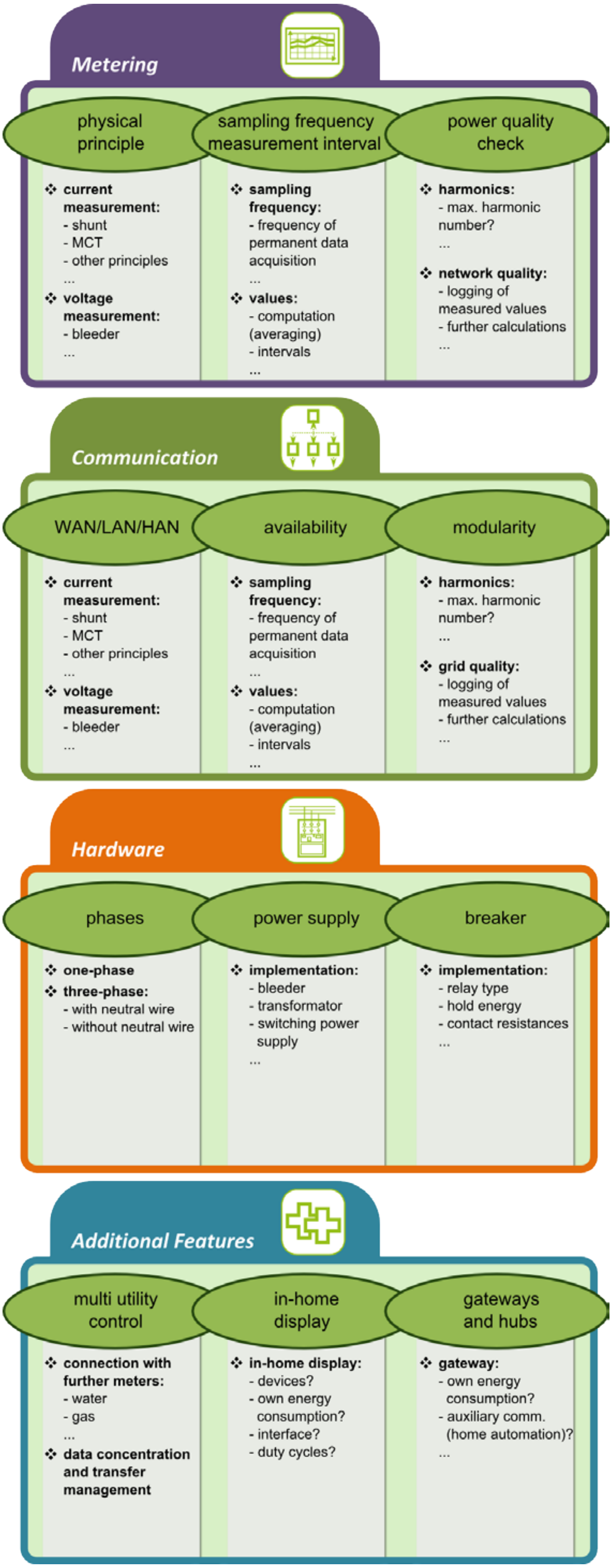


Figure 5: Influencing parameters from the perspective of a metering point.

## 3.4 Development of the methodology

The influencing parameters identified during the workshop were not yet assessed for their relative importance.

These and further parameters were successively used to develop the project methodology, for the classification of the different solutions and the modeling of smart metering networks, and finally, to extrapolate the total energy consumption of the systems.

The initial subdivision originally developed during the workshop considering a “basic meter”, an “enhanced meter”, and a “multifunctional meter” was discarded afterwards, for the following reasons:

- According to the opinion of experts, the total consumption of the metering point is not only determined by the basic meter itself, but even more by any (possibly) integrated module, by the associated additional devices, and by the configuration to enable the activation/deactivation or fine-tuning of different functions.
- There compact and modular meters differ between them on the communication modules inserted (modular meter). With respect to add-on options, it would be inappropriate to assign the same device one time as “enhanced meter” and another time as “multifunctional meter”.
- The minimal requirements for the configuration of the devices, as required by the Austrian directive IMA-VO [IMA-VO, 2011], could be assigned to the “enhanced meter” or to the “multifunctional meter”. This set of minimum requirements largely coincides with the requirements already set by most of the interviewed energy utilities, even before the directive entered into force. For Switzerland there are no obligatory minimal requirements yet.

The preconditions for the development of the methodology are explained as follows:

**1. Requirements for the calculations and extrapolations**

1.1 Applicability: the extrapolations should mainly use “primary” data, which can be directly collected. Here, different datasets need to be (and have to be) considered, described as follows:

- Product specific data, namely own measurements, which are to be complemented with manufacturer specification sheets in case not all measurements are completed;
- Statistical data on regions from direct surveys with the corresponding network operators, and complemented with statistic data from other institutions;
- Data on specific solutions for networks, obtained from statements made by network operators and system providers.

1.2 Adaptability/differentiation: The classification should follow the same logic as currently used by the energy utilities for their own decisions on particular regions. Another aspect is the prioritization according to the existing, prevalent system characteristics, for example WAN-transmission for compact smart meters, and the devices with fixed integrated communication modules or gateways. Afterwards, the classification can include the other system characteristics which are flexible for adaption, as for example, multi-utility control (MUC), add-on solution with M-Bus, or the connection of additional devices at the metering point. The aim is to have combinations of solutions for a variety of scenarios of interest. Network operators currently do not use the same (homogeneous) meter systems for the entire region they serve. It is very likely that a similar situation will establish for the smart metering infrastructure. Technical and geographic reasons, as well as the topology of the network itself, do not allow using the same communication technology up to the "last mile" all over the grid.

1.3 Integrity: Ideally the extrapolation method used for the project shall assess the own energy consumption of the smart metering infrastructure in a comprehensive way. This means that all physical components which have an own energy consumption and belong to the system (for example the IT system of the control center) should be included. In some cases, it is not only about including the components that are assigned directly to the network operator, but also the cases in which a telecommunications operator provides the network operator with communications services, and runs other infrastructures (e.g., GPRS connections).
Furthermore, it has to be considered that the system does not only consist of the technical infrastructure, but also incorporates processes which belong to the regular metering operations of the energy utility. This may include the (counting for) the access to different metering points because of recalibration regulations, due to remote shutdowns using breakers, and/or unnecessary access to cut-off of end users.

Based on the expert inputs collected, the system characteristics which have a large potential to influence the own energy consumption of the meter were pre-selected. This pre-selection is to be preferably used for the system description. Minor aspects might be included using realistic estimations or they might be left out.

1.4 Accurateness and validity (up to date) of data: in relation to point 1.1, with the expert partner on metrology for the project, the methods suitable for the metrological measurement are to be developed, particularly for measuring the smallest power values under (partly difficult) conditions.
The limits for interpretations based on measured data have to be clearly presented in the documentation (Under which circumstances is the measured data valid?). Data that could not be directly obtained from measurements should be verified by additional sources, if possible.

The validity of the data plays also a major role in the project, due to rapidly changing environment of smart metering. The methodology chosen for the project also determines that the data collected on the systems has to be similar to that being used by energy utilities in their pilot projects, so that project partners can contribute with information, and occasionally, their equipment could be tested on-side. Within the project it was also considered, to test and analyze, as much as possible, the best available technologies already available on the Swiss and Austrian markets.

## 2. System boundaries for the calculations and extrapolations

2.1 Product life cycle: The life cycle of a technical product is divided into raw materials, manufacturing, distribution, use, and end-of-life. Due to their long lifetime and the associated energy consumption, electric meters can be considered as use-intensive products, namely, the majority of the environmental impacts are associated to the use phase. The (cumulative) energy demand for the whole life cycle of a smart meter also depends on the embedded energy in the materials used in the meter, the energy used in its production process, the energy associated to the transport of the final product, the embedded energy in the packaging materials, and the energy needed for the processes dealing with the product at the end of its life. The evaluation of all these additional aspects might bring minor contributions when compared to the energy needed for the use of the meter over the planned service life. Therefore the analysis considers only the specific own energy consumption of the system during the use phase, under the assumption of a stationary, normal operation of the devices.

The case, in which a premature change of the technology occurs before the meter reaches its planned service life, is not considered in this project either. This would lead to a (partial) replacement of installed meters, and therefore could also result in an incorrect estimation of the energy input in relation to the life cycle of the product.

2.2 Secondary energy saving effects: Within the SMc project only the system-inherent changes in energy consumption, namely, the direct efficiency of the supply chain, are considered. Nevertheless, the smart metering infrastructure is believed to be an enabler for other technical solutions which could improve the environmental performance of (parts of) the energy supply system. This may include the case where decentralized, environmentally friendly energy sources (such as private photovoltaic systems) are incorporated to the system, or the fully automated charging of electric vehicles according to the network load, or the expected electricity savings in the home due to awareness raising on power consumption through the use of home monitoring systems. These and other possible secondary energy saving effects are not investigated within the SMc project.

2.3 The relationship between system characteristics relevant for its consumption and other features of smart meter systems: Some aspects of technical solutions are not only directly related to the own energy consumption of meters, but also indirectly related to basic requirements of power supply operations, such as service security (namely, accessibility of the meters, security and data privacy, reliability, resilience, and other useful features in case of an emergency). Therefore, low own energy consumption is only one of the many criteria to include when selecting smart metering infrastructure solutions. The SMc project does not provide assessments coupled with those additional aspects. Instead, the assessment considers only the own energy consumption in isolated form.

## 3. Parameters with an influence on the energy consumption per metering point

3.1 Additional devices operating at the metering point, for example:

- Multi utility control (MUC) via an extra gateway.
- Add on-bridges for any kind of local communication.

3.2 Device-specific details of the smart meter, for example:

- Design of the power supply of the meter.
- Measurement principle on the current path.
- Modularity (integrated or separated communication module/component).
- Hardware/firmware design (e.g., choice of integrated circuits (ICs), scale of integration, and efficiency of the algorithms).

3.3 WAN/HAN communication modules at the meter, for example:

- Power consumption of the module during active transmission, according to the mode of transmission.
- WAN communication and its stand-by modus.
- Local gateway in permanent use: M-Bus master, S0 entrance
- Influencing factors for the active communication:
    - o Data amount and implemented protocols
    - o Encryption overhead
    - o Network impedance (in the case of PLC)
    - o Repeating functions
    - o User specific factors (e.g., amount of data and additional features which generate traffic).

3.4 Number of phases:

- 1-phase meter
- 3-phase meter (3 or 4 lines)

3.5 Additional energy consumption of devices not available in the previous static metering system:

- Operation of data concentrators (Number of meters installed per data concentrator).
- Operation of data processors and servers around the power station (HES/OSS/MDM-area).
- Additional components demanding energy in the network, to carry out communication operations.

### 3.4.1 Preliminary findings related to the methodology

1. Every technical, manufacturer-specific implementation of a smart meter differs from its competitor products in a couple of criteria. Five basic characteristics were identified during the mapping process (Which cannot be configured by energy utilities). Based on comparative measurements it became clear that these have an influence on the power consumption per metering point. However, it is impossible to identify the influence of product features, which cannot be changed in the closed product. Nevertheless, by looking at results from specific products (e.g., combinations of technical solutions as available on the market) some insights can be gained in relation to the product characteristic. The five characteristics are:

   – Measurement principle in the current path.

   – Design of the power supply unit.

   – Hardware architecture (integrated or compact solution).

   – Manufacturing design and manufacturer´s specific features.

   – Design of the breaker (cut-off device).

2. The type of communication is in principle a feature that can be configured, and is therefore directly chosen by the utilities. There are no legislative requirements, neither in Switzerland nor in Austria, on the type of communication.
   The market offers a big variety of modular meters with fixed design features for the basic metering hardware components, but which provide exchangeable and configurable communication modules.
   According to the type of communication, the auxiliary devices mentioned in the box above under point 3.1 are configurable, and so are other characteristics that might influence the own consumption. Therefore, this allows for a flexible modeling and extrapolation.

### 3.4.2 Consequences of the finding on the modeling

The type of communication between the smart meter and the head-end system or data concentrator within the data collecting network sets the first level for the classification in the modeling (see Figure 6). This way it is possible to model:

– The amount of data transmitted.

– Further additional devices and the active interface per metering point.

– Hardware solutions of the head-end.

– Communication solutions of the data transmitting network.

The sequence in which the modeling is done is not established according to the assumed contribution to the consumption (even though this is all known and accounted for in the calculations).

The approach used rather follows a similar logic as that of an energy utility in making decisions for deploying a smart metering system in a region. This approach starts with a look at the physical product. When the meter is of a compact type, the connection for the data collection network is already given. All other options will be selected according to specific needs and how the product already may fulfill these with its existing configuration.

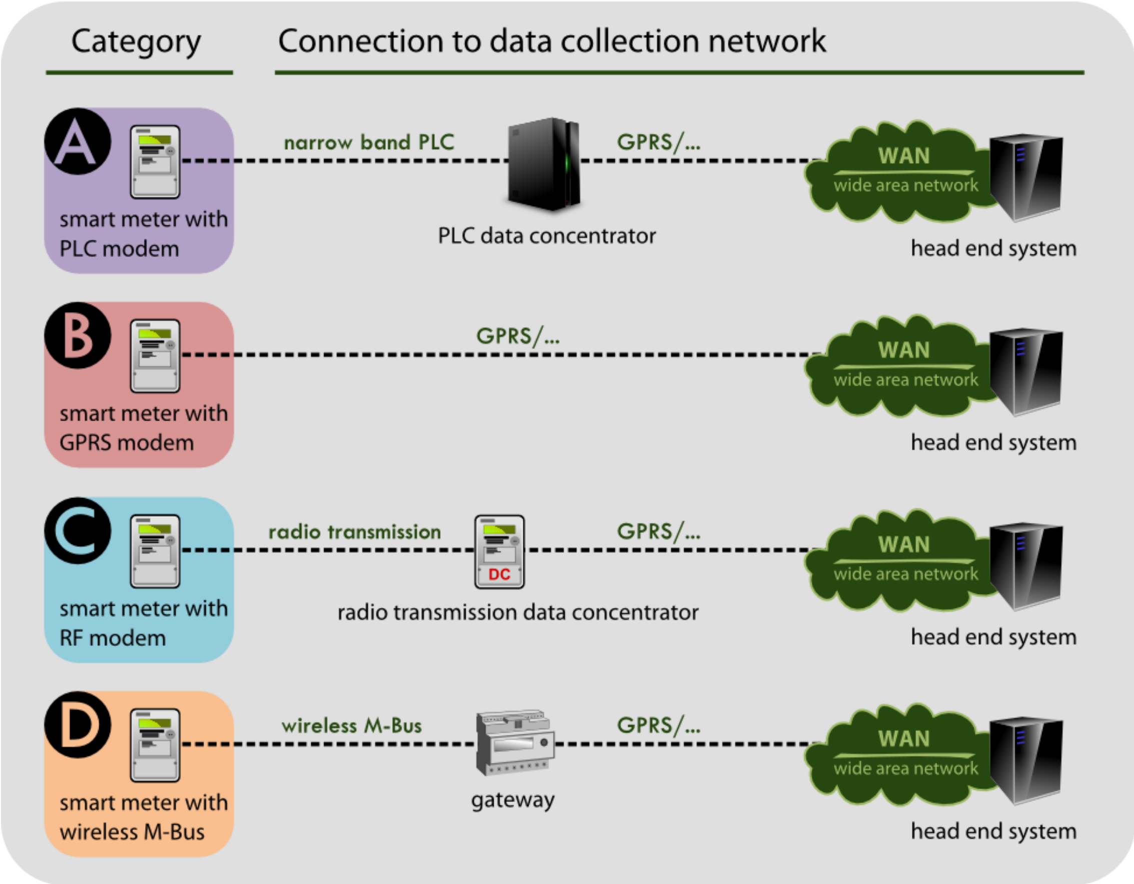


Figure 6: Main classification of smart metering solutions in four categories according to the connection type in the data collection network. The connection types match those from the existing solutions in the market, but also those from the technologies mostly used by the utilities (as of 2011).

This modeling approach is also useful as it has a lower error rate, because the information gathered from datasheets and from the manufacturers and utility operators helps identify non-compatible devices and parameter combinations. To avoid wrong interpretations of results these incompatible elements are not included in the calculations.

### 3.4.3 Modeling process

Data on power consumption of single devices or processes is needed to obtain a representative annual consumption value corresponding to a specific rollout scenario. These smallest pieces of information will now be assembled in layers to form a complete system description, as shown in Figure 7, and according to the following steps:

1. *Documentation of individual performance data*: comprising the analysis of the measurements, interpretation of expert´s opinions, review of energy consumption data from datasheets, correction of calculations, and inclusion of the consumption data corresponding to different operational modes.
2. *Formal description of technical components*: this step is focusing not only on individual devices, but also on groups of devices or processes. In the case of a meter this includes the number of phases, modular or compact type, and presence of the breaker, for the allocation of consumption data. An average value for the different modes of operation can be calculated in the case when reasonable assumptions on duty cycles can be made. Otherwise, this will be done in the modeling of technical scenarios, or even in the modeling of rollout scenarios.

3. *Definition and description of technical scenarios:* these are different and relevant combinations of technical components, such as for example the smart meter, together with the data concentrator and the processes at the head-end system (SM + DC + HES processes). The power consumption of the metering point is calculated based on the specific assumptions on the number and proportion of associated devices (e.g., one data concentrator collecting data from 100 smart meters).
4. *Roll-out scenarios and assumptions:* the roll-out scenarios are different combinations of systems, as described in technical scenarios. Provided that the technical scenarios are defined in a way to cover a number of sub-cases, these can be considered for further variations (e.g. to distinguish between additionally used local interfaces).

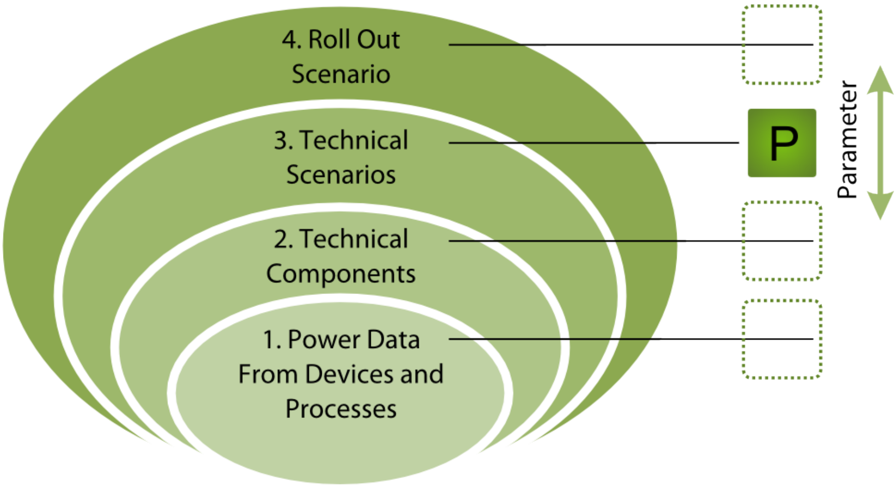


Figure 7: “Layer scheme” developed for the modeling of the total energy consumption of a specific roll-out scenario. With power data from the devices, and the use of a flexible description and calculation model, it is possible to estimate the overall annual consumptions of the smart metering infrastructure for an entire region.

Within this modelling approach it is possible to show the range of values of own energy consumption for the categories shown in Figure 6. These categories have different (easily identifiable) own characteristics. A distinction between categories can also be considered by using a relevant parameter (parameter P, in Figure 7), at any of the four levels of the model. Some parameters in the last model layer might remain undefined to allow for specific (desired) variations and flexibility of the rollout scenario (e.g., to consider the case of a special meter solutions with or without a breaker). When data is insufficient (e.g., no measurements are available for the consumption of the meters with breakers), then the relevant parameter (P) is already defined at the innermost layer of the model.

This modeling approach is limited in its capacity to illustrate the differences in own power consumption resulting from manufacturer-specific features (e.g., specific hardware devices or the particular implementation at the system level). Examples of aspects which could be tracked for their impact on energy consumption include:

- The specific details of the measuring principle and of the measurement amplifier circuit.
- The degree of integration and optimization of the semiconductor technology in use.
- The algorithms for the power quality calculations.
- The computational processes that run at the (DSP) semiconductor devices.

- The implementation of various security features like anti-fraud protection, including its associated sensors.
- The proprietary transmission protocol in use.

Other solutions with the same basic functions and within the same categories mentioned in Figure 6 could be investigated to understand these additional aspects and sub-systems, but this is not an easy task. The involvement of manufacturers to clarify these aspects and their relationship to energy consumption proves to be challenging due to the sensitive product and technology related information that would be needed for such an assessment. The complex structure of the smart meter and the associated sub-systems cannot be described in a simple way. This report discusses later on the features and characteristics that are common to various meters, but also those which are specific and different within the same metering category, as a way to explain the differences in their energy consumption values.

## 3.5 Laboratory setup and measurements

A major part of the project work was the metrological analysis of different smart metering solutions available in the Swiss and Austrian markets. The Institute of Power Systems (Institut für Elektrische Anlagen - IFEA) at the Technical University of Graz was responsible for this metrological work.

The devices to be measured were selected so that the specific data to describe the four categories of connectivity A, B, C and D (from Figure 6) were available as well. The manufacturers provided the devices to be tested and some even actively participated in the measurement work.

The devices tested are part of particular system solutions which are representative for the different types of connectivity, but these devices are not representative in stand-alone form. For some of these system solutions there are possible alternatives (e.g., there are various ways to design a data concentrator) or different combinations are possible (e.g., different communication modules could be placed in a particular modular meter).
Energy consumption measurements were undertaken for:

- A single-phase meter, identified as SSXX-SM-1ph
- A three-phase meter, identified as SSXX-SM-3ph
- A data concentrator, identified as SSXX-DC (when applicable).

The abbreviation “SS” stands for “specific solution” and is based on manufacturer-specific implementation for the meters and the infrastructure in the data collection network (consecutively numbered as: SS01, SS02, etc.).
To measure the own consumption of smart meters it was necessary to create testing conditions and methods, especially for the measurements carried out in various laboratories and “on-site” at the utilities pilot sites. An appropriate test circuit was developed and the suitable observation periods were also defined.

First, the test circuit was tested in the laboratory of IFEA on meters from two different solutions. After that, a sensitivity analysis was performed. This consisted of a series of measurements to characterize the consumption behavior of the meters under the influence of physical parameters, both from grid side and the user side. The parameters were varied according to the ranges as they typically occur in households (That is network level 7). These steps were completed at the laboratory of the IFEA. For the equipment of a manufacturer the tests were done in the calibration facilities of a network operator.

### 3.5.1 Test circuits

For the measurements the measuring computer DEWETRON DEWE-3020 was used as a multi-channel data logger, and the transducer card DEWETRON DAQP-DMM was used for the analog-digital conversion of the measured voltage signals. The number of channels was sufficient to measure a single-phase and a three-phase meter simultaneously.

Figure 8 shows the test circuit based on a simple power measurement with shunt resistor, for the case when there is no load applied to the smart meter on the user side ("off-load condition").

The current power was calculated by the measuring computer, by multiplying the instantaneous values of:

- Voltage between phase and neutral conductor, and
- Current (proportional to the measured voltage drop across the 10 Ω shunt).

An OMICRON CMC 256-6 was used as voltage and current source. This setting at IFEA is also illustrated in Figure 9.

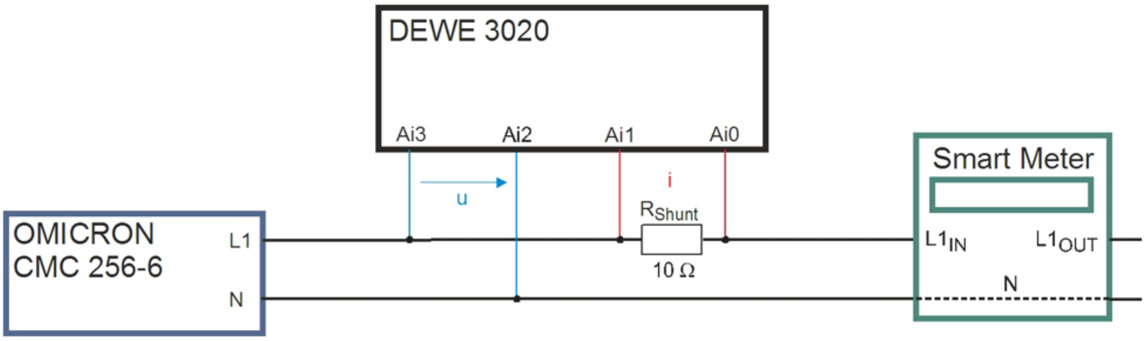


Figure 8: The shunt measurement is a circuit to determine the internal consumption of the meter without load on user side (off-load condition).

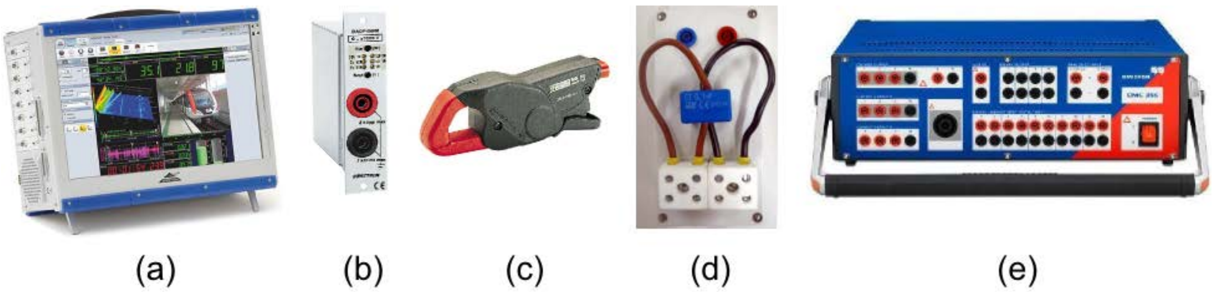


Figure 9: Most important components in the setup for the power measurements at IFEA:
(a) Measuring computer DEWETRON DEWE-3020, (b) Transducer card DEWETRON DAQP-DMM, (c) Clip-on ammeter CHAUVIN ARNOUX MN39, (d) Current transducer LEM CT 0,1–P, and (e) Voltage and current source OMICRON CMC 256-6.

The measurement of the own consumption of the meter required the use of a particular circuit to assess the power difference between the input and output of the smart meter. This is shown in Figure 10. To measure ΔU the probes were attached directly to the terminals of the smart meter, to compass eventual voltage drops on the supply side. A current transducer was used to assess the differential current ΔI. A clamp-on ammeter was used to measure the load currency $I_o$.

Both circuits are shown only for one phase, and these were expanded for the measurement of three phases. The current transducer measurement of a three-phase electricity meter requires 12 input channels on the measuring computer.

It was recognized that a meter needs time to warm up until the desired operation level is reached. A waiting time of 20 minutes proved to be adequate, but the energy consumption of the meter changes significantly during this warm up period though.

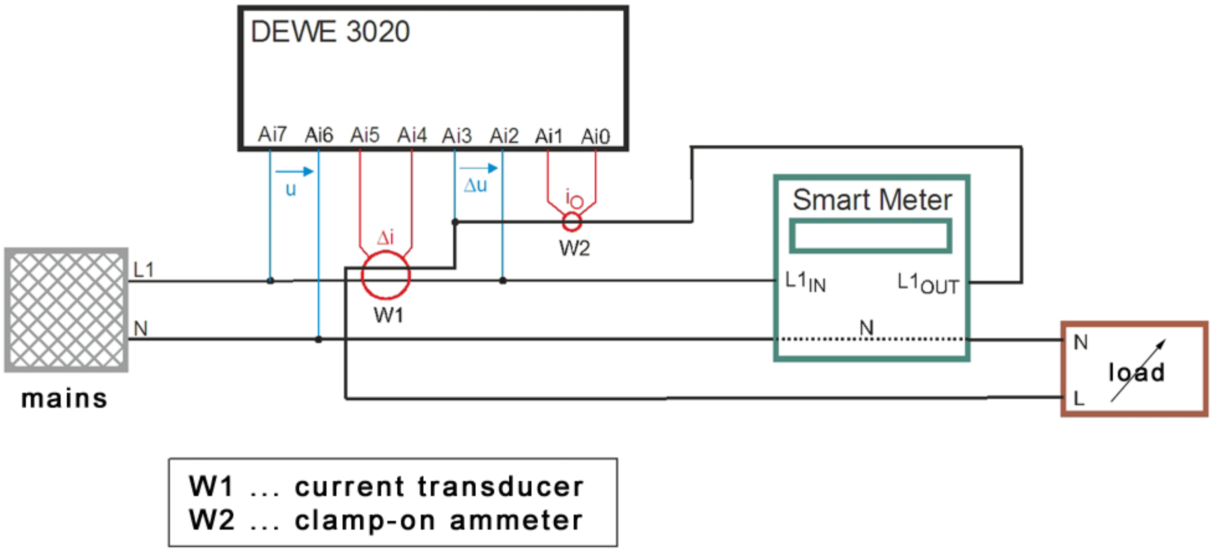


Figure 10: Current transducer circuit for power measurements at metering point in real use cases, when there is a certain load at the end-user side.

The values from the two measurement circuits in the laboratory were compared and showed to be consistent. Table 2 shows the variations in the absolute and relative power consumption measurements with the current transducer, compared to the measurements with the shunt circuit. All values were evaluated in off-load condition.

Table 2: Deviation of the power measurements using the current transducer and the shunt circuit, for one-phase and three-phase meters.

| Device | ΔP - SM-1ph | ΔP - SM-3ph |
|---|---|---|
| **SS01-SM** | 0.00 W … < +/- 0.44% | +0.01 W … +0.39% |
| **SS02-SM** | +0.04 W … +1.30% | -0.01 W … -0.22% |

The total active power consumption of smart meters ($P_{own}$), as measured by the current transducer is calculated as the sum of two contributions:

$$P_{own} = P_1 + P_2$$

$P_1$ is the fraction of the active power consumption that depends on the measured differential current. $P_2$ is the portion that depends on the measured load current (see W1 and W2 in Figure 10).
Figure 11 shows the active power components $P_1$ and $P_2$ as a function of load current. These measurements were taken for two single-phase smart meters from different manufacturers.

While the load current dependent portion $P_2$ follows a parabolic curve for the interval from 0 to max. 160 mW, the current difference dependent portion $P_1$ (shown on the left) slightly deviates from the own energy consumption, resulting in the off-load state, hence only $P_2$ will be used to describe the load current dependent behavior.

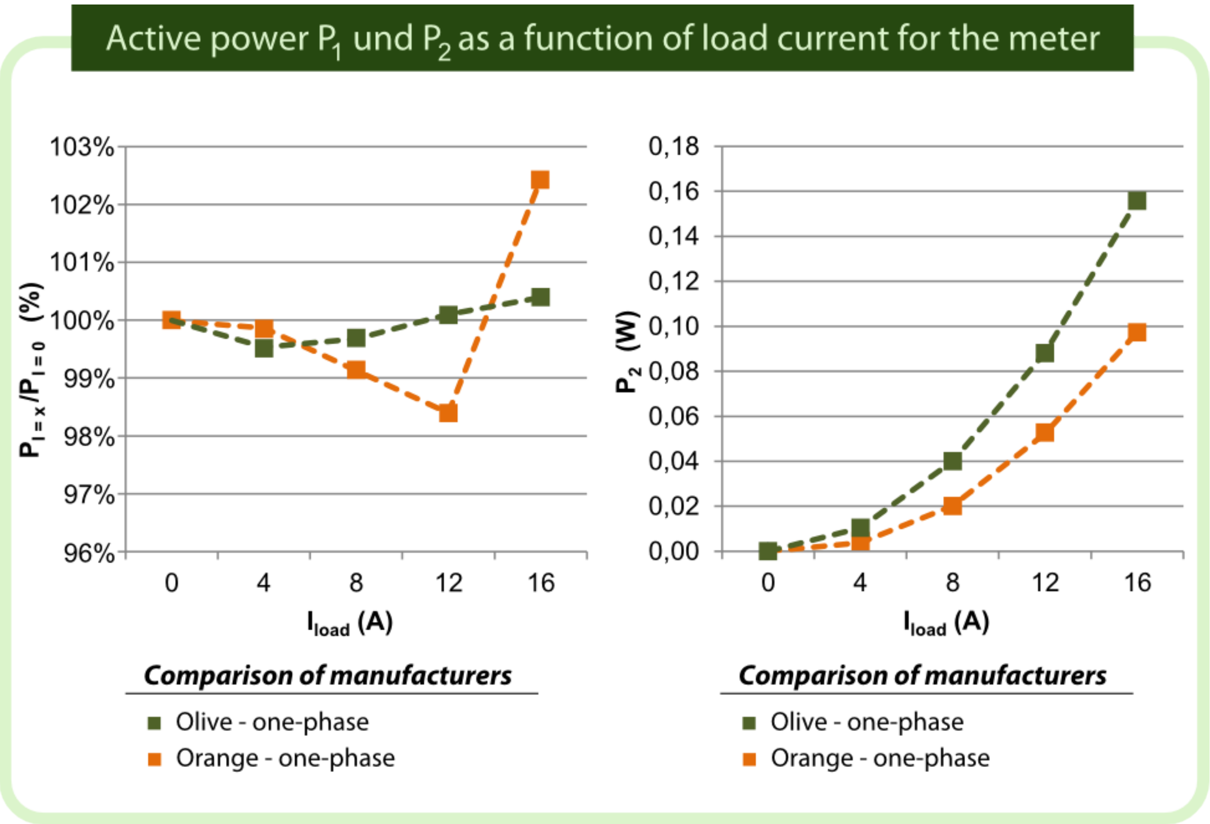


Figure 11: Active power demand for two one-phase smart meters from different manufacturers as a function of load current.

### 3.5.2 Sensitivity analysis

Electricity meters under real conditions do not function at one ideal operating point (3x230V, 50 Hz, no harmonic distortions, and rated load) rather function within an operating range. Deviations from ideal operating conditions are, on the one hand, caused by fluctuations in voltage level and voltage waveform, both typical for the distribution grid. On the other hand, the deviations are also due to fluctuating load conditions at the end consumer side.
Depending on their technical design and implementation it is likely that meters will show differences in the own energy consumption. It is therefore useful to examine their sensitivity to key parameters to get an overview of the performance of currently available devices in the market. The magnitude ranges selected to vary different key parameters were chosen based on experts opinion and values indicated in the norm DIN EN 50160 [EN50160, 2010].

The following sections describe and explain the results from the sensitivity analyses performed on various parameters. The results reported were obtained from measurements taken in the laboratory, for two up to three smart meters. The different colors used in the legends are used interchangeably to guarantee anonymity, therefore are not consistently referring to meters designated as SSXX-SM.

– **Effective value of the supply voltage: 210 – 220 – 230 – 240 – 250 V**

  The smart meters were tested under a load free condition with the shunt circuit to determine the sensitivity of the own consumption due to changes in mains voltage, as shown previously in . Results are shown in Figure 12.

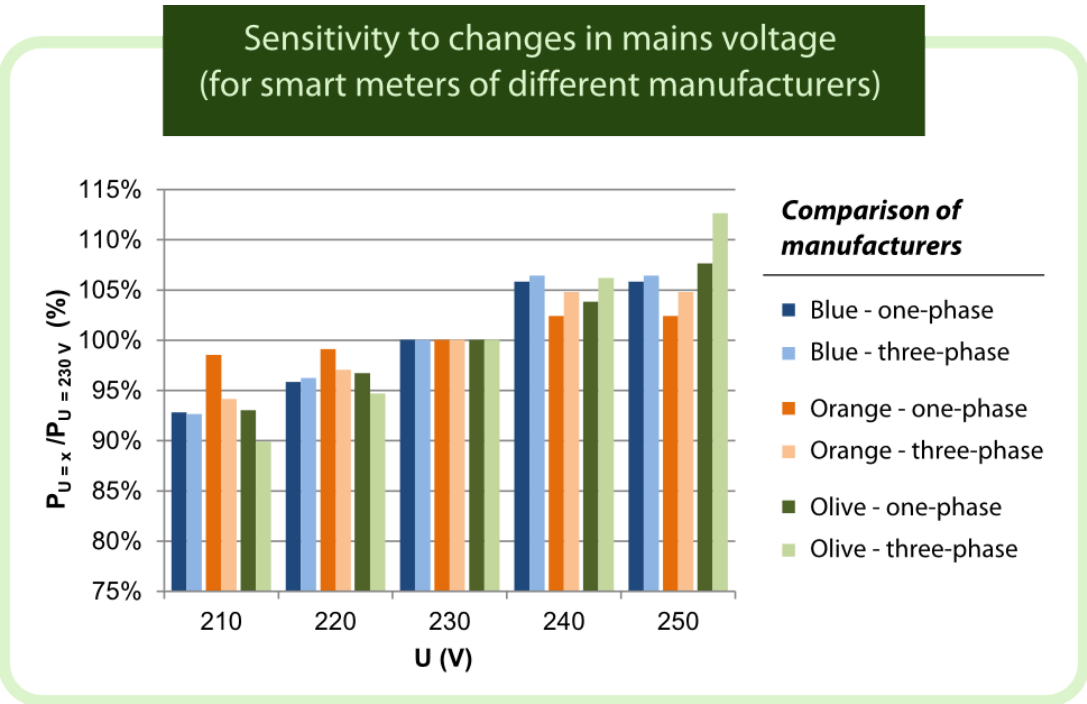


Figure 12: Changes in own consumption due to variations in the mains voltage. Comparison between one-phase and three-phase meters from different manufacturers.

– **Harmonic distortion of the supply voltage: THD1 – THD2 – THD3 – THD4** Four voltage waveforms (total harmonic distortion) indicated as THD1 to THD4 have been considered in the tests, each consisting of a fundamental voltage (50 Hz), and further portions with multiple frequencies. These combinations (see Table 3) shall be understood as possible conditions in low voltage distribution networks:

Table 3: Harmonic distortion cases considered when measuring the consumption of the meters.

| | **Case THD1** | | **Case THD2** | | **Case THD3** | | **Case THD4** | |
|---|---|---|---|---|---|---|---|---|
| **Harmonic** | **U/Ueff** (%) | **Phi** (°) | **U/Ueff** (%) | **Phi** (°) | **U/Ueff** (%) | **Phi** (°) | **U/Ueff** (%) | **Phi** (°) |
| **1.** | 100 | 0 | 100 | 0 | 100 | 0 | 100 | 0 |
| **3.** | 0 | - | 0,6 | 175 | 0,6 | -60 | 4,2 | 175 |
| **5.** | 0 | - | 3 | -160 | 3 | 0 | 3,5 | -160 |
| **7.** | 0 | - | 1 | -25 | 1 | 25,7 | 1 | -25 |
| **THD in %** | 0 | | 3.2 | | 3.2 | | 5.6 | |

THD1: Pure sine wave

THD2: Type of voltage as it is found at the premises of the testing laboratory

THD3: The same voltage level as in the case THD2, but the phasings were adjusted so that the peak value of the sum signal reaches its maximum. Experience from previous low-power measurements (e.g., standby of electronic devices) showed that this approach leads to an increase in energy consumption.

THD4: The type of voltage with the same phasing as THD2, but increasing the harmonic distortion to a THD of 5.6%.

The consumption values of the smart meters have been determined by shunt measurements (as shown in Figure 8), in off-load condition. Results are shown in Figure 13.

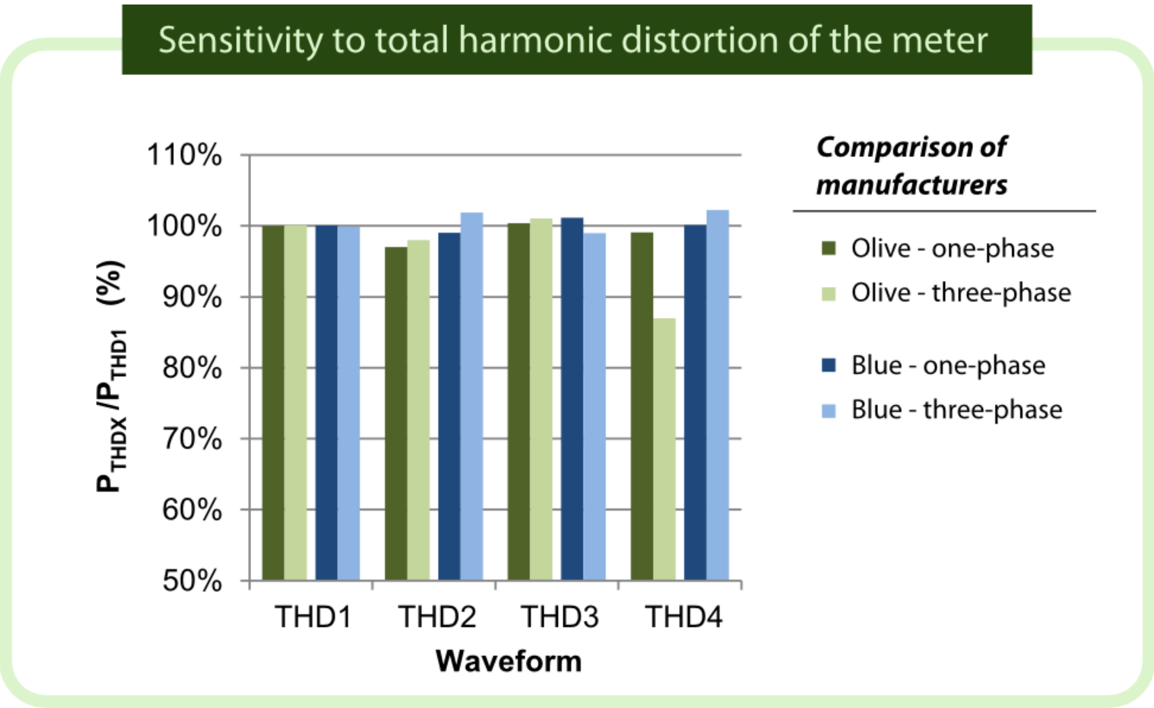


Figure 13: Changes in the consumption of the meter as a function of the supply voltage waveform. Comparison of one-phase and three-phase meters from different manufacturers.

– **Load current: 0 – 4 – 8 – 12 – 16 A**

By means of load resistors, different currents were set to simulate the energy consumption of end users. The consumption of the smart meters were measured using the current transducer circuit with a given load (as shown in Figure 10). Figure 14 includes the results.

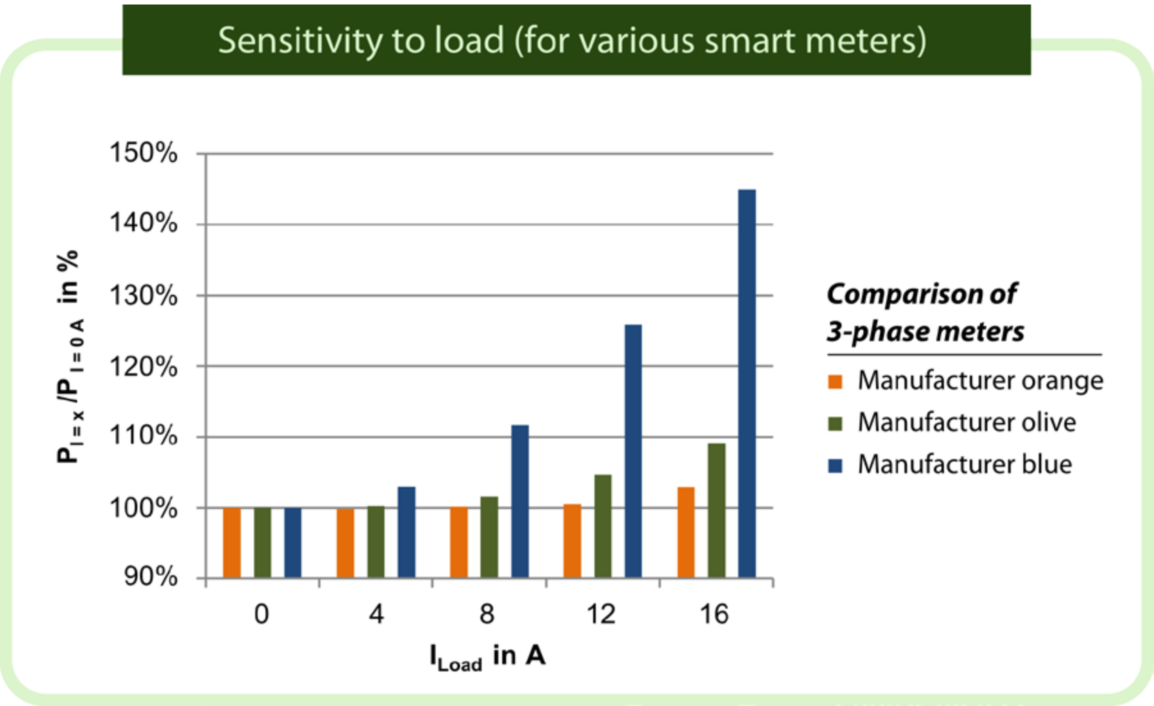


Figure 14: Changes in the consumption of the meters due to variations of the load current - Comparison of three-phase meters from different manufacturers.

– **Power factor of the load: 1 – 0.5 – 0.4**

Using examples of load values of real household devices the influence of the power factor (which characterizes the nature of the load resistance with respect to the phasing between load voltage and current) was tested for a single-phase smart meter. The devices were:

- Radiant heater with 762 W power and λ = 1
- Television set with 51 W power and λ = 0.5
- Vacuum cleaner with 345 W power and λ = 0.4

The own energy consumption of smart meters was also determined using the current transducer circuit. When connected to the television or to the vacuum cleaner the own consumption of the meter varied only by less than 0.5% as when connected to the radiant heater.

### 3.5.3 Laboratory measurements

In this section all measurements on smart meters and data concentrators as carried out in the laboratory are documented.

#### Power measurements at the meters

For the single-phase and three-phase meters SS01-SM, SS02-SM, SS03-SM the results of the measurements of active input power **in an off-load condition, without active communication processes, under nominal voltage, and without harmonic distortions** are shown below in Table 4.

Table 4: Active input power as a result of own energy consumption of one- and three-phase meters analyzed in the laboratory (; as determined by shunt measurements under almost ideal conditions).

| | Active input power of smart meters | |
|---|---|---|
| | **SM-1ph** | **SM-3ph** |
| **Measuring object** | P (W) | P (W) |
| **SS01-SM** | 2.25 | 2.55 |
| **SS02-SM** | 3.09 | 4.64 |
| **SS03-SM** | 0.90 | 1.41 |

*Note:* Beside other input data, the measured active powers listed in Table 4 have been used in describing the “technical components” (see Section 3.8). The technical components were then used to generate technical scenarios (Section 5.1), which in turn helped create various combinations for the rollout scenarios (See sections 5.2 and 5.3). A decisive factor is the meter technology used for communication, as well as the corresponding communication modules and systems (PLC, GPRS, radio transmission, M-bus connection). This sequence is explained in detail in Section 3.4.3 “Description of the modeling process”.

The characteristics of the meters which lead to the different power consumptions shown in Table 4 are described in Section 4.2 “Mapping the energy consumption of the product characteristics”.

Smart meters capable of remote data exchange (and other functionalities) consume more energy than a non-communicating meter. With respect to the communication, the following processes were tested in the laboratory:

– Reading of load profile data over one day

– Activation of the disconnecting mechanism of the breaker

– Reading of the meter status (e.g., checking its availability in the communication network), when appropriate.

IFEA launched specific events by means of a network operator that registered an additional meter to the existing network, and also in the calibration laboratory jurisdiction of competence of another cooperating network operator (Occasionally with the direct support of the system provider).

The time periods over which measurements were made have been adjusted to the duration of the effects of the particular event. The changes were recorded by the data logger.

**Monitoring of the load profile over one day - Connection category B (GPRS, 96 average power values registered every quarter of an hour) - SS01-SM-1ph, SS01-SM-3ph**

The 96 values correspond to the load profile in the course of a day (24x4 = 96 quarter of an hour averages). The collection, storage, and transmission under this resolution of time is required by the Austrian "Smart meters regulation" [VO IMA, 2011], but is also common in various other international cases.

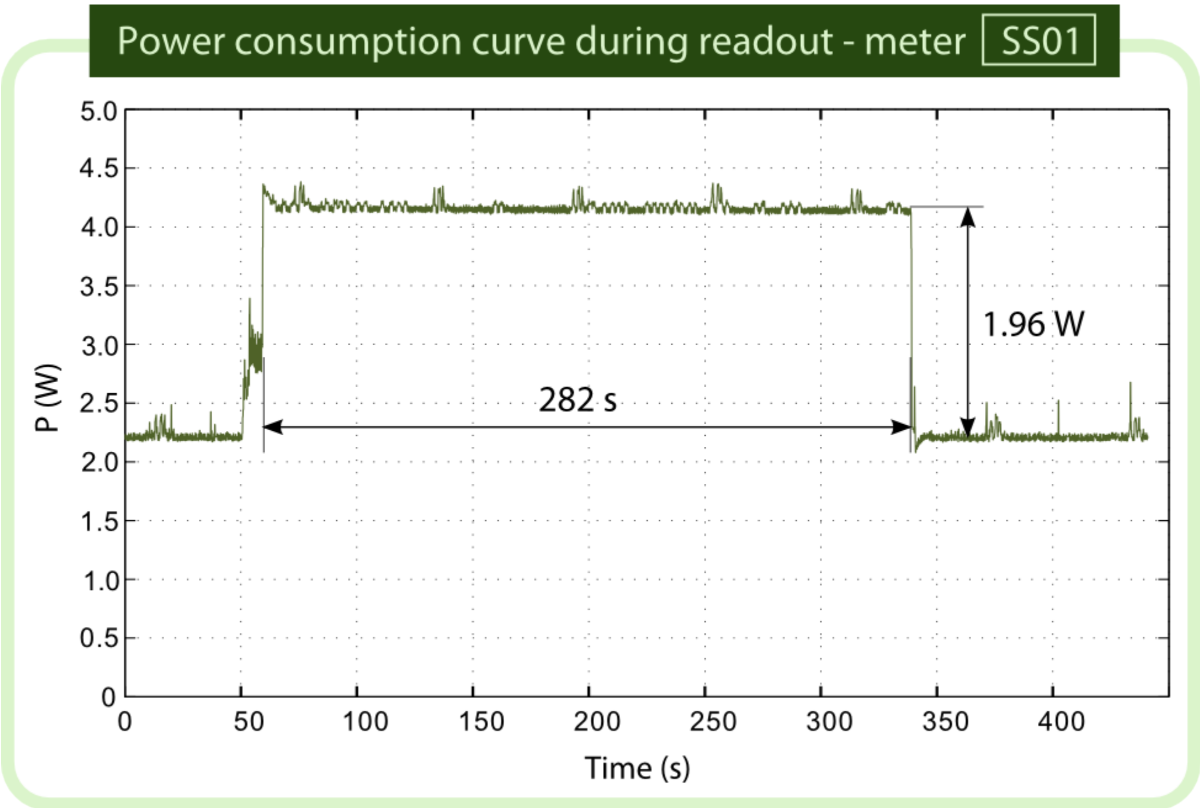


Figure 15: Input power readout from a meter connected through GPRS for a duration of less than 5 minutes (The additional power consumption (ΔP) was 1.96 W during this period).

Figure 15 shows the input power curve of the single-phase meter SS01-SM-1ph. For both, single-phase meter and three-phase meters under laboratory conditions, there were power consumption differences (ΔP) during transmission via GPRS of 1.95 W, and 1.95 W, respectively. These occurred during time spans of 203 seconds, and 282 seconds, respectively. Consequently, scheduling a daily readout would lead to an additional consumption between 400 Ws and 550 Ws, respectively.

The consumption at the remote location of the telecommunication company who provided the GPRS connection could not be determined through this procedure.

**Monitoring of the load profile over one day - Connection Category C (Radio transmission, 96 average power values, every quarter of an hour) - SS03-SM-1ph, SS03-DC-MM**

The data concentrator corresponding to the SS03 solution (SS03-DC-MM) is also a meter installed on the network, but it is equipped with an additional module for data concentration, and GSM communication to the data transmission network. The module enables the reading of data from several meters, and sending the collected data via GSM connection to the head end system.

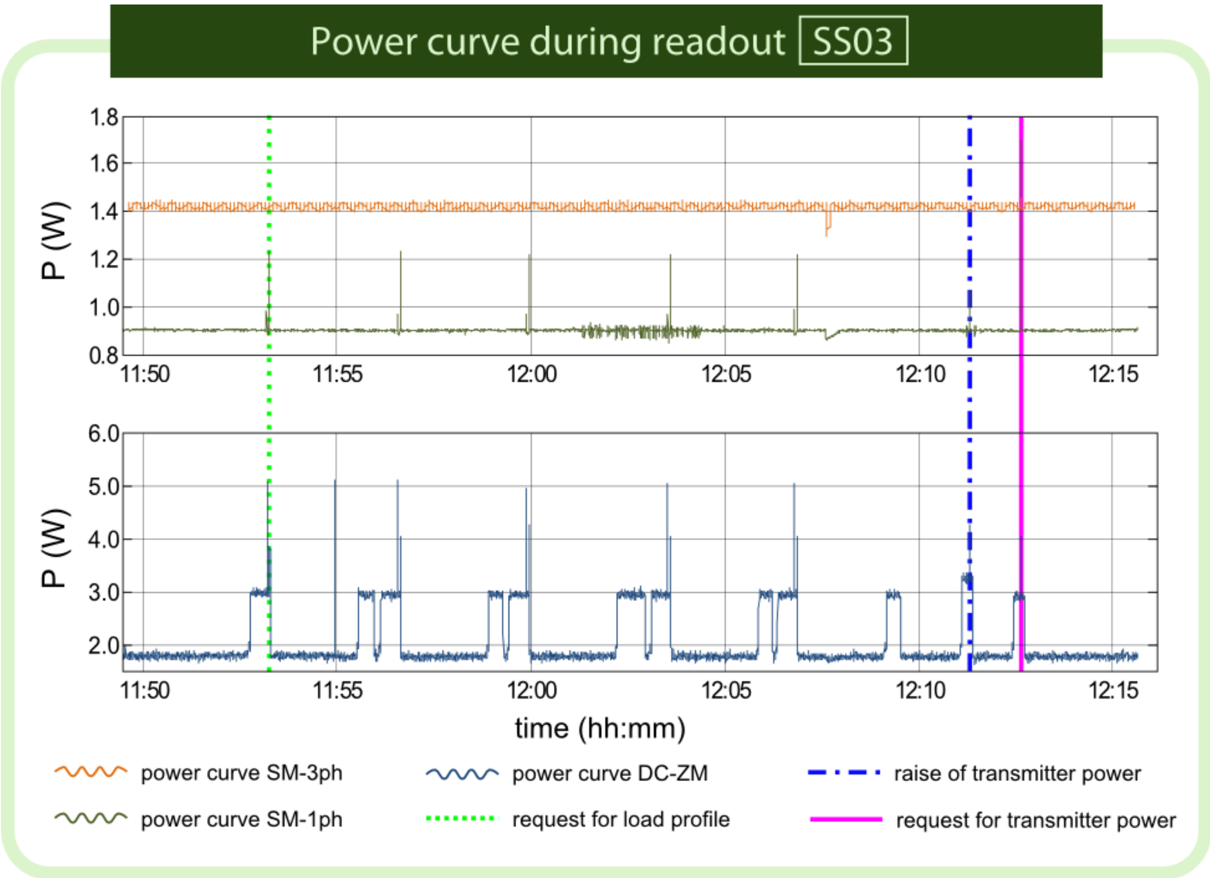


Figure 16: Series of subsequent readouts of the input power for the one-phase meter SS03-SM-1ph. The communication between data concentrator and meter took a couple of seconds each time.

Figure 16 shows the power curve of the single-phase meter and the data concentrator during several readings (Mostly readings of the load profile). The power consumption of the three-phase meter is also shown, without any readout requests though.

Peaks of consumption occurred during the transmitting period of the 96 load profile values from the single-phase meter, with about additional 0.35 W (ΔP) over the regular power consumption values.

Figure 17 shows in more detail the power curve of the data concentrator. This is a three-phase meter, which was connected to just one phase in the laboratory settings. It is therefore likely that, in real application cases, the standard power consumption would not be 1.78 W. The difference between one-phase and three-phase meters (0.51 W, as implied from Table 4) needs to be added. The result would therefore be 2.29 W. The values in Table 5 are corrected accordingly.

Table 5: Consumption values for the three-phase meter SS03-DC-MM operating as a data concentrator (Average values with corrections from load profile requests, unless otherwise indicated).

| **Load profile readout – Averaged energy consumption of SS03-DC-MM** | | |
|---|---|---|
| **Operational state / process** | **Averaging time (s)** | **P (W), corr.** |
| Inactive GSM communication | 1834 | 2.29 |
| Active GSM communication | 536 | 3.45 |
| Send request to the meter over radio transmission | single measurement | 5.45 |
| Receiving meter data over radio transmission | single measurement | 4.76 |

The input power curve shows that communication via GSM between the head-end and the data concentrator requires more energy than the communication over radio transmission between the data concentrator and the meter. The peaks that occurred during radio transmission can be seen in Figure 17 (for the events marked with vertical red lines). When sending a command over radio transmission the peak corresponds to power increases of about 2.0 W (ΔP), and for the reception over radio transmission of the load profile of the meter, of about 1.31 W.

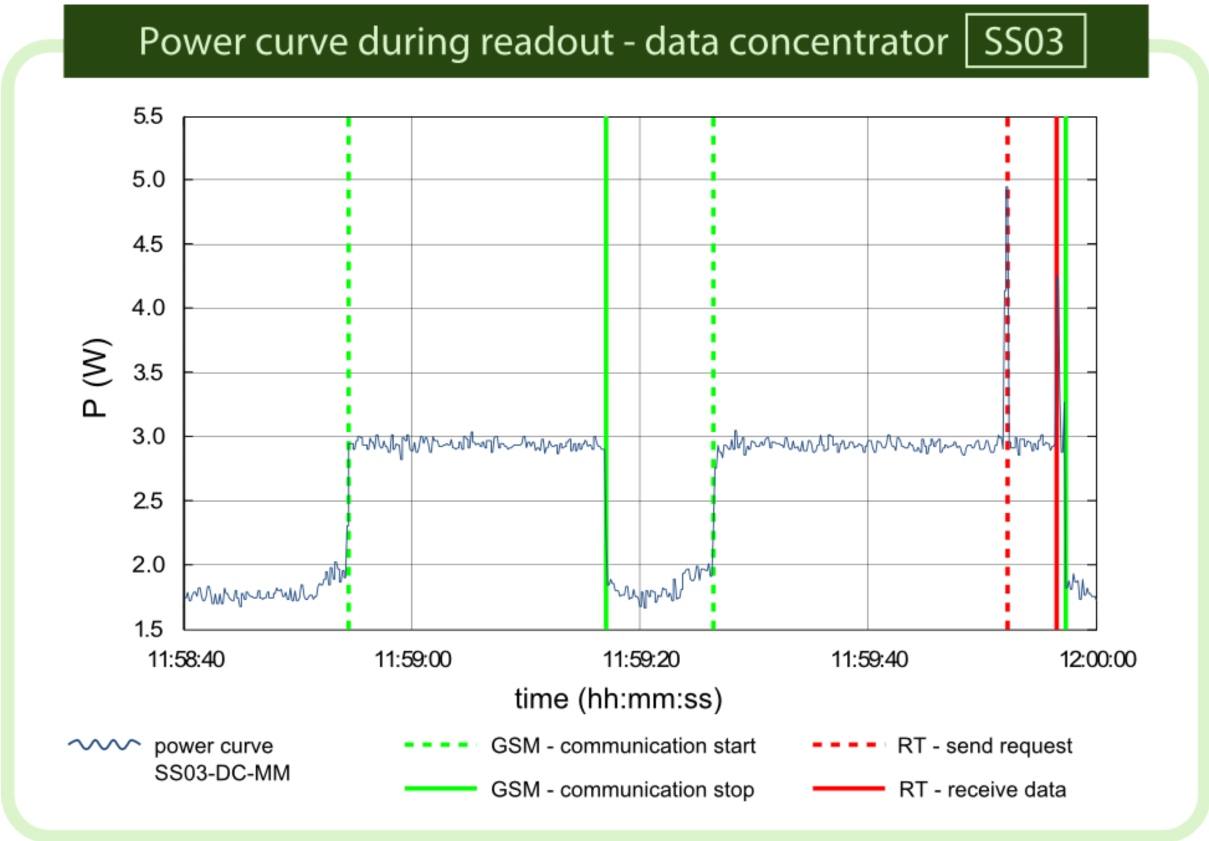


Figure 17: Input power curve measured at the data concentrator SS03-DC-MM (a three-phase meter with a GSM and data concentrator module).

**Status request for meter - SS02-SM-3ph**

The additional consumption of the meter due to a status request was evaluated through measurements on SS02-SM-3ph, which is a three-phase meter connected via PLC. The meters SS01-SM and SS03-SM do not have this function.

The highest measured power peak during the measured period was 1.5 W (ΔP) for 0.6 s (see time: 13 seconds in Figure 18). This peak resulted in an additional active power of about 0.45 Ws. It is believed that this amount of power corresponds to one request. In the reactive power curve (not shown here), the peak can be identified more clearly.

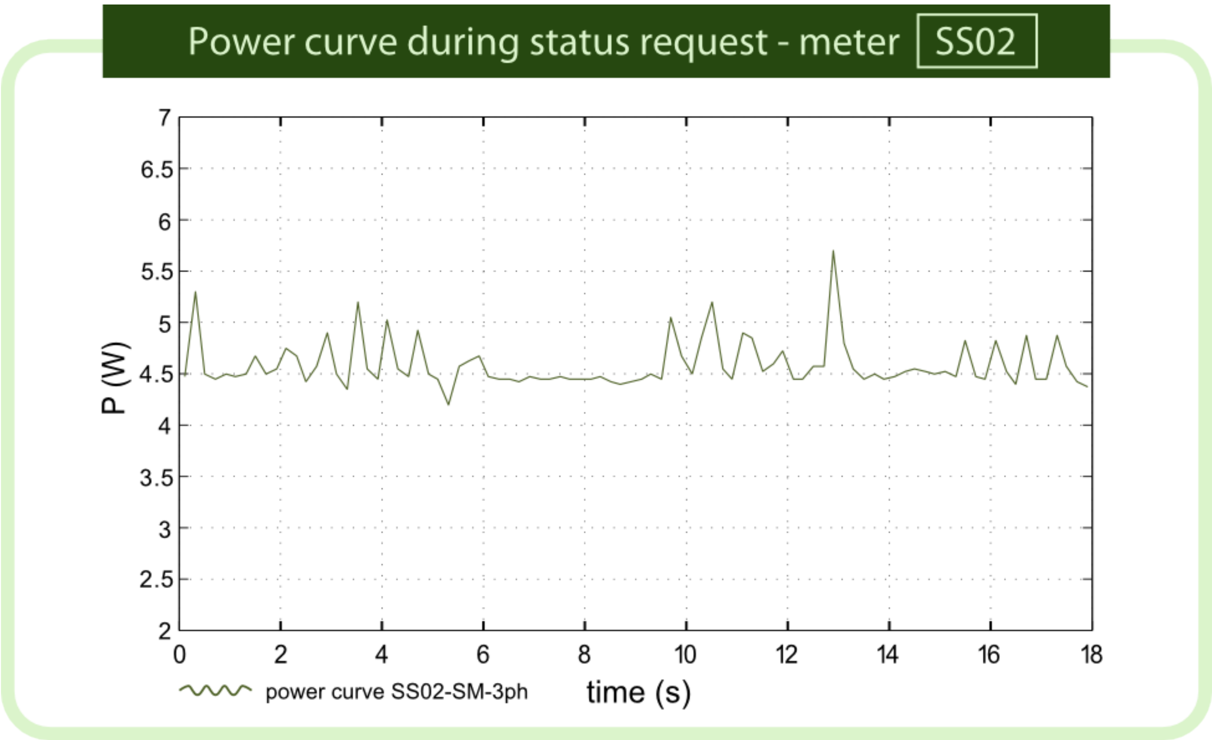


Figure 18: Input power curve of the three-phase meter SS02-SM-3ph while processing a status request.

**Operation of the breaker for meter - SS02-SM**

The additional consumption when operating a breaker was evaluated through measurements on a three-phase meter SS02-SM-3ph. The meters SS01-SM, available at the laboratory did not have breakers.
Within a period of about 15 seconds, both requests were sent, for opening and closing the breaker. In terms of consumption the behavior is quite similar as that of the status request. In both cases, a power increase of about 1.1 W with lasting about 0.6 s was identified. However, this value is identified with difficulty, because it is in the same order of magnitude as the threshold of the load curve. According to the tests, the power consumption for measuring the load is about 0.3 Ws. There are no permanent differences between open and closed relay states.

**Operation of the breaker for meter - SS03-SM**

The SS03-SM meters use breaker relays, which need energy to hold a closed position. Figure 19 shows the power consumption curves for the different operation modes, and Table 6 shows the average power consumption. In contrast to meter SS02-SM, an input power of about 0.09 – 0.10 W per phase is needed to hold the closed position.

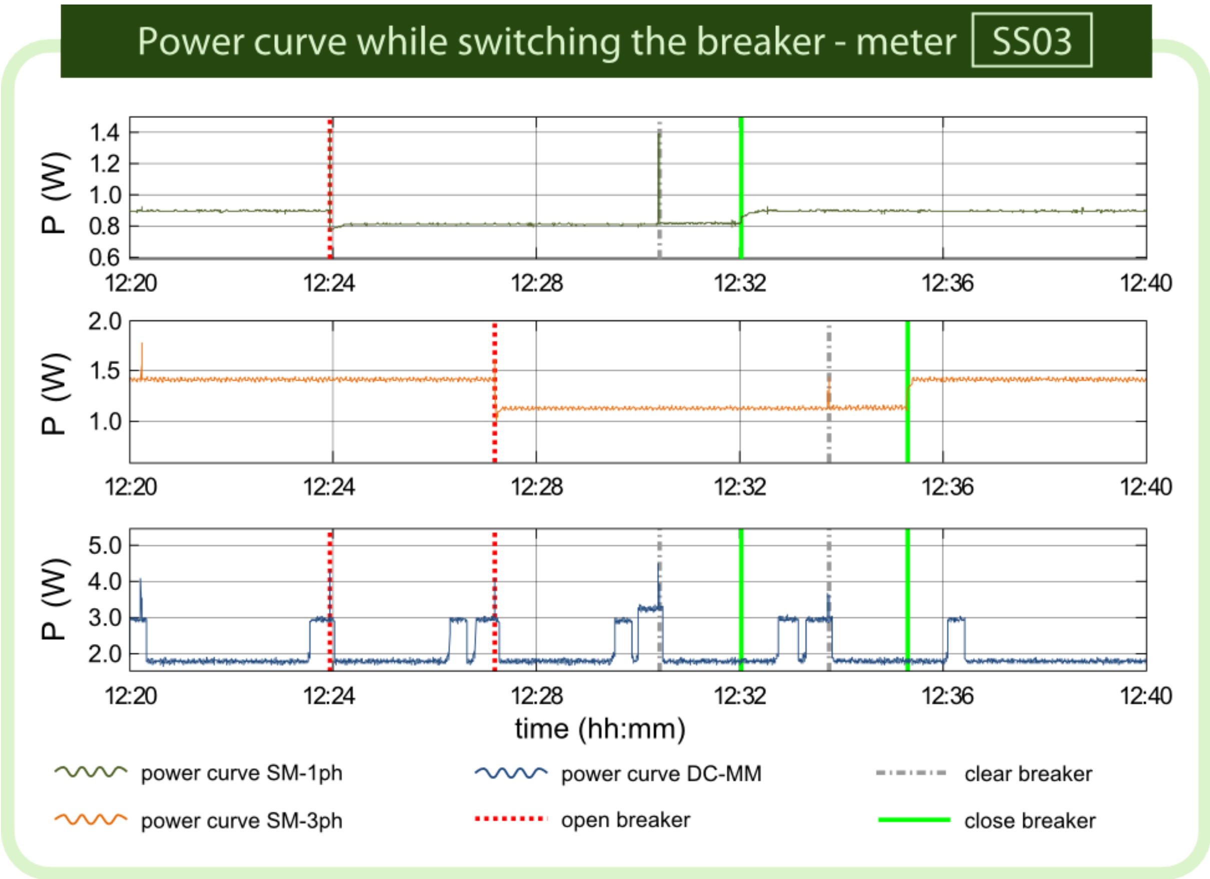


Figure 19: Input power curves of the meters SS03-SM when switching their breakers. The activity of the data concentrator is plotted while receiving commands from the head-end (GSM) and forwarding these to the meters (radio transmission), to trigger the breaker events.

Table 6: Input power of the one-phase and three-phase meters SS03-SM, with respect to the switching of the breaker, for a measurement period of 64 minutes.

| **Switching the breaker – Average energy consumptions of meters SS03-SM** | | | |
|---|---|---|---|
| **Device** | **Operational state** | **Average time** | **P (W)** |
| One-phase meter SS03-SM-1ph | Breaker closed | 56 min | 0.90 |
| | Breaker open | 8 min | 0.80 |
| | | **Difference (ΔP)** | 0.10 |
| Three-phase meter SS03-SM-3ph | Breaker closed | 56 min | 1.41 |
| | Breaker open | 8 min | 1.13 |
| | | **Difference (ΔP)** | 0.27 |

**Additional wireless M-Bus module – M-Bus**

For an optional wireless M-Bus module measured together with a meter, the additional power consumption during standby mode (i.e., without data transmission) was about 0.13 W. It was assumed that this value could be used as a representative average.

## 3.6 Live measurements on-site

To complement the laboratory measurements, comparative live measurements were carried out on-site (for the Austrian case, in 2011). Cooperation was secured from Swiss and Austrian energy utilities, which facilitated access to measure real household meters of their pilot projects. The same meter types were previously tested under laboratory conditions. The motivations for undertaking these complementary measurements were to verify the results, and to identify deviations occurring from conditions not replicable under laboratory conditions.

To obtain average values for a real operation mode, a 24-hour cycle was set for completing the measurements. The reading of consumption values but also any other remote-controlled processes routinely performed by the network operator were included in the observation period, therefore could be accounted for in the measurement process and, whenever appropriate, could be separately evaluated.

At three network-operators, the measurements were done for three-phase meters connected via GPRS, radio transmission or PLC. The associated data concentrator was also measured, when relevant for the communication technology under investigation.

The current transducer test circuit was selected because of the loads by at the end-user side. However, after the measurements were completed, the data analysis showed that this test circuit results brings significant measurement errors when used to assess meters in real time operation and conditions. Consultation with the metrological partner involved in the measurements revealed that this was related to offset errors, and concluded that the magnitude of the difference in power consumption readings for different operation modes are correct.
The measurements conducted on the data concentrator by means of the shunt circuit do not have offset errors.

### 3.6.1 Measurement of meters and data concentrators

**Measurement of SS01 - SS01-SM-3ph**

Time: measured from November 7$^{th}$ 2011, starting at 13:15 to November 8$^{th}$ 2011, until 15:00.

Location: A three-phase meter in a household of a suburban area.

Details:

- Category type B: Direct GPRS/GSM connection of the meter to the head-end, with no data concentrator.
- Measurements include the additional consumption of an in-home display.

Figure 20 shows relatively uniform power consumption over a period of 24 hours for this meter.

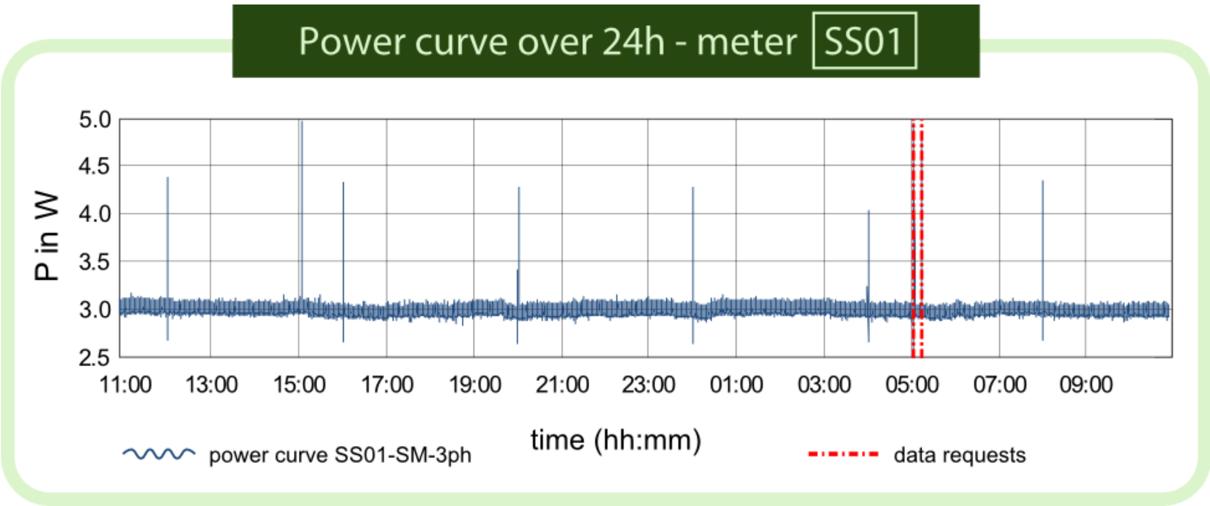


Figure 20: Input power curve over time for the three-phase meter SS01.

Due to the error on real time measurements mentioned before, the measured average consumption value of the meter is not directly included in the calculations, but the difference in consumption between active and inactive communication modes can be used. The GPRS reading took only 2 minutes and can be seen as a peak ($\Delta P$ = 1.43 W) in the 24-hour observation cycle.

The measurements do not show any significant differences in the basic load, apart from small peaks that occur periodically, every four hours, during active transmission. It was not possible to determine the processes responsible for these peaks.

**Measurements of SS02 - SS02-SM-3ph and SS02-DC**

Time: measurements taken from September 27th 2011 starting at 13:15, to September 28th 2011 until 14:00.

Location: urban household with a three-phase meter and corresponding transformer station.

Details:

- Category type A: PLC connection of the meter to the data concentrator (Located at the transformer station).
- Simultaneous measurement of consumption at the meter and at the data concentrator.
- The metering point was at the end of the service connection.
- Connection of the data concentrator to the head-end via GPRS/EDGE modem (Separate power supply).

Again for this case, the average of the measured consumption of the meter is not to be directly considered, but the difference in power consumption between active and inactive communication modes is relevant.
The extrapolations performed later on are based on the absolute consumption values obtained for this type of meter in the laboratory (Refer to Table 4). The additional consumption of the communication feature is calculated based on the differences in consumption from the real time (on-site) measurements.

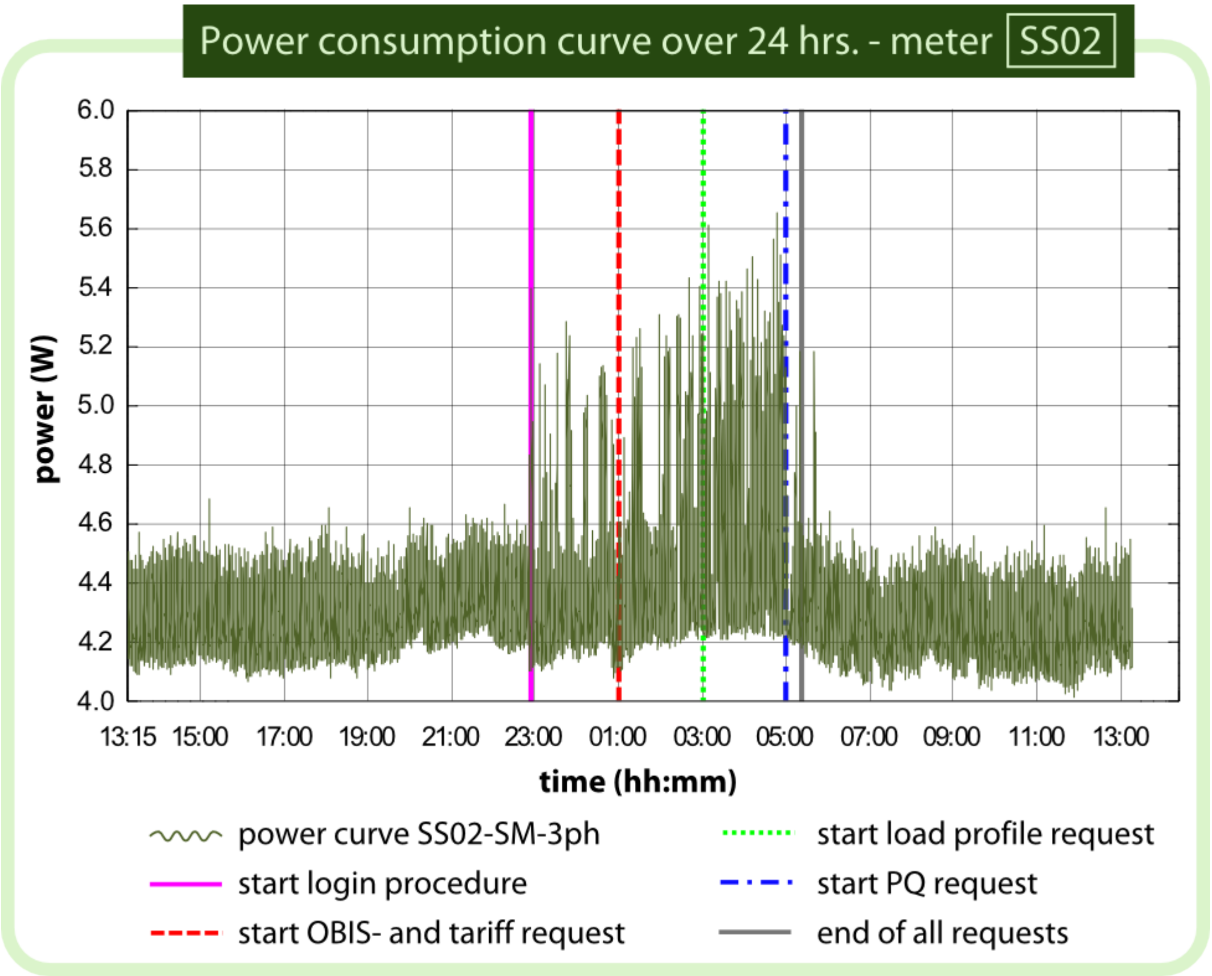


Figure 21: Input power curve of the three-phase meter SS02-SM-3ph connected via PLC, as registered during a 24-hour period in a pilot project.

The data concentrator was measured using a shunt circuit at the clamps on the meter's power supply side (See Figure 22). Therefore the interpretation of these measurements is still possible. The energy consumption related to the power supply decreases during active communication. The grid voltages and currents at the data concentrator were not measured. It is possible that, an additional though small amount of active power exists over the three-phase network, which does not appear in the measurements, and therefore could not be considered further.

The modem in the data concentrator, which sends data from to the head-end system, was also measured. During the periods of active data transmission the observed increase of power was between 0.3 and 0.4 W (ΔP).

Figure 21 and Figure 22 provide the raw values used to generate averages over time, as summarized in Table 7.

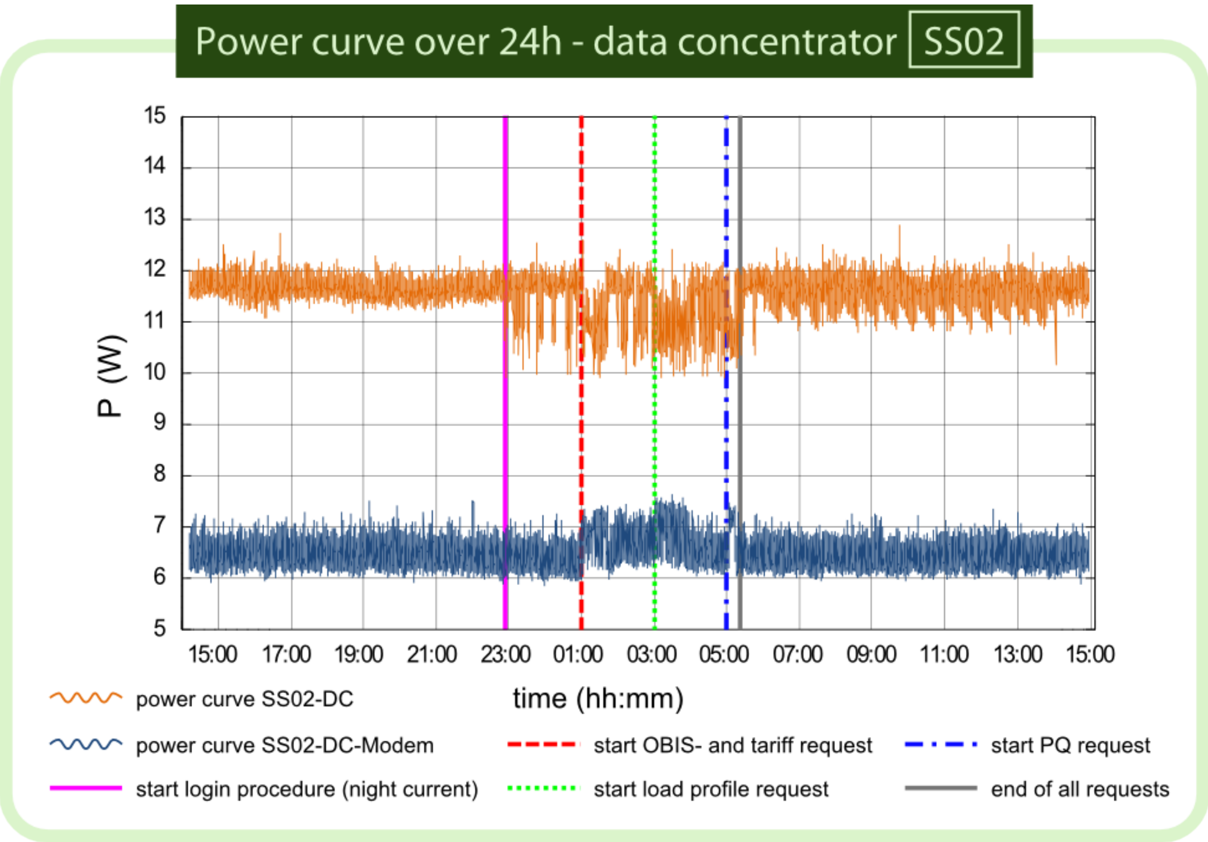


Figure 22: Input power curves for the data concentrator SS02-DC and the corresponding modem, as registered during a 24-hour period in a pilot project.

Table 7: Average power values according to different operational modes for SS02-SM-3ph and SS02-DC with corresponding modem.

| **Average input power for the devices of SS02 (Real time measurement)** | | | | | |
|---|---|---|---|---|---|
| **Operational mode/process** | **Time span (hh:mm)** | **Duration (min)** | **SS02-SM-3ph P (W)** | **SS02-DC P (W)** | **SS02-DC-modem P (W)** |
| Inactive communication | 13:15 - 22:51<br>5:23 - 14:00 | 1029 | 4.25 | 11.61 | 6.41 |
| Total, including all re-quests | 13:15 - 14:00 (next day) | 1440 | 4.31 | 11.52 | 6.46 |
| Active communication (All events included) | 22:51 - 5:42 | 411 | 4.46 | 11.30 | 6.57 |
| Log in after start | 22:45 - 1:00 | 129 | 4.37 | 11.54 | 6.34 |
| Send (Tariff data and OBIS data) | 1:00 - 3:00 | 120 | 4.46 | 11.23 | 6.71 |
| Send (Load profile data) | 3:00 - 5:00 | 120 | 4.59 | 11.09 | 6.65 |
| Send (PQ data) | 5:00 - 5:23 | 23 | 4.34 | 11.,06 | 6.80 |

**Measurements of SS03 - SS03-DC-E**

Time: measurements were taken from October $19^{th}$ 2011, starting at 14:00 to October $20^{th}$ 2011, until 14:00.

Location: at the calibration laboratory of an energy utility, for a meter as registered in their pilot project (Access to a metering point in a real household was not possible).

Details:

- Category type C: radio transmission of the meter data to the data concentrator.
- Ethernet connection of the data concentrator to the head-end.
- Power consumption measurements taken simultaneously at the meter and at the data concentrator.

Real time measurements for the solution SS03 could not be completed as planned, it was only possible to measure the meter at the household premises but instead measurements were done with a registered meter at the calibraton laboratory of the operator. On the load side the meter was connected to the lighting of the calibration stand. The data concentrator was not ready for the measurements on the scheduled date. Limited meter readouts were carried out.

In contrast to the laboratory measurements taken for SS03, the data concentrator operated as a stand-alone device in the test field. Table 8 shows the average power consumption that occurred during a short time operation of about 2.5 minutes.

Table 8: Average input power for the data concentrator SS03-DC-E during real time measurement.

| Average of power values for the data concentrator SS03-DC-E (Real time measurement) | | |
|---|---|---|
| **Operational mode** | **Duration (s)** | **P (W)** |
| Inactive sending module | 120 | 1.06 |
| Active sending module | 30 | 2.44 |

The numerical values associated with the corresponding errors of measurements are given in Table 9.

### 3.6.2 Measurements of an in-home display - IHD

An in-home display connected via wireless M-Bus to a smart meter in a household was measured during the real time test (see Figure 23). Three operation modes showed different levels of power consumption, but the differences between them were small. The five distinctive power peaks of about 0.7 W over the normal values ($\Delta P$) occurred due to the background lighting of the display during the readings taken in the home. The average input power of a display over 24 hours was estimated to be around 0.52 W.

According to manufacturer specifications, an in-home display consumes 1.20 W when the background light of the display is active, and 0.60 W when in standby mode (without background lighting). Real time measurements on-site, however, showed higher values.

These measurements serve only as supplementary source of information; the results were not used in later extrapolations (especially since the systems evaluated within the project are limited to the non-metered area, therefore in-home displays are outside of this boundary).

Moreover, the average power value obtained is not representative for all different types of in-home displays.

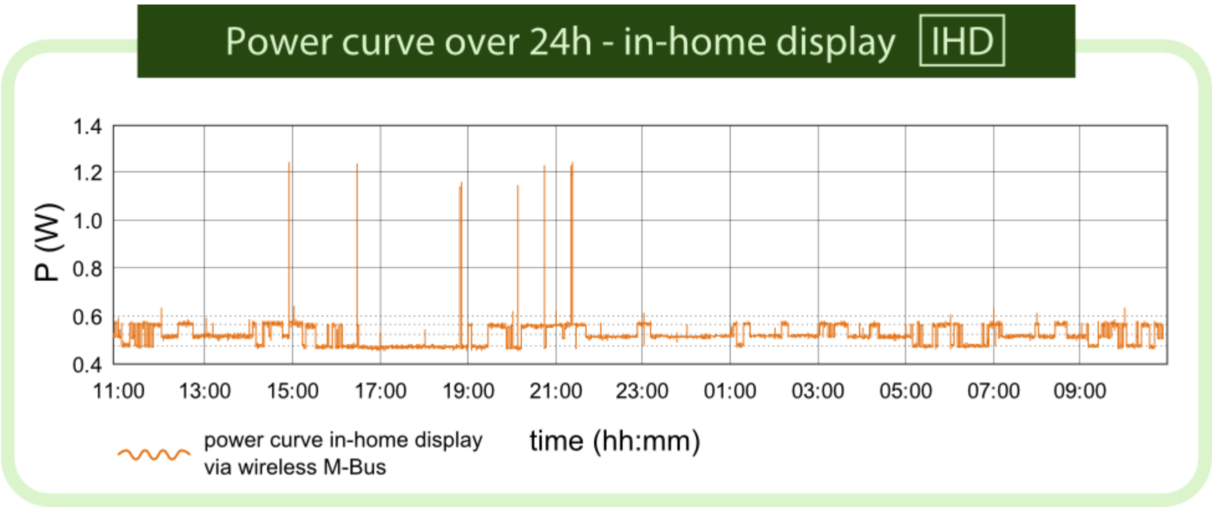


Figure 23: Input power curve over time for an in-home display IHD, communicating via wireless M-Bus with the residential meter.

**Measurement results and uncertainties**

Table 9 shows the power consumption data for the meters both, in the laboratory and on-site, and includes relative and absolute measurement errors. Entries highlighted in green were further used in the calculations. Due to large measurement errors the entries highlighted in the red could not be further evaluated or used for calculations.

When distortions of the voltage signal in the grid were present (increased THD compared to laboratory conditions), offset voltages occurred in the current transducer of the test circuit. In combination with low phase angles between current and voltage this led to unexpectedly large errors of measurement. This explains why the current transducer measurements were insufficiently accurate under on-site conditions. This was also the case for the measurements of the solution SS03 with the current transducer, which were carried out in another laboratory with no stable enough voltage and current supply.
Errors were calculated individually for each meter according to the principle of propagation of error, and therefore vary depending on the load condition (Mainly on the phase angle, and the load distribution over the three phases).

Table 9: Overview of the collected data from shunt measurements and current transducer measurements, including calculated errors.

| | | | Laboratory measurements with shunt circuit | | | Lab. measurements with current transducer circuit | | |
|---|---|---|---|---|---|---|---|---|
| Solution | Meter | Phase | P (W) | ΔP/P (%) | ΔP (W) | P (W) | ΔP/P (%) | ΔP (W) |
| SS01 | SM-1ph | L | **2.25** | **0.58%** | **0.013** | **2.25** | **14.04%** | **0.32** |
| | SM-3ph | L1 | 0.84 | 1.42% | 0.012 | 0.88 | 45.89% | 0.40 |
| | | L2 | 0.85 | 1.40% | 0.012 | 0.85 | 47.92% | 0.41 |
| | | L3 | 0.86 | 1.39% | 0.012 | 0.83 | 49.45% | 0.41 |
| | | Total | **2.55** | **1.40%** | **0.036** | **2.56** | **47.72%** | **1.22** |
| SS02 | SM-1ph | L | **3.09** | **0.27%** | **0.008** | **3.13** | **4.33%** | **0.14** |
| | SM-3ph | L1 | 1.55 | 0.31% | 0.005 | 1.64 | 5.77% | 0.09 |
| | | L2 | 1.54 | 0.45% | 0.007 | 1.44 | 23.73% | 0.34 |
| | | L3 | 1.55 | 0.44% | 0.007 | 1.55 | 21.66% | 0.34 |
| | | Total | **4.64** | **0.40%** | **0.019** | **4.63** | **16.68%** | **0.77** |
| SS03 | SM-1ph | L | **0.9** | **0.46%** | **0.004** | - | - | - |
| | SM-3ph | L1 | 0.34 | 0.60% | 0.002 | 0.35 | 32.39% | 0.11 |
| | | L2 | 0.41 | 0.49% | 0.002 | 0.53 | 17.03% | 0.09 |
| | | L3 | 0.66 | 0.52% | 0.003 | 1.03 | 19.91% | 0.21 |
| | | Total | **1.41** | **0.53%** | **0.007** | **1.91** | **21.40%** | **0.41** |

| | | | Real time (on-site) measurements with current transducer circuit | | |
|---|---|---|---|---|---|
| Solution | Meter | Phase | P (W) | ΔP/P (%) | ΔP (W) |
| SS01 | SM-1ph | L | - | - | - |
| | SM-3ph | L1 | 0.73 | 6214% | 0.46 |
| | | L2 | 1.37 | 26.24% | 0.36 |
| | | L3 | 0.84 | 5053% | 0.43 |
| | | Total | **2.95** | **42.15%** | **1.24** |
| SS02 | SM-1ph | L | - | - | - |
| | SM-3ph | L1 | 1.49 | 5.96% | 0.09 |
| | | L2 | 1.32 | 25.89% | 0.34 |
| | | L3 | 1.43 | 23.29% | 0.33 |
| | | Total | **4.25** | **18.00%** | **0.76** |
| SS03 | SM-1ph | L | - | - | - |
| | SM-3ph | L1 | 0.34 | 35.52% | 0.12 |
| | | L2 | 0.46 | 21.53% | 0.10 |
| | | L3 | 1.02 | 20.98% | 0.21 |
| | | Total | **1.82** | **23.86%** | **0.43** |

## 3.7 Additional input data

### 3.7.1 Data of Ferraris and non-communicating electronic meters

Active and apparent power values reported in Table 10 were collected from measurements carried out by an energy utility (for devices which could be considered state of the art as of 2009), as well as from manufacturer data sheets. Some considerations about these data are:

- The measurements provided by the energy utility for the project were taken under off-load condition. Therefore it is not possible to understand the behavior of such meters under load conditions.
- The period over which the (average) value was calculated is unknown.

In some cases there are differences in performance between meters of different power ratings, as the manufacturers offer meters that are, e.g. for maximum 60A and for maximum 100A. In the study "*Analyse der Kosten – Nutzen einer österreichweiten Smart Meter Einführung"*[1]*,* conducted by Capgemini in 2010, three-phase meters are classified in three categories according to end user groups defined by E-Control [Capgemini, 2010]. 2,800,000 meters had maximum amperage of 60A; 812,000 meters had maximum amperage of 100A, and 253,000 were double-rate meters. In other words, approximately four fifths of the three-phase metering points have maximum amperage of 60A, and the rest 100A. According to the datasheets and consultations with manufacturers, no distinction is made between these two major categories of meters, as the differences of own energy consumption are considered as negligible.

Under conditions of maximum power (e.g., 40 kW or rather highest current of 60A) network operators often require to use transducers at metering point. Within this study, the volume of meters is much more relevant and therefore these transducers were neglected.

Table 10: Average power values of various meters, taken as status quo for this project.

| Average input power values for solution SS04 | | | | |
|---|---|---|---|---|
| **Meter type** | **Phases** | **P (W)** | **S (VA)** | **Source** |
| **Ferraris** | **1** | **1.43** | **4.13** | **Manufacturer 3, utility measurement.** |
| Ferraris (different $P_N$) | 1 | 0.9 - 1.0 | 4.3 | Manufacturer 1, datasheet |
| Ferraris (60 A) | 1 | 1.1 - 1.3 | 4.2 | manufacturer 2, datasheet |
| Ferraris (100 A) | 1 | 1.3 - 1.5 | 5.4 | Manufacturer 2, datasheet |
| | | | | |
| **Ferraris** | **3** | **3.92** | **11.37** | **Manufacturer 4, utility measurement.** |
| Ferraris (different $P_N$) | 3 | 3.6 - 4.0 | 15.9 - 16.2 | Manufacturer 1, datasheet |
| Ferraris (100A) | 3 | 3.3 - 3.6 | 14.1 | Manufacturer 2, datasheet |
| | | | | |
| **Electronic MFM** | **3** | **4.42** | **45.82** | **Manufacturer 2, utility measurement.** |
| **Electronic MFM** | **3** | **4.65** | **4.67** | **Manufacturer 2, utility measurement.** |

[1] This is a cost-benefit study concerning scenarios for smart meter rollouts in Austria.

| | | | | |
|---|---|---|---|---|
| **Electronic MFM** | **3** | **4.16** | **4.21** | **Manufacturer 5, utility measurement.** |
| Electronic (100 A) | 3 | 6.0 | 31.5 | Manufacturer 1, datasheet |
| Electronic (state-of-the-art) | 3 | 1.5 | 7.6 | Manufacturer 2, datasheet |

### 3.7.2 Data from an energy utility for solution SS04

The connection type D (see Figure 6) via wireless M-Bus is designed for areas of high population density (urban areas), where smart meters are located close to each other (such as in a residential building with multiple apartments), and where the readouts can be performed on a local data collection network. The "last mile", that is, the distance needed to connect individual households, is in this case very short and easy to be covered. A gateway communicates with individual meters via wireless M-Bus, and transmits the aggregated data (using various possible types of transmission) to the head-end system.

This section explains in detail the measurements for a solution already tested by an energy utility, including a meter connected through either wireless M-Bus or through WAN transmission via FTTB. The company agreed to provide internal data of their measurements for the project.

The measurements were taken with a Memobox 808, where current and voltage were registered at the supply lines. The current measurements were made with a clamp-on ammeter. To obtain a better resolution on the basis of 1A nominal range, the supply lines were fed with several turns through the clamps.

#### Meter SS04-SM with wireless M-Bus module

The SS04-SM-3ph meter was already tested by an energy utility. This is a three-phase meter which was connected in one case to a single-phase, in another case to a three-phase connector, and operated under off-load conditions.

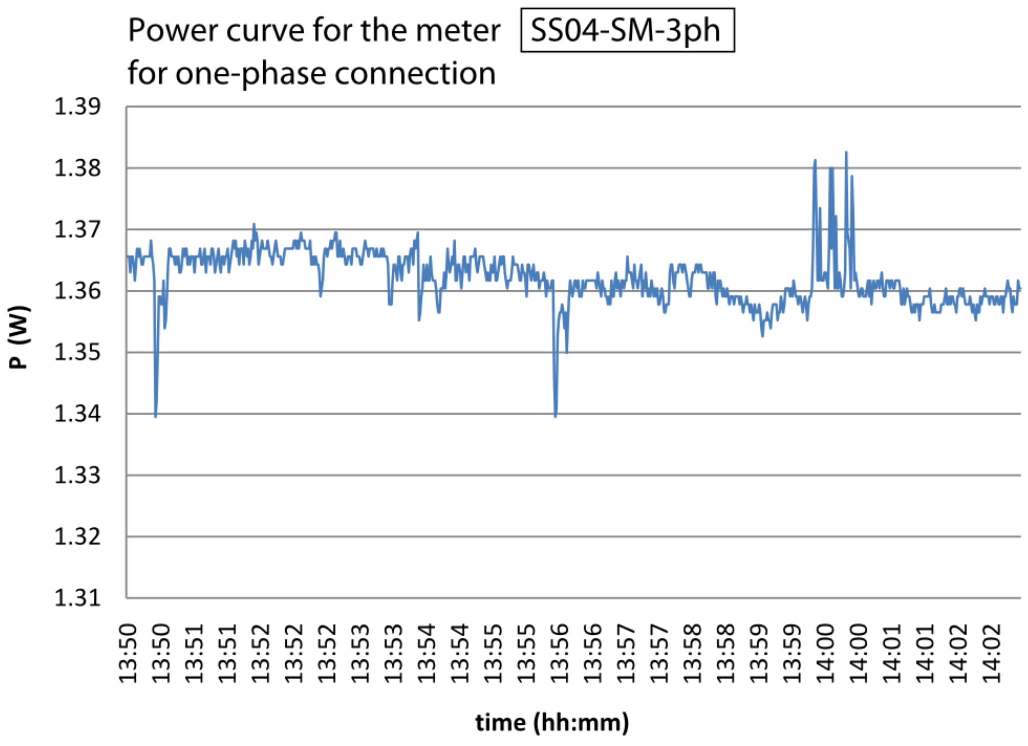


Figure 24: Power curve of the meter solution SS04-SM-3ph connected to *one phase*.

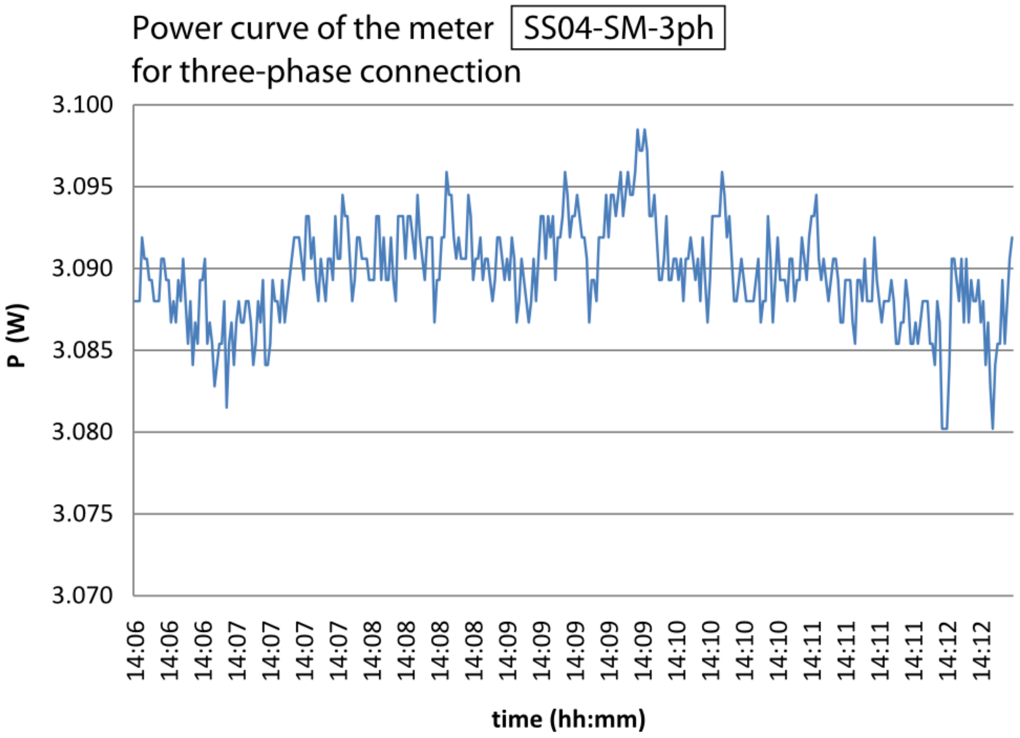


Figure 25: Power curve of the meter solution SS04-SM-3ph connected to *three phases.*

In this case, the meter readings were transmitted every 40 seconds to the gateway. The measurements presented in Figure 24 and Figure 25 are obtained with a time resolution of 1 second. No leaps in performance, possibly associated with the active transmission modes via wireless M-Bus, were identified. The performance was found to be mostly steady. A scale in the magnitude of 10mW was chosen for the diagrams to better observe the variations. On the measurement plot for the single-phase meter, peaks were visible. According to the energy utility this was due to voltage fluctuations within a space of $\Delta U = 2$ V and because of the existing ripple control system.

**Gateway SS04-GW and OFC bridge SS04-BR**

In the case of the specific solution of one of the energy utilities participating in the project, a gateway installed at an apartment block is connected to the head-end over optical fiber. To transfer the signal from Ethernet to light impulses it is then necessary to deploy a CPE (Customer premises equipment), which technically acts as a bridge. The same has to be installed at the data node of the remote station (Similar functionality but different devices).

Figure 26 shows details of the power curves for the gateway and the bridge. Both devices were observed for a period of 8 hours. As in the previous example, performance levels were quite steady. The power increases that occurred periodically every 15 minutes at the gateway can be attributed to real-time transmission of the values to the head-end corresponding to every quarter of an hour readings. In real conditions, gateway data from 30 meters is collected and transmitted to the HES in a period of 28 seconds. During a comparative measurement with 5 meters, the process took about two seconds. Therefore, a time period of 1 second per meter can be extrapolated.

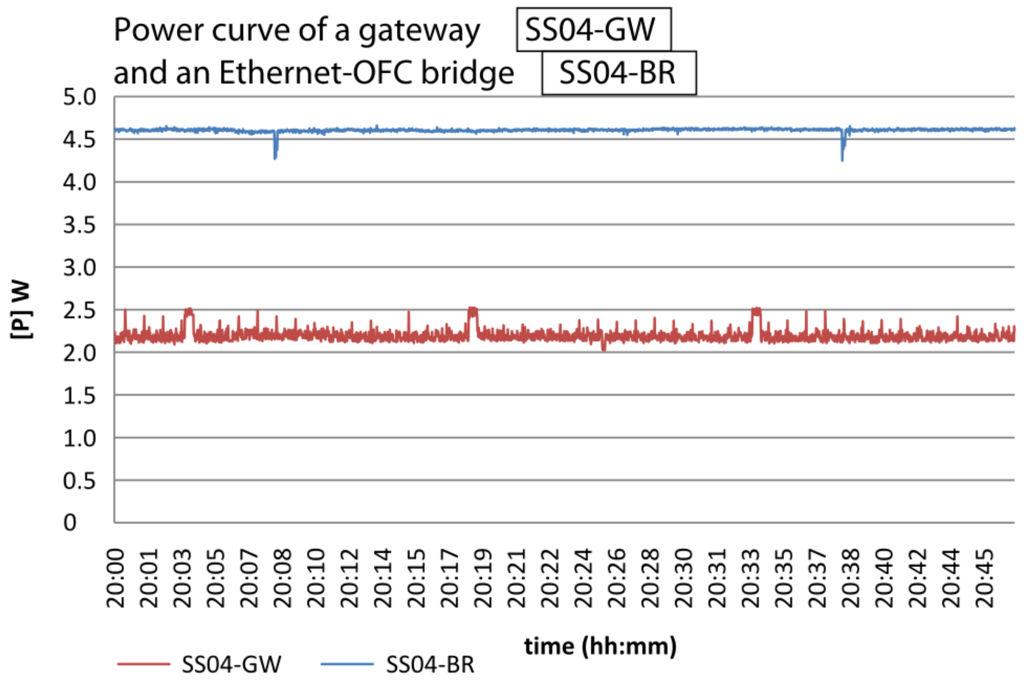


Figure 26: Power curves for the gateway SS04-GW and for the Ethernet OFC bridge SS04-BR.

After the measurements were taken for the bridge, a connected Ethernet device was removed and therefore a decline in performance 0.29 W (ΔP) was observed (see Figure 27). The value obtained during the 8-hour period was therefore corrected by being lowered.

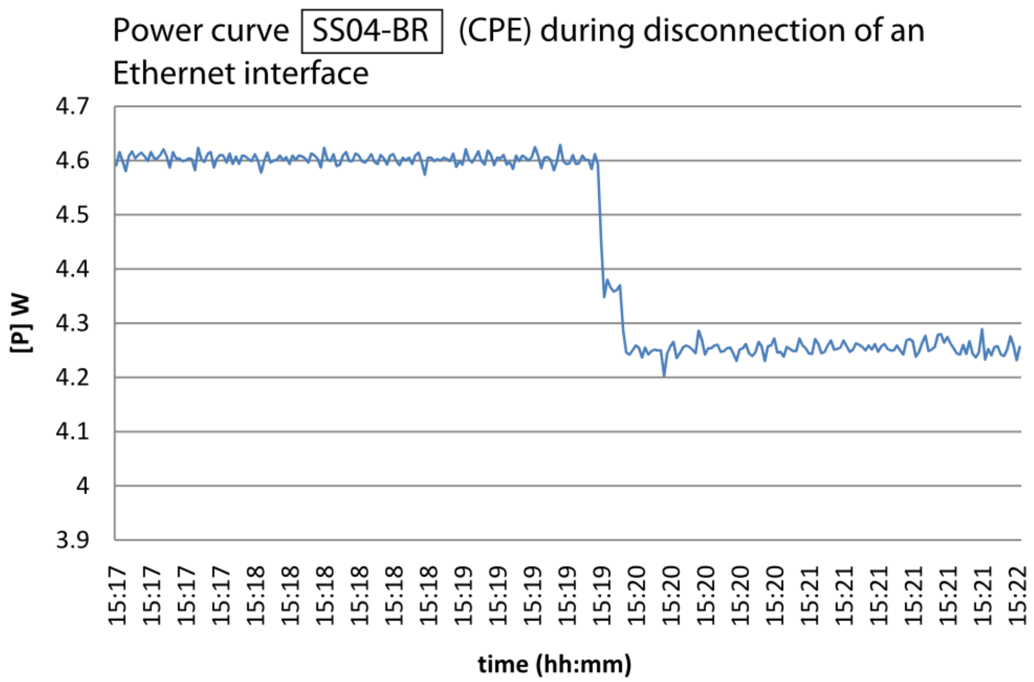


Figure 27: Power curve showing a drop after disconnecting an Ethernet interface at the Ethernet OFC bridge.

Table 11 shows the power values of the devices that comprise solution SS04. The energy utility indicated that, for every connection of CPE to the OFC infrastructure, an added average power consumption of about 0.6 W can be expected at the opposite end of the connection.

Table 11: Measured power values for devices included in solution SS04.

| Average power values for the devices of the solution SS04 | | | |
|---|---|---|---|
| **Device** | **Operational state** | **Duration (min)** | **P (W)** |
| Meter SS04-SM-3ph, one-phase connection. | Realistic mix | 12 | 1.36 |
| Meter SS04-SM-3ph, three-phase connection. | Realistic mix | 6 | 3.09 |
| Gateway SS04-GW | Active communication | 16 | 2.47 |
| | Inactive communication | 484 | 2.18 |
| | | **Difference ΔP:** | 0.29 |
| Ethernet OFC bridge SS04-BR | Realistic mix | 500 | 4.23 |

### 3.7.3 Data input from manufacturers

#### Meter with PLC connection – SS05

A meter manufacturer performed laboratory measurements of a modular three-phase meter from its own product line for the project. A PLC module was installed in the meter. The measurements were carried out with a precision wattmeter Infratek type 304B. From these measurements, average power consumption values were calculated, as shown in below:

Table 12: Measured power values for the three-phase meter of solution SS05.

| Measured power values of the modular three-phase meter SS05-SM-3ph | |
|---|---|
| **Measuring object/operational state** | **P (W)** |
| Basic three-phase meter | 1.00 |
| PLC communication module, inactive | 1.75 |
| PLC communication module, active | 2.40 |

It can be seen that the total consumption of the meter when in active communication and passive communication differs only by 0.65 W (ΔP). The power consumption during active communication is 23.6% higher (ΔP/P) than for the passive communication state.

For these measurements apart from testing the active and passive communication states of the module, the net impedance of the supply source was also varied within the range of 2 to 10 ohms. The manufacturer interpreted the results in the way that, for the special case how this PLC communication has been implemented, the own energy consumption of the meter was probably not affected by more than 10% from any of the parameters assumed for the use case (including network topology, data traffic, and network impedance).

## 3.8 Analysis of the consumption data for technical components

This section deals with the time averaged effective power of the devices as used to calculate the consumption values of a metering point, according to different system characteristics. Data taken from measurements (whenever possible) or combined with the corresponding load data, for the case of different modes of operation, has been used for the estimations corresponding to real operating conditions. This part of the modeling marks the transition from Point 1 to Point 2 of the "layers" model illustrated in Figure 7.

### 3.8.1 Technical components for the status quo case

The data from the measurements as provided in Table 10, for three different classes of devices considered in the status-quo case are again reported in Table 13. In the case of the electronic multifunctional meter, the three available values from Table 10 were combined into an average.

Table 13: Characteristic active and apparent power of the meters considered for the status quo.

| Meter type | P (W) | S (VA) |
|---|---|---|
| Ferraris meter, one-phase | 1.43 | 4.13 |
| Ferraris meter, three-phase | 3.92 | 11.37 |
| Multifunctional meter, three-phase | 4.41 | 18.23 |

For a comparison, Table 14 shows the average active power as reported in KEMA, 2009.

Table 14: Approximate values for energy consumption of electricity meters as reported in „Endenergieeinsparungen durch den Einsatz intelligenter Messverfahren (Smart Metering)" [KEMA, 2009].

| Device | Annual energy (kWh/a) | Input power (W) |
|---|---|---|
| Ferraris meter (average) | 30.0 | 3.4 |
| Electronic meter | 13.0 | 1.5 |

In this study, the consumption for electronic meters is considerably higher because these presumably corresponds to an older generation of meters, similar to those in the installed stock of meters for Austria and in Switzerland.

### 3.8.2 Technical components for smart metering systems

Technical components were categorized into four classes: A, B, C and D, as shown in Figure 28. Each class corresponds to a specific solution, for which previous measurements and data provided by the cooperating partners allowed further investigation in this project.

As explained in section 3.4.2, a distinction was made based on the connection type used in the data collection network. Therefore, the connection type was used to define the nomenclature to describe the technical scenarios and the technical components within the scenarios (For further information see Chapter 5).

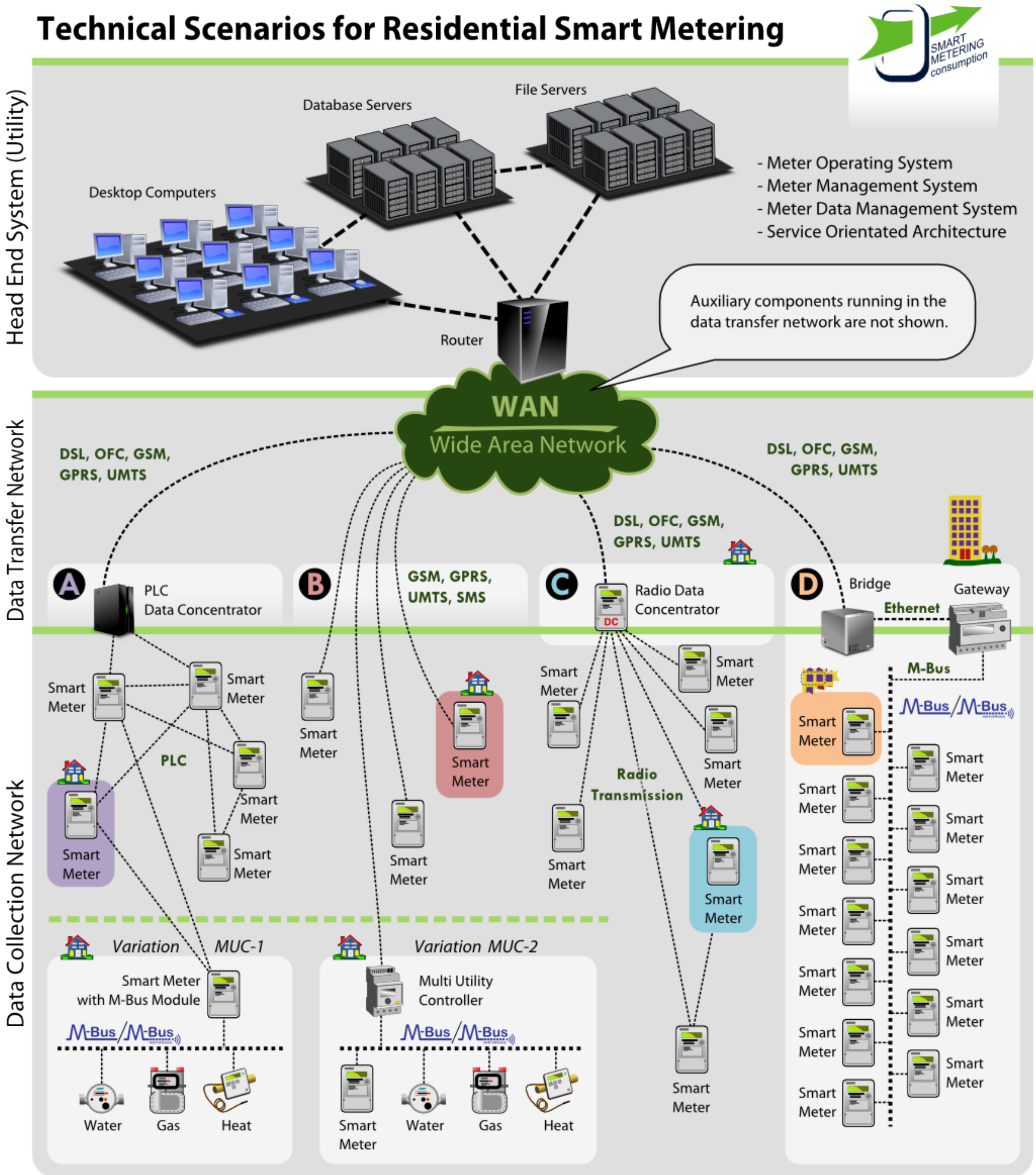


Figure 28: Technical scenarios for smart metering systems according to the categories A, B, C, and D.

The connection types can be described as follows:

**A:** Connection of several metering points to a data concentrator using power line carrier as the means for transmission. The metering points also serve as intermediate nodes responsible for the repeating functions. Different technologies would be suitable for transferring the aggregated data to the head-end system.

**B:** Direct connection of each metering point to the mobile network of a telecommunication operator, responsible for transmitting the data to the head-end system. Similarly to the mobile telephone, each meter is provided with a corresponding transmitter and a SIM card.

**C:** Connection of several metering points with radio transmission to a data concentrator. The data concentrator is implemented through a module in one meter. This system is structured similarly as in the type A, in the form of a network of meters with repeating functions. Different technologies would be suitable for transferring the aggregated data to the head-end system.

**D:** Connection of multiple metering points of a building (or complex of buildings) to a common gateway via M-Bus or Wireless M-Bus. Different technologies could be suitable for transferring the aggregated data to the head-end system (when necessary, across a bridge or through a modem).

The following symbols have been included in the coming tables to indicate the type of data available:

- **R:** Robust data. In general for the case of data resulting from measurements carried out during the project itself.
- **I**: Indicative data. In general, data derived from other documentation from third-parties, such as datasheets or other data.
- **X**: Illustrative data, which is based on conservative estimates. It is not possible to make reliable statements with illustrative data, so results are to be interpreted with caution.

The manufacturer´s specific equipment has not been the only reference to build up the modeling. These devices represent special solutions for which alternatives within the same technical scenario can be created. For example, it would be possible to calculate and differentiate the total consumption with and without breaker for technical scenario type B. Power consumption values were determined according to the same minimum functionalities, whenever possible, such as:

- Bi-directional, real-time communication
- Measurement and logging of active power values every 15 minutes (For a minimum of 60 days)
- Daily reading of the 96 load profile values per end-user.

A more differentiated interpretation of the scope of these functionalities, and the consequences when comparing the systems, will be discussed later.

**Representation of the processes at the telecommunications operator**

The contribution of the active power of the transmission network, for the connections using a data concentrator or a gateway to reach the households, is of minor importance on a per-metering point basis. The number of corresponding connections is considerably smaller than the amount of meters.

Estimations from a Capgemini study [Capgemini, 2010] were used for the data transmission types within the Austrian smart metering transmission networks. A similar distribution is assumed for Switzerland, as follows:

- 35% radio systems
- 27% GPRS
- 24% fibre optics
- 12% WiMax
- 2% DSL

For the representation of the technical scenarios only a GPRS type connection has been used between the data concentrator and the head-end system. For this type there is data available, and from experts´ opinion it builds a conservative scenario regarding power consumption.

### Power consumption at the operating facilities of the energy utilities

The power consumption values per metering point are considered to account for all activities at the operating sites of the energy utility, for all technical scenarios.

Unfortunately, no specific reference values could be obtained from the participating (and interviewed) energy utilities. The modeling would require a lot of effort when considering the large number of complex processes at energy utilities, and this was beyond the scope of this study. Table 15 provides an overview of such processes [Horváth et al., 2010].

Table 15: Terms and components of the IT infrastructure for smart metering systems at the utility site (adapted from Horvath et al., 2010).

| Meter operating system | Meter management | Meter data management |
|---|---|---|
| **System management and parametrization**<br>• Automatic configuration and registration of meters (parametrization)<br>• Monitoring, logging and reporting<br>**Configuration of business processes**<br>• Definition of process flow and workflows<br>• Provision of data from meters<br>• Dealing with alarms and special situations<br>• Firmware updates<br>• Monitoring of the processes and service levels<br>• Automatic requests<br>• Logging services for interfaces<br>• Evaluation and data mining functions | **Maintenance of devices**<br>• Meter analysis tools (overview about installation and certification)<br>• Fix and changing data management<br>• Synchronization and management of devices in the back-end<br>**Configuration and business processes and operating cases**<br>• Tariff models and functions<br>• Opening and closing of the breaker (cutting-off the meter)<br>• Monitoring and limiting the load<br>• Monitoring of communication processes | **Maintenance of data**<br>• Plausibility check for measured data<br>• Complementing data and class estimates<br>• Data provision according to their sequence<br>• Identification of billing data<br>**Analysis Tools for measured data**<br>• Logging and reporting for measurement functions<br>• Aggregation and reporting<br>• Data-Mining, business intelligence, and benchmarking<br>**Optional functions**<br>• Web services for visualization of measured data<br>• Multi-client capability<br>• Clusters of customer´s data<br>• Support for the billing functions |

A medium-sized energy utility was taken as reference for the project, and this manages four servers (for data communication, data processing, data storage and archiving). Furthermore, it is assumed that for the case of small energy companies, these outsource these tasks to external service providers.

An average, constant power consumption value for the servers of 150 W is assumed, taken from Encontrol [Encontrol, 2009]. However, the power consumption for cooling and for other operations of the general infrastructure of the data center are not included.

It is assumed that in Switzerland about 300 companies would operate servers for smart metering. For each company, on average 4 servers are assumed (Database, communication, and 2 backups). This means altogether 1200 servers in Switzerland, each of which can handle on average 4300 meters. Consequently, 17000 meters (an average of 4,300 meters per server) could be managed per utility site.

The same assumptions and conditions are considered for the Austrian scenarios, namely, a server (150 W) is required for every 4300 metering points. The active power of the servers is included in the technical scenarios as shown in Table 16) and will not be directly shown in the successive tables.

Table 16: Active power per metering point due to the IT processes at the head-end of the smart metering system (Estimates based on the input power of the operating servers).

| Technical component | Description (reference) | $\overline{P_{MP}}$ | Data type | Source |
|---|---|---|---|---|
| IT server | Derived from the total server power to which 4300 metering points are allocated. | 35 mW | X | Conservative estimate. |

The power consumption of the IT infrastructure strongly depends on which type data must be managed, the frequency (e.g., daily reading of total load profiles of all customers or daily reading of consumption of 2% of customers), and in what form the data must be processed (e.g., long-term data storage, data which needs to be immediately available in the database and which is continually accessed, and other calculations performed). From the communications in the project it can be said that, at this point, the influence of all these parameters on consumption of the IT infrastructure is not clearly understood.

### Technical components as modeled

On the following section all the technical components, which are used later in the rollout scenarios, are presented various tables.

*Note:* the entries for $\overline{P}$ (W) correspond to the characteristic average values of power consumption for the devices and the associated processes. When necessary, supplementary information is given in the tables of the technical scenarios.

## Technical components of the TSC in the Category A

*Narrow band PLC connection to a data concentrator*

Category A consists of solutions using the lines of the low voltage distribution grid for the data transmission. Special modems are used modulate a voltage signal in the range of about 3 to 10 V. The solutions on the market today used the channels in the CENELEC A band (3 to 95 kHz).

Table 17: Technical Components for *TSC A_1.*

**TSC A_1 – List of technical components**

Aggregated values are estimated for the devices of the data collection network of TSC A_1. These are based on data given in Table 7 for the states with inactive communication, login processes, and the transfer of load profile data.

| Technical component | Description (reference) | $\bar{P}$ (W) | Data type | Source |
|---|---|---|---|---|
| *One-phase meter* | Compact one-phase meter with breaker (SS02-SM-1ph) | 3.13 | R | Measurements carried out during the project (2011) |
| *Three-phase meter* | Compact three-phase meter with breaker (SS02-SM-3ph) | 4.68 | R | Measurements carried out during the project (2011) |
| *Data concentrator* | Data concentrator with power supply unit, to be installed in the transformer station. A corresponding modem is used for communi-cation with the head-end via GPRS (SS02-DC) | 11.56 | R | Measurements carried out during the project (2011) |
| *Data concentrator modem* | | 6.42 | R | Measurements carried out during the project (2011) |
| *Telecom-munication operator* | For the processes run at the operator, the same power consumption as for a GPRS meter module has been considered. | 0.50 | X | Conservative assumption based on expert´s opinion (2012) |

The technical component "*IT server"* has been included with the values shown in Table 16.

Table 18: Technical components for *TSC A_2.*

**TSC A_2 – List of technical components**

| |
|---|
| Average power values for the meters based on information from the manufacturers on their own measurements (Refer to Table 12) and from datasheets. |

| Technical component | Description (Reference) | $\bar{P}$ (W) | Data type | Source |
|---|---|---|---|---|
| *One-phase meter* | Modular one-phase meter with breaker<br>Assumption: 20% of duty cycle time for the communication module - for active communica-tion in normal operation<br>(SS05-SM-1ph) | 2.33 | I | Measurement by manufacturer (2012), and manufacturer´s datasheet (2009) |
| *Three-phase meter* | Modular three-phase meter with breaker<br>Assumption: 20% of duty cycle time for the communication module - for active communica-tion in normal operation<br>(SS05-SM-3ph) | 2.88 | I | Measurement by manufacturer, opinion from manufacturer (2012) |
| *Data concentrator* | Data concentrator including power supply unit with integrated modem, and<br>GPRS connection to head-end. | 7.00 | I | Manufacturer´s datasheet (2010) |

| |
|---|
| The technical component "*Telecom operator*" is included with the values as for *TSC A_1.*<br>The technical component "*IT server"* has been included with the values shown in Table 16. |

## Technical components of the TSC in the Category B

*Direct connection to the head-end-system with mobile phone technology*

Table 19: Technical components for *TSC B_1.*

### TSC B_1 - List of technical components

Referring to Figure 15, the power required by the metering point for the reading process corresponds to approximately 0.2% of the annual energy consumption of the three-phase smart meter, and therefore is considered as negligible.

| Technical component | Description (Reference) | $\bar{P}$ (W) | Data type | Source |
|---|---|---|---|---|
| *One-phase meter* | Modular one-phase meter without breaker, including GSM/GPRS module (SS01-SM-1ph) | 2.25 | R | Measurements carried out during the project (2011) |
| *Three-phase meter* | Modular three-phase meter without breaker, including GSM/GPRS module (SS01-SM-3ph) | 2.55 | R | Measurements carried out during the project (2011) |

The technical component "*Telecom operator*" is included with the values as for *TSC A_1.*
The technical component "*IT server"* has been included with the values shown in Table 16.

Table 20: Technical components for *TSC B_2.*

### TSC B_2 - List of technical components

The average active power of the communication module was included, based on the load data from specification sheets for $\boxed{\text{SS03}}$.

| Technical component | Description (Reference) | $\bar{P}$ (W) | Data type | Source |
|---|---|---|---|---|
| *One-phase meter* | Modular one-phase meter with breaker. | 0.80 | R | Measurements carried out during the project (2011) and manufacturer´s datasheet (2011) |
| *Three-phase meter* | Modular three-phase meter with breaker. | 1.35 | R | Measurements carried out during the project (2011) and manufacturer´s datasheet (2012) |
| *GSM/GPRS module* | Communication module for meter as described above. | 0.50 | I | Manufacturer´s datasheet (2009) |

The technical component "*Telecom operator*" is included with the values as for *TSC A_1.*
The technical component "*IT server"* has been included with the values shown in Table 16.

# C Technical components of the TSC in the Category C

*Radio connection to the data concentrator*

Table 21: Technical components for *TSC C_1.*

**TSC C_1 – List of technical components**

The time effort for radio transmission processes running in the data concentrator module of the meter are multiplied by the number of meters served. An average value (conservative assumption) is estimated from the data presented in Table 5. Average values correspond to half of the peak value, with an influence of less than 1% to the basic consumption (i.e., inactive communication).

| Technical component | Description (Reference) | $\bar{P}$ (W) | Data type | Source |
|---|---|---|---|---|
| *One-phase meter* | Compact one-phase meter with breaker, slot for auxiliary module (SS03-SM-1ph) | 0.90 | R | Measurements carried out during the project (2011) |
| *Three-phase meter* | Compact three-phase meter with breaker, slot for auxiliary module (SS03-SM-3ph) | 1.41 | R | Measurements carried out during the project (2011) |
| *Data concentrator (Meter module)* | Compact three-phase meter with module enabling data concentration and communication via GSM (SS03-DC-MM) | 2.30 | R | Measurements carried out in the project (2011) |

The technical component "*Telecom operator*" is included with the values as for *TSC A_1.*
The technical component "*IT server"* has been included with the values shown in Table 16.

## Technical components of the TSC in the Category D

*M-Bus-connection to Gateway*

Table 22: Technical components for *TSC D_1.*

### TSC D_1 – List of the technical components

This is meter model EDL21, specifically designed for a wireless M-Bus connection with a integrated interface.

| Technical component | Description (Reference) | $\bar{P}$ (W) | Data type | Source |
|---|---|---|---|---|
| *Three-phase meter, one-phase connection* | Compact three-phase meter with integrated M-Bus communication module (SS04-SM-3ph) | 1.36 | I | Measured by energy utility (2011) |
| *Three-phase meter, three-phase connection* | Compact three-phase meter with integrated M-Bus communication module (SS04-SM-3ph) | 3.09 | I | Measured by energy utility (2011) |
| *Gateway* | Gateway, reads out metering points connected via wireless M-Bus and sends them aggregated every quarter of an hour to the head-end sys-tem via GPRS (push mode). | 2.50 | I | Manufacturer´s datasheet (2011) |

The technical component "*Telecom operator*" is included with the values as for *TSC A_1.*
The technical component "*IT server"* has been included with the values shown in Table 16.

Table 23: Technical components for *TSC D_2.*

### TSC D_2 – List of technical components

This is a modular electronic meter supplemented by a wireless M-Bus module. In the absence of manufacturer´s data for the specific module, robust data of the product performance for the case MUC -1 has been included.

| Technical component | Description (Reference) | $\bar{P}$ (W) | Data type | Source |
|---|---|---|---|---|
| *One-phase meter* | One-phase modular meter with breaker. | 0.80 | I | Measurements carried out during the project (2011) and manufac-turer´s datasheet (2011) |
| *Three-phase meter* | Three-phase modular meter with breaker. | 1.35 | I | Measurements carried out during the project (2011) and manufac-turer´s datasheet (2012) |

The technical components *Gateway* and *Telecom operator* have been included with values from *TSC D_1, the wireless M-Bus module* from *case MUC-1*.
The technical component "*IT server"* has been included with the values shown in Table 16.

### 3.8.2 Variations of technical scenarios

Modifications to the technical scenarios described above allow the investigation of the following variations:

Table 24: Technical components for the case MUC-1.

**TSC variation MUC-1 – List of technical components**

In the MUC-1 case, the electricity meter communicates with the head-end system and collects data from additional utility measuring devices (e.g., for gas, heat, and/or water). When the meter lacks a wireless interface, there is in some cases the possibility to use meter-specific modules.

| Technical component | Description (Reference) | $\bar{P}$ (W) | Data type | Source |
|---|---|---|---|---|
| *Wireless M-Bus module* | Manufacturer specific wireless M-Bus meter module (M-Bus) | 0.13 | R | Measurements carried out during the project (2011) |

Table 25: Technical components for the case MUC-2.

**TSC variation MUC-2 – List of technical components**

In the case MUC-2, a standalone device (MUC) collects the data from all consumption measuring facilities and sends it to the HES.

| Technical component | Description (Reference) | $\bar{P}$ (W) | Data type | Source |
|---|---|---|---|---|
| *MUC* | The MUC reads out via wireless M-Bus (or via other interface) the data of the connected metering points and transmits the aggregated data every quarter of an hour via GPRS to the HES, or via PLC to the data concentrator. | 2.50 | I | Manufacturer´s datasheet (2010) |
| *MUC-DC* | Data concentrator with PLC connection to the MUC. | 5.00 | I | Manufacturer´s datasheet (2010) |

An additional possibility includes components which allow a connection between the meter and the MUC through a CS interface (Current-loop).
It is assumed, that the meters are modern electronic meters (without communication modules).

| | | | | |
|---|---|---|---|---|
| *MUC (CS)* | MUC gateway, which allows the readout of meters connected through the CS interface and sends the data in aggregated form to the HES via an IP network. | 3.00 | X | Manufacturer´s information (Press release for the introduction of the product to the market, 2010) |

The MUC (CS) could be connected to an IP network. It is assumed that this CS interface already exists before the smart metering deployment, and can be used in together with other configurations (It is not accounted for separately).

**Power consumption of the upgraded electronic meter for reading the CS interface according to case MUC-2**

When the installed meters are read-out through the CS interface, the following data (derived from values in Table 10 for “Electronic meters”) are used.

Table 26: Active power for a metering point for a state-of-the-art electronic meter.

| Technical component | Description (Reference) | $\overline{P_{MP}}$ | Data type | Source |
|---|---|---|---|---|
| *Three-phase meter, one-phase connection* | Compact electronic three-phase meter with CS interface.<br>Input power estimated on the basis of the performance of comparable products under this connection type. | 0.70 | X | Conservative assumption (2012) |
| *Three-phase meter, three-phase connection* | Compact electronic three-phase meter with CS interface. | 1.50 | I | Manufacturer´s datasheet (2010) |

# 4 Results

The results summarized in this section refer primarily to the meter products and comprise those findings directly obtained from the application of the methodology developed in this project, and indirect findings from consultation with experts and literature review. Other system-wide active input power (i.e., in the data transmission network and at the site of the energy utility) are considered within technical scenarios, under Chapter 5.

## 4.1 Comparison of electricity meters

Table 27 provides a comparison of the average characteristic active input power of electricity meter (status quo) and the smart meter (in the case of modular meters, the basic meter with the communication module).

Table 27: Comparison of analyzed electricity meters

| **Category (connection type)** | **Status quo (*)** *No remote readout* | | |
|---|---|---|---|
| **Technical scenario** | **Ferraris meter** | | **Electronic MFM** |
| **Number of phases of meter** | **1ph** | **3ph** | **3ph** |
| **Characteristic input power** | **1.43 W** Table 13 | **3.92 W** Table 13 | **4.41 W** Table 13 |

| **Category (connection type)** | **A (*)** *Narrow band PLC connection to data concentrator* | | | | **B (*)** *Direct connection to head-end system through mobile phone technology* | | | |
|---|---|---|---|---|---|---|---|---|
| **Technical scenario** | **A_1** | | **A_2** | | **B_1** | | **B_2** | |
| **Number of phases of meter** | **1ph** | **3ph** | **1ph** | **3ph** | **1ph** | **3ph** | **1ph** | **3ph** |
| **Characteristic input power** | **3.13 W** Table 17 | **4.68 W** Table 17 | **2.33 W** Table 18 | **2.88 W** Table 18 | **2.25 W** Table 19 | **2.55 W** Table 19 | **1.30 W** Table 20 | **1.85 W** Table 20 |

*Table continues on next page.*

**(*)** The description of the technical components and the classification of smart meter connections are included in Section 3.8.2 (See also the reference table for the values of the characteristic input power).

| Category (connection type) | C (*) *Radio transmission to data concentrator* | | D (*) *M-Bus connection to gateway* | | | |
|---|---|---|---|---|---|---|
| Technical scenario | C_1 | | D_1 | | D_2 | |
| Number of phases of meter | 1ph | 3ph | 1ph | 3ph | 1ph | 3ph |
| Characteristic input power | **0.90 W** Table 21 | **1.41 W** Table 21 | **1.36 W** Table 22 | **3.09 W** Table 22 | **0.80 W** Table 23 | **1.35 W** Table 23 |

**(*)** A description of the technical components and a categorization of the connection types of smart meters are presented in section 3.8.2 (See also the table references for the values of the characteristic power consumption).

## 4.2 Allocation of energy consumption to the product features of the smart meter

Unlike Ferraris meters, smart meters perform several functions. The aspects directly related to the fulfilment of these basic functions ("measure", "login", "submit") are described in this section, as well as "Additional functions".

### Number of phases

According to available data, the ration between the consumption of the three-phase Ferraris and the single-phase meter is 2.74 (approximately 3). Review from datasheets also confirmed that this factor three is typical, as the electro-mechanical assembly is essentially the same for each phase. The metering/display assembly is driven by a joint shaft.

Electronic meters work differently, as the semiconductor ICs and other electronic components (e.g., display) need energy. These associated power consumption for one-phase or three-phase meters is partly the same. This is also the case for the consumption related to the modem – except for PLC solutions where the voltage signals are modulated for all phases. Moreover, manufactures use different power supply technologies for one-phase or three-phase meters. There could be a case where the three-phase version of a meter model has an optimized switching power supply, while the single-phase version uses a simple bleeder with lower efficiency.

The ratio between the consumption of a three-phase meter to the one of the corresponding single-phase version of the same product line depends on diverse design details. For the meters from specific product lines investigated within the project, the following ratios were obtained:

1.50; 1.24; 1.13; 1.69; 1.57; 2.27; 1.69

There is a factor two between the smallest and the largest ratios. For the extrapolation of the total consumption for a region, it is therefore useful to distinguish between single-phase and three-phase metering points, especially if there is an important share of single-phase meters installed in a region.

### Connection type and communication system

Based on the distinction between the different forms for data transmissions (Categories A, B and C), it was found that the PLC solution (under category A) is the most energy intensive. It is not possible to generalize this statement. However, for modular meters, where measured data is available on the operation with the different communication modules (PLC and GPRS), this statement is appropriate. In this case, the three-phase meter in PLC operation consumed 13% more energy than with the GPRS-module.
Comparative measurements on a larger number of products would be necessary to find out a percentage rate indicating the ratio between the average consumption values of the different classes (e.g., category A versus category B).

According to the assertion of several manufacturers, the own energy consumption of PLC systems also depends on the nature of the system implementation. Unlike for GPRS modules, the development of PLC modems or the entire communication systems is still ongoing, the migration to other open standardized systems may be coming. This has mainly been driven by the European research project “OPEN meter[2]” which aims to create interoperable systems.
PLC systems were initially very popular due to a favourable business case, as these allow the read-out in the data collection network without external infrastructure. (The meter reading via mobile technology would make energy utilities depend on telecommunications providers).
The use of power lines, originally not designed as signal transmitting lines, requires highly complex transmission mechanisms and corrective actions. When transmitting within the currently, most commonly used CENELEC A band (3 to 95 kHz) several sub-frequencies can be used, which allow for different baud rates. How much the individual areas are affected by disruptions, and how large the impedances are within the network area have ultimately an effect on the band which can be used for active transmission. These factors are subject to constant fluctuations.

According to several experts, in the coming years the network impedance will decline due to the increasing use of switching power supplies in electrical equipment, and also due to the use of inverters. This will make the transfer within the CENELEC A band considerably more difficult. Standardization bodies, therefore, not only aim at developing open standards but also at building more robust transmission procedures.
The so-called OFDM method would bring significant improvements, but may require more processing power for the signal processing (performing frequency transformations would be necessary all the time). If data transmission with a lower effort for retransmissions, frequency hoppings and repeatings were possible, it still would be of interest. Another option would be displacement to a different frequency range, from 150 to 500 kHz, this is not currently regulated in Europe however. The OFDM prime and G3 process are prepared for this case.

Even radio systems have to deal with different transmission conditions, e.g., weather conditions (humidity), but also with interferences or shielding by objects along the transmission path.

Both PLC and radio systems usually use network lists stored at the data concentrator, with different intervals for updating. According to a manufacturer, initializing these lists takes place only at the start-up of the sub-net operations. The best connection paths, determined from signal strength of the incoming signals, are stored and linked to according to specific priority. Thus, the data concentrator “knows” along which connection paths (nodes acting as repeaters) each meter could be reached. Depending on the quality of the connection, the signal from a metering point goes over one or more repeatings. A certain maximum number of repeatings are defined (This is called credit level or hop level by manufacturers), to set a limit for the transferring time.

[2] www.openmeter.com

When the setting of the transfer is constantly changing due to these choices, there is a constant overhead of continuous input power to maintain the “availability” of a single meter. This explains why the power consumption of PLC meters differs only by a small difference between inactive communication (Permanent completion of “keep alive” functions, or only “handshakes” between reporting points), and active transfer.

During the laboratory measurements at IFEA, there were no changes in the input power possibly originating from the communication of commands. In the case of the PLC solution, the very short distance between the data concentrator and the meter of less than one meter might have played a certain role. Furthermore, the high loop impedance provided particularly favourable conditions for the transmission.

Industry experts had the following remarks regarding own consumption of meters, referring also to the measurements under laboratory conditions:

– “...The configuration of the end-devices involved in communication is usually set up by the network operators based on more conventional criteria, such as an increased availability of meters, and as a result, better security of the supply.”

– “...Large scale communication networks behave differently than the small scale networks used in most pilot projects. This is partly due to the growing requirements in for many implementation cases (Interferences within wireless transmission, disruptions, or network impedances for PLC communication), and, due to the need for monitoring more frequently, use more intensively the repeating functions, and increase the transmission power.”

– “...In some transmission networks the repeater functions are fixed components, so that the accessibility to all meters (or a minimum percentage of these) in the WAN is given. Under laboratory conditions the replication of these real situations is quite difficult, and even if it was possible, it can only be partially accomplished.”

– “...The number of meters per repeater, and the possibly needed additional equipment, which is not included in the sample (pilot) networks is different depending on specific use cases.”

**Measurement principle**

As in the case of the classical Ferraris meters, in any type of electronic meter there are separate systems for measuring voltage and current. Their combination supports the detection and recording of electrical power values, enabling the calculation (integration over time) of the energy consumption values.

– A bleeder was used in all the solutions investigated as the means for measuring voltage (The phase voltage is scaled to a very small value, which can be digitized by the use of an AD converter).

– Different principles apply in the measurement of the current. Under considerations of low-cost implementation and sensitivity to magnetic interference fields, shunt resistors are the most popular in use. These have a specific resistance, which creates a proportional voltage difference under the current flow. This difference is measured and converted to digital form. Other options include hall sensors, Rogowski coils, and mutual conductance transformers.

During the project it was not possible to allocate characteristic own energy consumption values to the specific measuring principles. This would primarily depend on which input circuits are used for signal processing, the extent in which these are integrated into semiconductor solutions, and the frequency of data acquisition.

### Integration of single functions

As indicated in the previous section, the own energy consumption of the smart meter is highly dependent on the level of integration of individual product features. Factors with relevance include the presence (or not) of separate power supply units for the measuring component of the device and the communication component, or if the meter has a modular or a compact design.

The choice of chips (e.g., for performing intensive signal processing within the communication component) may also play a major role in consumption. Ultimately, the design of all individual functions, even simple ones such as magnetic field detection, or recognition of the opening of the terminal cover; has an influence on the total energy consumption of the device.

### Breaker (Cut-off device – Additional function)

The breaker is not strictly speaking a smart metering feature. The breaker does not perform electricity consumption measurements, but it is used by the energy utilities to perform billing operations remotely. The cut-off device comprises relays for each phase of the meter, which can interrupt and restore the energy supply. The influence on the own energy consumption of the meter occurs in two ways:

1. By voltage drops from resistances in series at the switching contact.
2. By the need for continuous energy for keeping the relay in a particular state, switch condition.

Referring to the first point above, the datasheet of a specific manufacturer listed information for the breaker, for example, the power dissipation that occurs at maximum current flow. The specifications are included below:

- Maximum current flow per phase, $I_{max}$.....100 A
- Power dissipation $P_V$ per phase at $I_{max}$ ........5.5 W

Contact resistances values of 550 µOhm result from the reference values above. At 5 A a low power dissipation of 13.75 mW occurs. On average, the power losses are quite small and only relevant during peak periods.

Referring to the second point above, manufacturers might use bi-stable relays, which do not require continuous energy input because the breaker stays in the correct position for both switching states without any assistance. The breaker would require a very low amount of energy only for the switching process itself. For specific design solutions, the remote monitoring of the relay´s state also requires a rather small amount of power.

### Power quality features (Additional function)

The standard EN 50160 "Voltage Characteristics of Electricity Supplied by Public Networks" [EN 50160, 2010] aims at defining and establishing the characteristics of voltage with respect to frequency, magnitude, wave shape, and symmetry of the line voltages.

Network operators have to comply with quality criteria within defined boundaries. This also applies to the low voltage distribution grid; therefore, some smart meters provide functions to enhance the possibilities for the assessment of power quality. However, there is no smart meter solution on the market able to monitor accurately all of the relevant parameters. The limiting factor here is mainly the evaluation of the total harmonic distortion. Measuring the voltage to detect the highest harmonic order (25th order) requires at least double the sampling frequency. The implementation of the Fourier analysis at the metering point requires intensive computations and is rather energy intensive. Consequently, most meter manufacturers offer power quality analysis only up to a lower order, or, alternatively simplify this to the identification of simple voltage quality parameters such as peaks and sinks.

## 4.3 Sensitivity analysis of the smart meter's own energy consumption

The series of measurements as described in Section 3.5.2 helped understanding the sensitivity of physical parameters of the network and of the load side (without communication load) on the consumption of the smart meter. The analysis follows:

**Influence of the load current**

The consumption as a function of different load currents varied only marginally. Apparently, the current path of the meter has ohmic series resistances. Power loss is a quadratic function, as seen in the results in Figure 14. At 16A, the highest additional measured consumption of a three-phase meter was +0.43 W compared to the off-load state.

**Influence of the supply voltage**

The meter consumption changes according to different line voltages varying from -0.3 W (at 210 V) to +0.2 W (at 250 V). Assuming an equally distributed variation around the set point of 230 V, this effect is negligible for the purpose of the extrapolations.

**Influence of the total harmonic distortion within the voltage signal**

The variation of the total harmonic factor of the supply voltage (THD) for the four scenarios under consideration showed an increased consumption of maximum + 0.3 W. This value occurs at THD 4 while the proportion of the third order was 4.2%, already close to the authorized limit of 5.0% given in EN 50160.

**Influence of the power factor of the load**

The power factor had no significant effect on the own consumption of the meters. As the limit of accuracy in the measurements is reached, the influence of the power factor can be neglected altogether.

**Influence of temperature**

The laboratory measurements showed that it takes a meter about 20 minutes for its own consumption to reach a stable value (Input power varies significantly during this "warming up" time). This is not relevant anymore for meter measurements under stationary conditions.

**Summary**

The completed measurement series at three different meters showed that the influence of the line voltage, the harmonic distortion, and the power factor is very low on the own consumption of the meter. Therefore, the analysed physical parameters have negligible or only minor contribution on the estimates of total consumption for the typical solutions of meters considered as suitable for implementation in Switzerland and Austria.

Apart from periods of active data transmission, the additional contributions due to performing of commands and switching operations are very small. These influences are negligible for the extrapolation. This would be an ideal case where the meter has a rather constant input power throughout the year, and this input power is changing when there are periods of active data transfer (To be taken into account, at least for the case of PLC transmission).

# 5 Development of consumption scenarios

The methodology (as described in Section 3.4.3) and the available power consumption values structure the consumption models, according to the following two steps:

– Creating the *technical scenarios:* these contain the main characteristics and description of the data collection and transmission networks. Other differences arise through the devices considered for the network nodes, the organization of the data collection network, and the modes of transmission.

– Creating the *rollout scenarios*: these are combinations of technical scenarios and, where applicable, include additional considerations for the region(s) and network topology (e.g., number and distribution of the one-phase and three-phase metering points), and any references to concrete regional or national policies.

The resulting technical scenarios from this modelling approach are not suitable to describe all possible cases, but are flexible and applicable to various national rollout scenarios, so that the same basis for the calculations is set for Austria and Switzerland.
Using the effective power uptake per metering point it is possible to calculate the annual energy consumption for the specific rollout scenarios. The reference to a "metering point" allows for easier understanding, further adaptations of the data, and reduces the risk of errors in the calculations.

## 5.1 Creating the technical scenarios

Table 28 to Table 32 show the active input power per metering point and for the system as a whole.

The names of the scenarios (e.g., "C_1 – 60MP") are set up as follows:

A/B/C/ … Category distinguishing the connection type within the data collection network (see section 3.8.2).

1/2/3/ … Manufacturer´s specific solutions investigated during the project

XXMP … Distinction of additional considerations, for example regarding the number of metering points (MP) allocated to one data concentrator.

The system-wide active input power $\overline{P_{MP}}$ (W) of a technical scenario comprises the active input power values of the technical components that belong to this scenario (calculated per metering point - MP). This part of the modelling process corresponds to the transition from Level 2 to Level 3 of the "Layer scheme" in Figure 7.
In some cases, for example in the case of a data concentrator, only a small portion of the energy consumption of that device corresponds to the (single) metering point. For all the coming tables the column "assumptions" indicates the particular remarks valid for each case.

## Technical Scenario A

*Narrowband PLC connection to a data concentrator*

Table 28: Metering point active input power values for the TSC of the Category A connection.

| Scenario | Assumptions | Metering point type | $\overline{P_{MP}}$ (W) |
|---|---|---|---|
| **A_1 – 200MP** | 200 metering points per data concentrator | One-phase | 3.26 |
| | | Three-phase | 4.81 |
| **A_1 – 100MP** | 100 metering points per data concentrator | One-phase | 3.35 |
| | | Three-phase | 4.90 |
| **A_1 – 35MP** | 35 metering points per data concentrator | One-phase | 3.69 |
| | | Three-phase | 5.24 |
| **A_2 – 200MP** | 200 metering points per data concentrator | One-phase | 2.40 |
| | | Three-phase | 2.95 |
| **A_2 – 100MP** | 100 metering points per data concentrator | One-phase | 2.44 |
| | | Three-phase | 2.99 |
| **A_2 – 35MP** | 35 metering points per data concentrator | One-phase | 2.58 |
| | | Three-phase | 3.13 |

## Technical Scenario B

*Direct connection to the head-end system with mobile technology*

Table 29: Metering point active input power values for the TSC of the Category B connection.

| Scenario | Assumptions | Metering point type | $\overline{P_{MP}}$ (W) |
|---|---|---|---|
| **B_1** | For every connection at the operator the same power consumption as for a GPRS meter module occurs - conservative assumption. | One-phase | 2.78 |
| | | Three-phase | 3.08 |
| **B_2** | For every connection at the operator the same power consumption as for a GPRS meter module occurs - conservative assumption. | One-phase | 1.83 |
| | | Three-phase | 2.38 |

## C Technical Scenario C

*Radio transmission to a data concentrator*

Table 30: Metering point active input power values for the TSC of the Category C connection.

| Scenario | Assumptions | Metering point type | $\overline{P_{MP}}$ (W) |
|---|---|---|---|
| **C_1 – 60MP** | 60 metering points per data concentrator | One-phase | 0.96 |
| | | Three-phase | 1.47 |
| **C_1 – 200MP** | 200 metering points per data concentrator | One-phase | 0.94 |
| | | Three-phase | 1.45 |

## D Technical Scenario D

*M-Bus connection to a gateway*

Table 31: Metering point active input power values for the TSC of the Category D connection.

| Scenario | Assumptions | Metering point type | $\overline{P_{MP}}$ (W) |
|---|---|---|---|
| **D_1 – 5MP** | 5 metering points per gateway | One-phase | 1.99 |
| | | Three-phase | 3.72 |
| **D_1 – 18MP** | 18 metering points per gateway | One-phase | 1.56 |
| | | Three-phase | 3.29 |
| **D_1 – 30MP** | 30 metering points per gateway | One-phase | 1.49 |
| | | Three-phase | 3.22 |
| **D_2 – 5MP** | 5 metering points per gateway | One-phase | 1.43 |
| | | Three-phase | 1.98 |
| **D_2 – 18MP** | 18 metering points per gateway | One-phase | 1.00 |
| | | Three-phase | 1.55 |
| **D_2 – 30MP** | 30 metering points per gateway | One-phase | 0.93 |
| | | Three-phase | 1.48 |

### Other variations for the technical scenarios

Table 32: Metering point active input power values for the cases of MUC solutions.

| TSC Variation | Description/distinction of cases | Metering point type | $\overline{P_{MP}}$ (W) |
|---|---|---|---|
| **MUC-1** | Additional input power for the M-Bus module (for a modular meter not equipped with M-Bus from the factory).<br>No contribution is considered for any other case. | Smart meter with an additional wireless M-Bus module | + 0.13 |
| **MUC-2** | Additional input power for a MUC | Smart meter already featuring the wireless M-Bus | + 2.50 |
| | Additional input power for a MUC and an additional wireless meter M-Bus module | Modular smart meter suitable for M-Bus | + 2.63 |
| | Additional input power of the MUC type data concentrator, 200 MP per data concentrator, and PLC connection with the MUC. | PLC version of MUC installed at metering point | + 0.03 |
| | Additional input power of the MUC, reading out through the CS interface.<br>This applies to electronic meters already installed, or to new electronic meters (See Table 25) only. | Electronic meter with a CS interface | + 3,00 |

Other battery driven utility metering devices, with wireless M-Bus interfaces, are not included in the assessment of these MUC cases above.

## 5.2 Calculation of the total energy consumption for the rollout scenarios of Switzerland

In the case of Switzerland, project partner ENCONTROL AG was responsible for developing rollout scenario and extrapolating the total consumption. At the request of the commissioners of the study, the scenarios of interest only involve the infrastructure that fulfils the basic smart metering functions, and is located in the non-metered area. Feedback systems and home monitoring solutions are not included in the calculations.

The authors prepared the extrapolations by referring to the technical components included. Hereby these refer also to tables under section 3.8.2.

### 5.2.1 Meter stock in Switzerland

For the purposes of modelling, the metering points have the following distribution: each household has a meter, and all multi-family houses, as well as partially residential use buildings, are equipped with an additional meter for general consumption. In addition, all companies are metered separately. These assumptions are not completely accurate, because many small companies might be included in existing households. According to information from the Federal Office of Statistics, there is no statistical data at the national level on the general consumption of buildings used solely for commercial purpose.

The source of the values for buildings and apartments, shown in Table 33, is the interactive online database of the Federal Office of Statistic [BFS1, 2010]. The data review included the following sources of information:

- Number of apartment by canton, number of rooms, building category and construction period; for 2009 and 2010.
- Buildings by canton, building category and construction period, number of floors and number of apartments per floor; for 2009 and 2010.

The commercial figures are taken from the interactive online database of the Federal Office of Statistics [BFS2, 2008], and from the report "Census of commercial facilities by canton and business sector" [NOGA 2008, sectors 1-3].

The number of households, multi-family homes, partial residential use buildings, and the commercial buildings (Companies) allow for the calculation of a total number of meters, adding up to 5.226 million meters. The number of single-family houses is not included in this total as it is already part of the calculated total of households. However, this information is of relevance when referring to energy consumption.

Table 33: Number of households, single family houses, partly residential and commercial buildings in Switzerland.

| Category | Number |
|---|---|
| Households (Apartments and homes) | 4,079,000 |
| Single family houses | 945,000 |
| Multi-family houses and partly residential buildings | 697,000 |
| Commercial buildings (Companies) | 450,000 |

*Note to Table 33:*
The validation of previous calculation included a comparison of data from specific regions (i.e., city of Zurich, city of Thun, and the municipality of Gossau in the Canton Zurich) with the real number of meters provided by electricity utilities. The deviation in this case is +/-5 %.
The value of 5.2 million meters as of 2010 closely matches the information from the Federal Office of Metrology (METAS) in Switzerland. METAS registered about 5,038,000 operating electricity meters as of 2009 [METAS, 2010]. The deviation in this case is -3%.

Five million metering points is the total reported in the study „Folgeabschätzung einer Einführung von Smart Metering im Zusammenhang mit Smart Grids in der Schweiz"[3]. Together with the stock of installed meters [BFE1, 2012], a new distribution in previous categories is included in Table 34.
These values are the basis for all calculations of the Swiss rollout scenarios. The number of metering points in family houses is included in the number of households, therefore not added in the 5.0 millions. The overall consumptions of the entire building would be accounted for in the case of the 670,000 metering points corresponding to multi-family homes and partly residential buildings.

Table 34: Number of metering points in households, buildings and companies as basis for extrapolations (in line with the Impact Assessment, [BFE1, 2012])

| Metering point type | Number |
|---|---|
| Households (Apartments and homes) | 4,000,000 |
| *Single family houses (Included under households)* | *930,000* |
| Multi-family houses and partly residential buildings | 670,000 |
| Commercial buildings (Companies) | 330,000 |
| **Number of metering points** | **5,000,000** |

### 5.2.2 Extrapolation for the status quo

#### Configuration

The extrapolations for the current situation include the following assumptions:

- Meters have no remote readouts via electronic systems (Currently only customers with a purchased electricity volume larger than 100,000 kWh per year benefit from remote readouts. This number of clients is negligible when compared to the whole stock of meters).
- The proportion of households with Ferraris meters is about 60% (According to information from energy utilities experts).
- The results correspond to calculations with only three-phase meters. The proportion of one-phase meters is less than 1% (Information from interviews with network operators).
- Commercial buildings (Companies) only use electronic multifunctional meters.

[3] This is an impact assessment study of the introduction of smart metering in Switzerland, conducted by the Swiss Federal Office for Energy. „Impact Assessment" for short.

### Own consumption of the meters

The input power of a Ferraris meter is 3.92 W constantly, and 4.41 W for a conventional electronic meter, as shown in Table 13. Considering the 60% share of Ferraris meters in the meter stock (as discussed before), the resulting average power demand corresponds to 4.12 W per household.

### Extrapolation

The calculation of the power consumption for one year follows:

*Energy consumption per year (kWh) = average power (W) x operating hours (h) / 1,000*

The resulting annual electricity consumption per metering point is:

4.12 W x 8760 h / 1,000 = 36.1 kWh

The extrapolation for the entire meter stock of 5.0 million metering points adds up to a value of **180.3 GWh per year** (Table 35). This is equivalent to approximately the annual electricity consumption of the city of Thun with 43,000 inhabitants.

Table 35: Own energy consumption of the electricity meters in Switzerland at status quo (in GWh/y)

| Metering point type | Number of electricity metering points | Consumption of the electricity meters (GWh/y) |
|---|---|---|
| Households | 4,000,000 | 144.2 |
| General consumption of multi-family houses and partly residential buildings | 670,000 | 24.2 |
| Companies | 330,000 | 11.9 |
| **Total** | **5,000,000** | **180.3** |

*Note to Table 35:*
The “households” comprise single-family homes, multi-family homes, and partly residential buildings accounting for 4.0 million metering points. Metering points that measure the general consumption in multi-family homes and partly residential buildings are included. For commercial use (small and medium enterprises), further 330,000 metering points are estimated. In total, this corresponds to 5.0 million metering points.

### 5.2.3 Rollout scenario CH-1: Smart meter with PLC connection

#### Configuration

The smart meter connects to the data collection network via power line communication (PLC) for this scenario. The communication module is in the meter itself, or physically attached to the device (Figure 29).

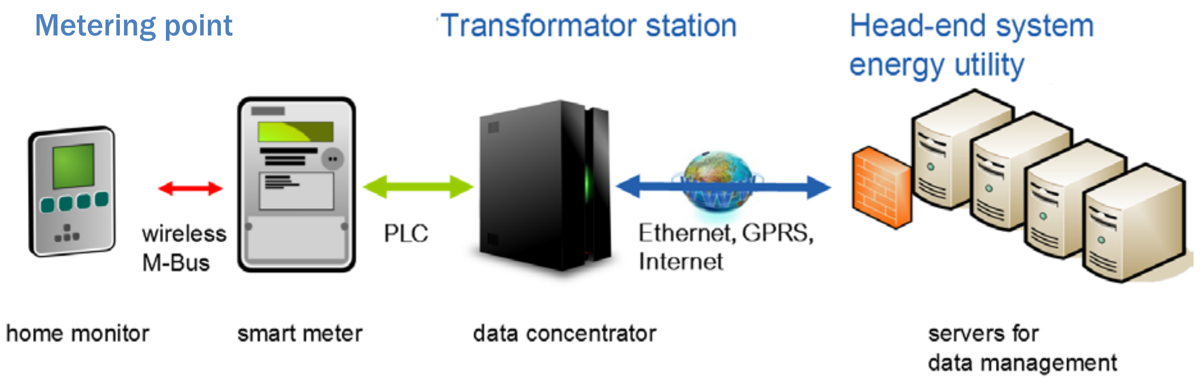


Figure 29: System overview for rollout scenario CH-1.

There are on average 200 meters connected to a data concentrator, assumed according to information from existing pilot projects in Switzerland. Therefore, the corresponding technical scenarios (TSC) refer to 200 metering points per concentrator.

#### Smart meter with communication module

The scenarios considered the metering of electricity only and no other metering for consumption on other utility services such as gas, water, or heat.

Only modern smart meters are in use, for which the average power consumption (Including the communication module), is below 3.0 W. For the solution TSC A_2 (Table 18) the power consumption of the communication feature is approximately 2/3 of the total consumption of the three-phase meter (2.88 W compared to 1.00 W without the communication module).

#### Data communication and server

The data concentrator transfers data to the server with an Ethernet or GPRS connection, and the internet. The resulting energy consumption for this connection at the operator´s side is comparable to the needs of the GPRS connection included in technical scenario *TSC A_1* (Table 17). Section 3.8.2 includes the description and estimates for the operation of the head-end server. The resulting average power consumption per metering point is 37.4 mW.

#### Extrapolation

The annual consumption values for Switzerland result from applying the formula presented in Section 5.2.2 with the above data.

| |
|---|
| Taking as reference the technical scenario TSC A_2 - 200MP, the total annual energy consumption is **129 GWh/year** (See Table 36). |

When referring to technical scenario TSC A_1 – 200MP the total energy consumption would be 211 GWh per year.

Swiss energy utility expert´s provided information on their ongoing, area-wide pilot project, for which a value of 2.88 W for the power consumption of the meter, including the communication module, is reasonable. This explains the lower consumption value in TSC A_2.

Table 36: Annual energy consumption for smart metering systems in Switzerland (in GWh/y), according to rollout scenario CH-1 (Based on TSC A_2-200MP).

| Metering point type | Number of metering points | Consumption of electricity meters (GWh/y) | Consump-tion of DCs (GWh/y) | Consumption of Telecom and IT (GWh/y) |
|---|---|---|---|---|
| Households | 4,000,000 | 100.9 | 1.2 | 1.3 |
| Multi-family houses and partly residential buildings | 670,000 | 16.9 | 0.2 | 0.2 |
| Commercial buildings (Companies) | 330,000 | 8.3 | 0.1 | 0.1 |
| **Total** | **5,000,000** | **126.1** | **1.5** | **1.6** |

Note to Table 36*:*
The classification of the metering points fits the same distribution as in Table 35. For each type the same calculations have been done, as always the same smart meter and the same contribution from the data concentrator per metering point is included (Table 18). This also applies to the consumption values of Telecom and IT (see Table 16 and Table 17), which report the energy consumption at the telecommunication operator and at the headquarters of the energy utility.

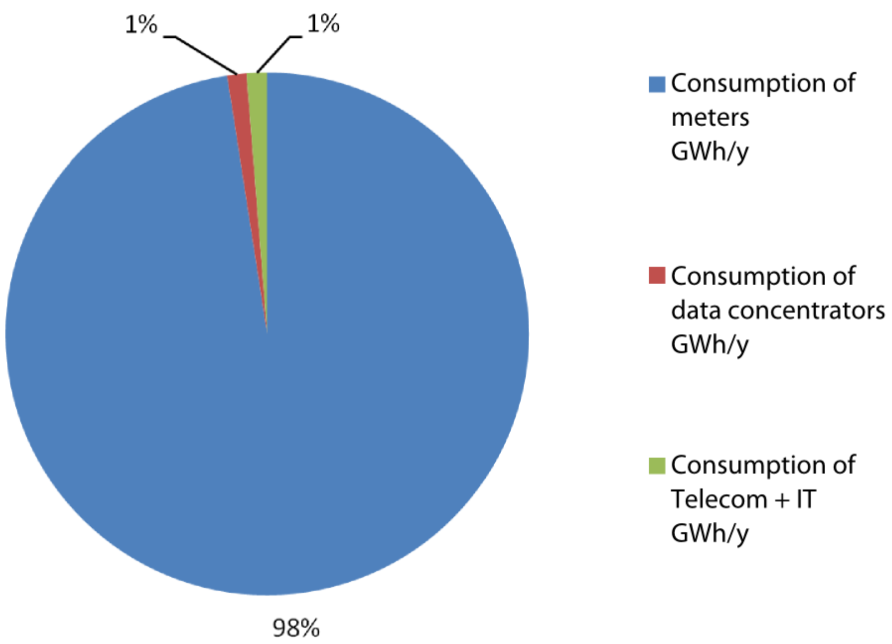


Figure 30: Own energy consumption for rollout scenario CH-1.

### 5.2.4 Rollout scenario CH-2: Smart meter and MUC

#### Configuration

For this scenario, an additional device works as a gateway and is responsible for communicating the data from the meter to the central server. The multi-utility controller, namely the device collecting consumption data from different services from a location and transmitting it to another specific location (known as MUC or MUC-C), serves several meters at one place. Each building has an additional MUC (see Figure 31). The number of single-family houses and multi-family houses builds up the number of buildings (see Table 33). Commercial buildings do not have installed MUCs.

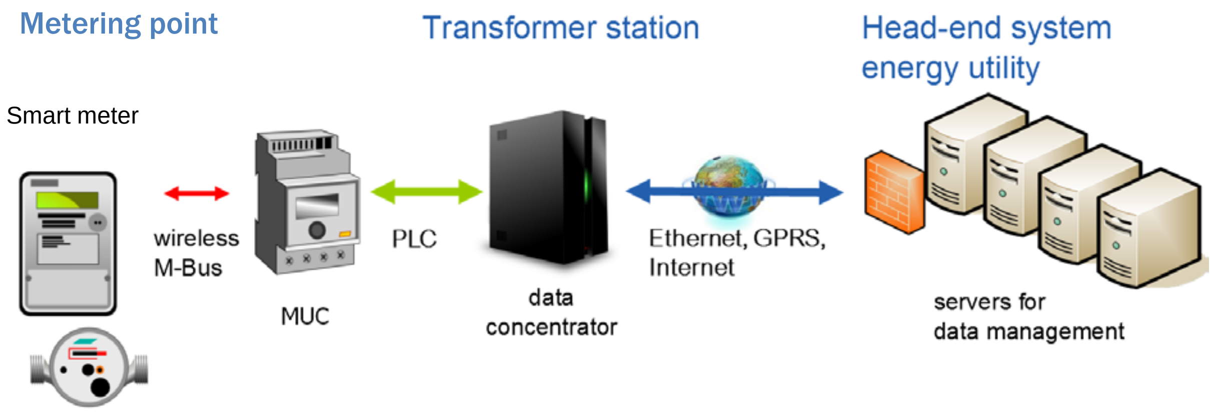


Figure 31: System overview for rollout scenario CH-2.

Replacement of the existing electricity meters is not included in this scenario because the assumption is that M-Bus interfaces or CS-interfaces are available. These meters would be rather having compatible MUCs as supplement. Modern electronic meters (With readout via CS interface) would replace the mechanical Ferraris meters, which make up 60% of the stock, that is to say, 3.0 million meters.

#### Smart meter

As illustrated in Table 13, the input power of a typical electronic meter is 4.41 W. For a new electronic meter without a communication feature, the average input power is about 1.5 W (see Table 25 for the *MUC-2* case). A 40:60 distribution is the reference for the calculation of a weighted consumption value.

#### Multi-utility controller (MUC)

The case MUC-2 considers a constant input power, already with the portion of energy for the communication link. The influence on the network configuration is negligibly small. Therefore, there are no additional calculations for various scenarios with different network topologies.

The MUC system also includes a data concentrator with PLC connection, as presented in Table 25. As in scenario CH-1, for every 200 metering points there is a data concentrator.

### Data communication and server

The central components (Telecom and IT) are the same as for the rollout scenario CH-1 (Section 5.2.3).

### Extrapolation

Using the calculation formula in Section 5.2.2 and the above amount of devices for Switzerland, the total energy consumption is **160 GWh per year** (See Table 37).

Table 37: Annual energy consumption of smart metering systems in Switzerland (in GWh/y), according to rollout scenario CH-2 (Based on TSC A_2-200MP and case MUC-2).

| Metering point type | Number of metering points | Number of MUCs | Consump-tion of meters (GWh/y) | Consump-tion of MUCs (GWh/y) | Con-sump-tion of DCs (GWh/y) | Consumption of Telecom and IT (GWh/y) |
|---|---|---|---|---|---|---|
| Households | 4,000,000 | | 93.3 | | 0.9 | 1.3 |
| Single-family houses | | 930,000 | | 20.4 | | |
| Multi-family houses and partly residential buildings | 670,000 | 670,000 | 15.6 | 14.7 | 0.1 | 0.2 |
| Commercial buildings (Companies) | 330,000 | | 12.7 | | 0.1 | 0.1 |
| **Total** | **5,000,000** | **1,600,000** | **121.7** | **35.0** | **1.1** | **1.6** |

*Notes to* Table 37*:*
The “households” comprise single-family homes, multi-family homes, and partly residential buildings. As only residential buildings (single-family homes, multi-family homes or buildings with partial residential use) are using MUC, only the corresponding entries for MUCs are included. In the table for single-family homes there is no corresponding meter displayed, as these are already within the total number of households. Other factors include the metering points as used in scenario CH-1, to derive the general consumption of multi-family homes, partly residential buildings, as well as commercial buildings (Companies). There is a data concentrator for every 200 metering points.

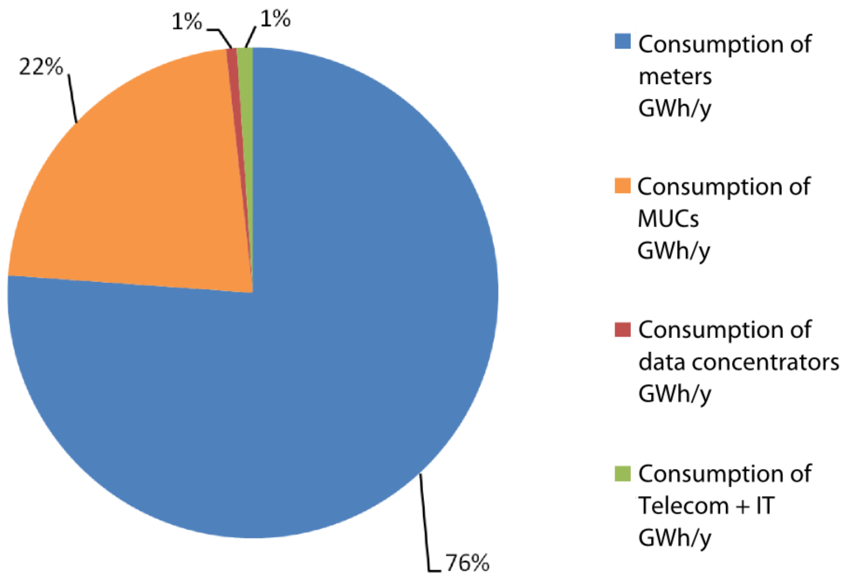


Figure 32: Own energy consumption for rollout scenario CH-2.

### 5.2.5 Rollout scenario CH-3: Smart metering with radio transmission within the data collection network

#### Configuration

The scenario CH-3 has the same structure as the rollout scenario CH-1, with the same solution for meters and the data collection network as in scenario TSC *C_1*.

#### Smart meter with communication module

The power demand of the three-phase meter, including the communication module is 1.41 W (see Table 21).

#### Data communication and server

The central components (Telecom and IT) are taken from rollout scenario CH-1, section 5.2.3.

#### Extrapolation

| |
|---|
| Using the calculation formula in Section 5.2.2 and the amount of devices from scenario CH-1, the total energy consumption is approx. **64 GWh per year** (See Table 38). |

Table 38: Annual energy consumption of smart metering systems in Switzerland (in GWh/y), according to rollout scenario CH-3 (Based on TSC C_1).

| Metering point type | Number of metering points | Consumption of electricity meters (GWh/y) | Consump-tion of DCs (GWh/y) | Consump-tion of Tele-com and IT (GWh/y) |
|---|---|---|---|---|
| Households | 4,000,000 | 49.4 | 0.2 | 1.3 |
| Multi-family houses and partly residential buildings | 670,000 | 8.3 | 0.0 | 0.2 |
| Commercial buildings (Companies) | 330,000 | 4.1 | 0.0 | 0.1 |
| **Total** | **5,000,000** | **61.8** | **0.2** | **1.6** |

*Note to*
*Table* 38*:* The same calculation procedure as in scenario CH-1 applies (See Table 36).

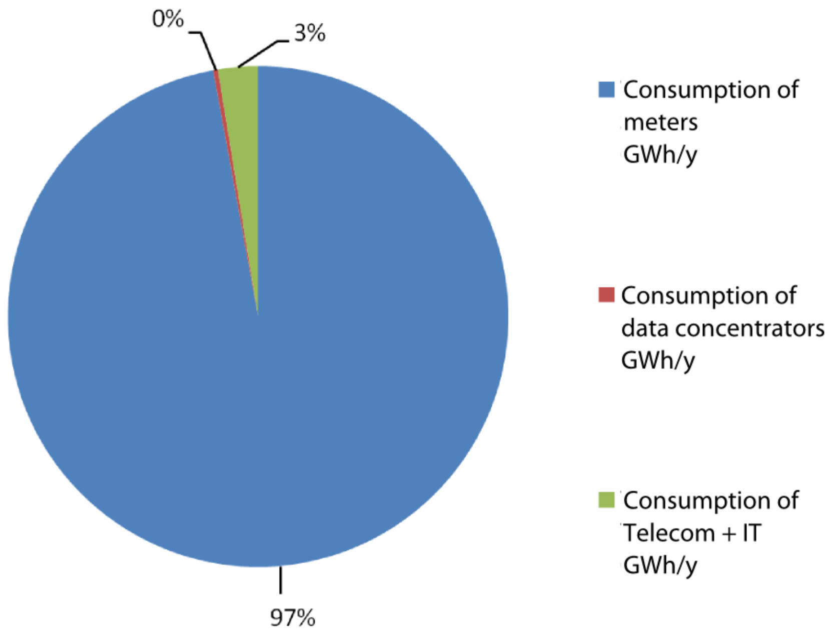


Figure 33: Own energy consumption for rollout scenario CH-3.

### 5.2.6 Rollout CH-4: Smart metering based on the Swiss impact assessment study

#### Configuration

Scenario CH-4 is a mix of possible scenarios considering the approaches within the impact assessment study [BFE1, 2012], with the following division for the transmission technologies:

- 70% of the metering points are connected via PLC to the data concentrator
- 30% of the metering points are connected via GPRS technology to the head-end.

### Smart meter with communication module

The assumptions from rollout scenario CH-1 apply for the PLC solutions in this scenario.

The own power demand of a three-phase meter connected via GPRS, including the communication module, is 2.55 W (See Table 19).

### Data communication and server

The central components (Telecom and IT) are taken from rollout scenario CH-1, section 5.2.3.

### Extrapolation

As in the case of scenario CH-1 with PLC, the consumption value corresponding to the technical scenario TSC A_2 is included (2.88 W power consumption by a three-phase meter including communication). According to utility experts, this solution has a wide coverage. For the solution TSC *B_1* communicating via GPRS the values of consumption are 2.55 W for the three-phase meter including the communication.

Using the calculation formula in Section 5.2.2 and the amount of devices from scenario CH-1, the total energy consumption is **131.0 GWh per year** (See consumption values from Table 39 and Table 40).

Table 39: Annual energy consumption of smart metering systems with PLC communication in Switzerland (in GWh/y), according to rollout scenario CH-4 (Based on TSC A_2).

| Metering point type | Number of metering points | Consump-tion of electricity meters (GWh/y) | Consump-tion of DCs (GWh/y) | Consump-tion of Telecom and IT (GWh/y) |
|---|---|---|---|---|
| Households | 2,800,000 | 70.6 | 0.9 | 0.9 |
| Multi-family houses and partly residential buildings | 469,000 | 11.8 | 0.1 | 0.2 |
| Companies | 231,000 | 5.8 | 0.1 | 0.1 |
| **Total** | **3,500,000** | **88.3** | **1.1** | **1.1** |

The contributions to the own consumption for the PLC system corresponds to that in Figure 30, as it is based on the same technical scenario.

Table 40: Annual energy consumption of smart metering systems with GPRS communication in Switzerland (in GWh/y), according to rollout scenario CH-4 (Based on TSC B_1).

| Metering point type | Number of metering points | Consumption of electricity meters (GWh/y) | Consumption Telecom and IT (GWh/y) |
|---|---|---|---|
| Households | 1,200,000 | 26.8 | 5.6 |
| Multi-family houses and partly residential buildings | 201,000 | 4.5 | 0.9 |
| Commercial buildings (Companies) | 99,000 | 2.2 | 0.5 |
| **Total** | **1,500,000** | **33.5** | **7.0** |

The distribution of the own consumption of the technical components of the GPRS system (See Figure 34) shows, in contrast to the previously described rollout scenarios, a significant higher contribution from telecommunication and IT. This is the result of assigning an own consumption of 0.5 W for each single metering point, to account for the demand at telecommunication operator´s side.

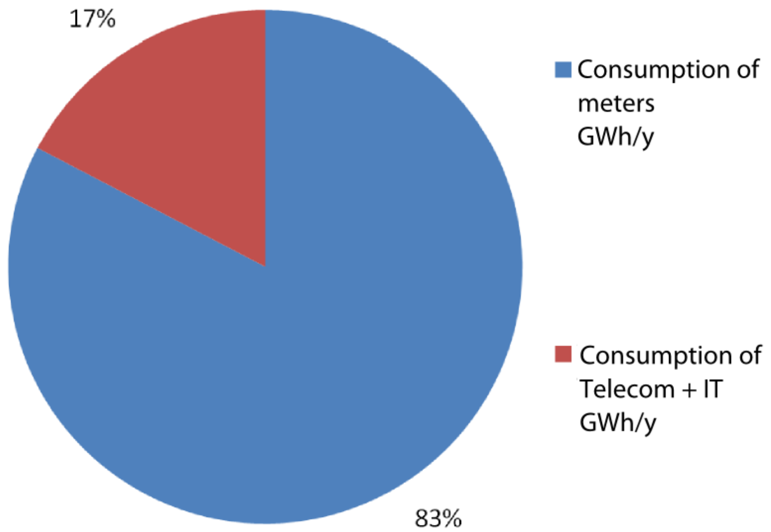


Figure 34: Own energy consumption for rollout scenario CH-4.

## 5.3 Calculations of the total consumption – Rollout scenarios for Austria

In the case of Austria, the ECODESIGN company GmbH was responsible for developing rollout scenario and extrapolating the total consumption. At the request of the commissioners of the study, the scenarios of interest only involve the infrastructure that fulfils the basic smart metering functions, and is located in the non-metered area. Feedback systems and home monitoring solutions are not included in the calculations.

The authors prepared the extrapolations by referring directly to the metering-based system–wide consumption data. The extrapolations also refer to the tables of the technical scenarios (Under Section 5.1).

### 5.3.1 Meter stock in Austria

Available data from E-control from the year 2010 allowed the estimation of the amount of meters [E-Control, 2011]. This includes information on meter points for specific federal states. Further classification considering customer segments for each federal state was available. Data for nationwide distribution of meter points follows:

- Households (71.3 %)
- Industry and other small businesses (24.8 %)
- Agriculture (3.3 %) and
- End consumer for which consumption is metered (0.6 %)

The first two segments are the most relevant for the extrapolation of residential meters in this project. Countrywide data shows that about 56.9% of the total metered end-user consumption is “End consumer for which consumption is metered” (Average over the period 2006 to 2010). However, the total number of corresponding metering points only represents 0.6% of the total number of meters in Austria. The agriculture sector only accounts for 3.3% of all metering points. For the purposes of the extrapolation all metering points are (or will be) equipped with “residential” type meters.

### 5.3.2 Extrapolation for the status quo

**Number of phases**

Interviews with the largest network operators in Austria brought information about their meter stock, to establish the distribution between one-phase and three-phase meters for the extrapolations. Six network operators provided information. Depending on the regions of these operators, the proportion of single-phase meters varies between 15 and 60%.

A distribution of 80:20 (Three-phase to single-phase meters) is set for the remaining network areas. According to E-Control Austria has a stock of 5,804,625 metering points. The following proportion is suitable for the extrapolations:

- 1,707,145 single-phase meters and
- 4,097,480 three-phase meters.

### Meter types

Four of the larger Austrian energy utilities provided information on the proportion of electronic meters within the stock of their installed meters (With respect to the condition where there were no smart meters before). The installation of electronic meters often takes place when there is a consumption reaching or exceeding a specific amount per year. The proportion of electronic meters is different depending on the region, varying between 1.0 and 4.6%. An average share of 3.0% of electronic meters for the other operator´s areas is plausible. According to the expert opinions, a status quo with all electronic meters having a three-phase connection is also reasonable for calculations.

### Extrapolation

Considering a total of 5,804,625 metering points and all assumptions presented above, the distribution of meter types for the status quo would be as follows:

- 5,631,082 Ferraris meters
- 173,543 electronic meters

The combination of the amount of meters in the meter stock and the power values for the meters from Table 13, the status quo has an average power consumption per metering point ($\overline{P_{MP}}$) of 3.20 W.

Table 41: Total active power of the installed stock of Austrian meters for the status quo.

| Meter type | Metering points nationwide | Percentage of metering points | $\overline{P_{MP}}$ (W) | Nationwide active power after meter types (MW) | Percentage of active power |
|---|---|---|---|---|---|
| **Ferraris meter one-phase** | 1,707,145 | 29.4% | 1.43 | 2.441 | 13.1% |
| **Ferraris meter three-phase** | 3,923,937 | 67.6% | 3.92 | 15.382 | 82.8% |
| **Electronic MFM, three-phase** | 173,543 | 3.0% | 4.41 | 0.765 | 4.1% |
| **Total** | 5,804,625 | 100% | **Total** | 18.588 | 100% |

The average active power is about 18.6 MW (Table 41), corresponding to an annual electricity consumption of **163 GWh/y**.

### 5.3.3 Rollout Scenario AT-1: Smart metering considering current (pilot) projects and the legislative existing requirements IMA-VO and IME-VO

The rollout scenario AT-1 is a representative mix of current technologies to build up a model for a national rollout scenario. The modelling included recommendations from experts of the utilities participating in the project, as well as additional information from other sources. In addition, it considers the legislative requirements currently into force in Austria.

The "Study Analyzing the Costs and Benefits of an Austria-Wide Introduction of Smart Metering", presented the costs and benefits of all market actors in Austria [PWC, 2010]. The rollouts followed the common requirement of the third legislative package from the EU energy market, where smart meters cover 80% of the metering points within EU member states). The technologies for the data collection and transmission network defined in this case are:

- 70% of the metering points are connected via a PLC to the data concentrator, which communicates over optic fibre to the HES, and
- 30% of the metering points transmit the data via GPRS directly to the HES.

In addition to the study of PWC in 2010, the organization Austrian Energy (Representing the interests of the Austrian electricity industry) commissioned the study “Analysis of the Costs and Benefits of an Introduction of Smart Meters throughout Austria” [Capgemini, 2010]. There are similar assumptions in this study concerning the transmission technologies used within the data collection network (Primarily taking PLC and different radio transmission solutions with data concentrators). According to network operator experts, the distribution for about 95% of the deployed solutions is as follows:

- 80% PLC connections
- 15% connections via radio technologies.

M. Holzinger conducted interviews in his study with eight Austrian energy utilities, focusing on their field trials and the smart metering systems already in active use [Holzinger, 2011]. In this study, the connection types within the data collection network were as follows:

- PLC solutions (stated by six companies)
- GSM/GPRS direct connections (two companies)
- internet connection of the customer (one company)

November of 2011 saw the entry into force of the mandatory regulation for smart meter in Austria [IMA-VO, 2011)]. A summary of the most important minimum performance requirements is as follows:

1. Every quarter of an hour measuring and storing average active power values (Electric energy as generated and fed into the grid), and recording a daily consumption value,
2. Storing within the meter the generated data mentioned under point 1, for 60 calendar days,
3. Capability for bi-directional communication with the network operator, which enables the daily transmission of the data mentioned under point 1. The time foreseen for this transmission is in total 12 hours, starting at midnight,
4. Capability for bi-directional communication with minimum four external utility devices (Battery operated flow meters, and the harmonization with the corresponding metered category should be possible),

5. Data encryption based on acknowledged “state-of-the-art” standards,
6. Capability for remote shutdown (Breaker), and
7. Possibility to update the firmware remotely

For the purpose of the extrapolation Point 4 would mean that the metering point has to include a wireless M-Bus interface. Experts indicated that Point 5 would likely mean AES128-bit encryption. All of these are only technical requirements the meter has to comply with, but the real usage of these features is optional depending on specific needs.

On 25 April 2012, the “Regulations for the introduction of smart meters” entered into force [IME-VO, 2012]. Under this regulation, the Austrian network operators have to fulfil the following requirements:

– 70% of the network metering points should be equipped with smart meters by the end of 2017 (That is, a smart meter fulfilling the IMA-VO regulation).
– “Whenever possible” 95% of the network metering points should be equipped with smart meters by the end of 2019.

These inputs serve as reference to create the rollout scenario AT-1 (Table 42). The proportion of meter points is 73%, indicated in TSC A (with PLC transmission, see Table 28), 11% in TSC B (with GPRS connection through the telecommunication provider, see Table 29), and 16% in TSC-C (With radio transmission, see Table 30). For connection types A and B a 50:50 ratio is included in the model for these solutions, but also for the PLC solution (TSC A) 15% of the metering points are located in sparsely populated areas. This means less metering points per line, and greater distances between the nodes, therefore in this scenario there is an average of 35 metering points per data concentrator. For TSC B and C, however, this is not applicable, as the impact on energy consumption is not significant.

Table 42: Distribution of the metering points (MP) in scenario AT-1, with the corresponding annual energy consumption values (in GWh/y).

| 5,804,625 Metering points | 73% TSC A | | | | 11% TSC B | | 16% TSC C |
|---|---|---|---|---|---|---|---|
| | 50% TSC A_1 | | 50% TSC A_2 | | 50% TSC B_1 | 50% TSC B_2 | 100% TSC C_1 |
| | 85% 100MP | 15% 35MP | 85% 100MP | 15% 35MP | | | |
| **29% 1-phase** | **522,257** | **92,163** | **522,257** | **92,163** | **92,584** | **92,584** | **269,335** |
| Consumptn. (GWh/y) | 15.3 | 3.0 | 11.2 | 2.1 | 2.3 | 1.5 | 2.3 |
| **71% 3-phase** | **1,278,628** | **225,640** | **1,278,628** | **225,640** | **226,671** | **226,671** | **659,405** |
| Consumptn. (GWh/y) | 54.9 | 10.4 | 33.5 | 6.2 | 6.1 | 4.7 | 8.5 |

The metering points also communicate via a wireless M-Bus interface with a gas meter (or other utility meter), so that 58% of all meters would have an interface to install a module for this communication, with the additional of energy accounted for according to case MUC-1.

The calculation of the power consumption values in Table 42 (In GWh/y) is as follows:

(Annual power consumption) = (Number of metering points) x (Active power per metering point) x 24 [h/day] x 365 [days/year] x 10E-09.

The active power per metering point corresponds to values from Table 28 to Table 30, for the individual technical scenarios as included above.

| |
|---|
| The annual power consumption for the scenario is **166 GWh/year**, with a resulting average active power per metering point of 3.26 W. |

**Rollout scenario AT-2: Use of gateways within urban areas**

Scenario AT-1 serves as the basis for rollout scenario AT-2. In this case, residential buildings in urban areas use specially adapted solutions, which allow for a more practical readout using less communication features (Corresponding to the technical scenario with connection type D, as in Figure 28).

Data from Statistics Austria from the study "Austrian Building and Housing Census 2001 – Main Findings" [Stat-Austria1, 2004] provided insights for exploring the theoretical boundaries and applicability of this connection type. The table, G1c ("Buildings and apartments by type of building)" shows a total number of 3,863,262 apartments in Austria. An apartment is "a room or several adjoining rooms, which form a complete unit, and is equipped with a kitchen or at least a kitchenette".
Furthermore, of all of the 2,046,712 Austrian buildings reported; 1,305,460 are single-family houses. 61,196 buildings and 1,134,782 homes are included in the category "residential building with 11 or more apartments".

These figures allow the following calculations:

- 3,863,262 homes represent the same number of residential metering points
- 1,305,460 / 3,863,262 = 33.8% of all household metering points correspond to single-family houses.
- 1,134,782 / 3,863,262 = 29.4% of all household metering points are for the end-users within residential buildings with 11 or more apartments, for which:
    - An average of 1,134,782 / 61 196 = 18.5 are apartments.
    - The remaining meter points (3,863,262 – 1,305,460 – 1,134,782 = 1,423,020) or 36.8% of all household based metering points correspond to buildings with 2 to 10 apartments.

Assuming that the relationships between these figures are still valid today, the percentages can be mapped to the numbers of existing meters, as published by E-Control:

For 29 % of the metering points, which correspond to "industry and other small costumers" as well as to "agriculture", the assumptions from rollout scenario AT-1 are adopted.

For the remaining metering points it will be distinguished between the following cases for common readouts through one gateway:

- Only for buildings with 11 or more apartments (Rollout scenario *AT-2 (>10)*, see the green portion of Figure 35) or
- For all residential houses with more than one apartment (Rollout scenario *AT-2 (>1),* see the green and red portions of Figure 35.

These metering points have a common readout through a gateway.

The case *AT-2 (>10)* includes the technical scenarios *TSC D_1 – 18MP* and TSC *D_2 – 18MP* (Assuming that an average of 18 metering points connect to a common gateway).

| |
|---|
| The annual power consumption for this scenario is **153 GWh**, with a resulting average active power per metering point of 3.01 W. |

In the case *AT-2 (>1),* for the buildings with 2-10 parties an average of five meter points per gateway is defined (*TSC D_1 – 5MP* and *D_2 – 5MP*).

| |
|---|
| The annual power consumption for this configuration is **186 GWh.**<br>Therefore the averaged meter point based effective power in this case is 3.65 W. |

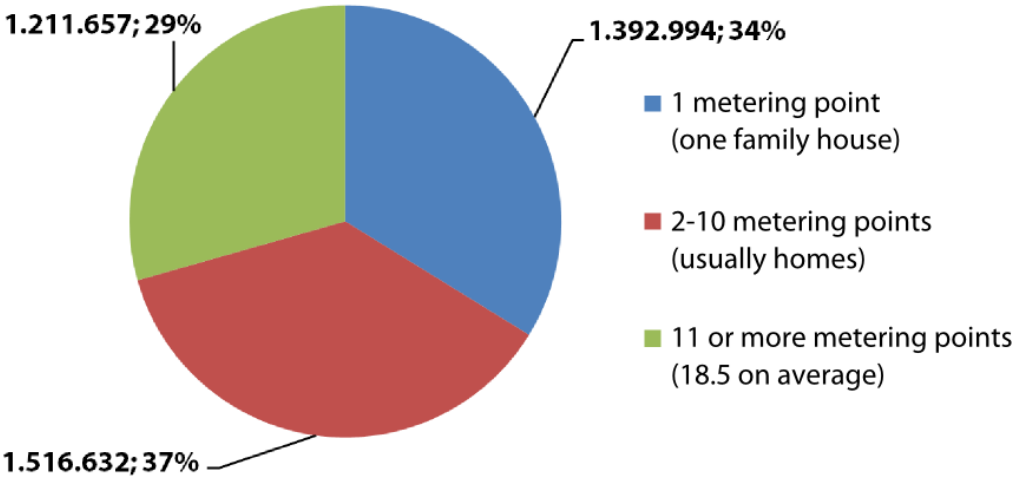


Figure 35: Residential metering points for Austria according to the number of apartments per residential building.

Table 43: Distribution of metering points (MP) in scenario AT-2 (>10), with the corresponding energy consumption values (in GWh/y).

| **1.211.657 Metering points** → | **100% D** | |
|---|---|---|
| **>10 MPs per building** ↓ | **50% D_1 18MP** | **50% D_2 18MP** |
| **29% one-phase** | **175,690** | **175,690** |
| Consumption GWh/y | 2.4 | 1.5 |
| **71% three-phase** | **430,138** | **430,138** |
| Consumption GWh/y | 12.4 | 5.8 |

| **4.592.968 Metering points** → | **73% A** | | | | **11% B** | | **16% C** |
|---|---|---|---|---|---|---|---|
| **Remaining metering points** ↓ | **50% A_1** | | **50% A_2** | | **50% B_1** | **50% B_2** | **100% C_1** |
| | **85% 100MP** | **15% 35MP** | **85% 100MP** | **15% 35MP** | | | |
| **29% one-phase** | **413,241** | **72,925** | **413,241** | **72,925** | **73,258** | **73,258** | **213,114** |
| Consumption GWh/y | 12.1 | 2.4 | 8.8 | 1.6 | 1.8 | 1.2 | 1.8 |
| **71% three-phase** | **1,011,727** | **178,540** | **1,011,72 7** | **178,540** | **179,355** | **179,355** | **521,761** |
| Consumption GWh/y | 43.4 | 8.2 | 26.5 | 4.9 | 4.8 | 3.7 | 6.7 |

Note to Table 43 : For the calculations in this scenario, the buildings with more than 10 apartments have a gateway.

## 5.4 Comparison of the systems for the technical scenarios

Previously in section 4.1 the comparison included only the meter as a reference for the consumption. In this Section the comparison includes system-wide based consumptions, namely beyond the meters to also consider data concentrators, additional modems, and any other processes which are relevant in terms of own consumption. The corresponding contributions are broken down proportionally to the individual meter. Figure 36 shows the annual consumption values for the technical scenarios in Section 5.

In the hypothetical case that a region or country would use the same technology (i.e., hardware, communication features, and transmitting protocols) under homogenous conditions (i.e., network topology, size of the sub-network, and additional features), it would be possible to calculate the average annual energy consumption of that region. By simply multiplying, the consumption values indicated for each technical scenario in the diagram below, and the number of metering points, the result would correspond to the total consumption, under the assumption that only three-phase meters are installed in that region.

For several reasons it is not possible to have scenarios with homogeneous technical solutions. These reasons might include legal aspects such as the authorization for radio frequencies in parts or all the region, but also others such as the preferences from network operators in selecting their technologies, or the applicability of certain connection types in certain regions (e.g., the connection in TSC D is generally not applicable everywhere).
These estimations serve primarily the purpose of indicating the range of possible energy consumption values from smart metering systems. In contrast to the previous two sections, this section does not refer to particular rollout scenarios.

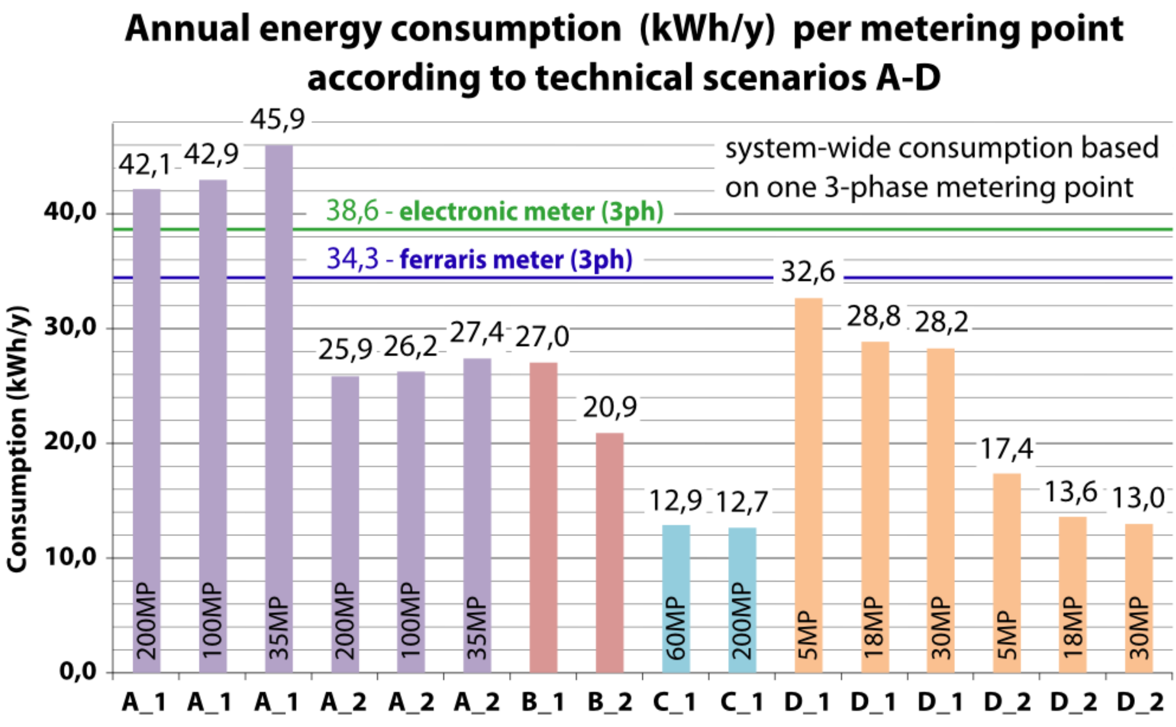


Figure 36: System-wide annual energy consumption (in kWh/y) according to technical scenarios A to D, including also the status quo consumption values for the reference three-phase Ferraris and electronic meters.

## 5.5 Extrapolated results in the national scenarios

From the comparison of results for the rollout scenarios for Switzerland and Austria, it appears that the expected total consumption for the smart metering infrastructure is in the same order of magnitude as in the status quo case (with non-communicating meters).

The approach to generate the rollout scenarios for Switzerland and Austria included various assumptions. Scenarios CH-1 to CH-4 take as reference concrete technical solutions, while scenarios AT-1 and AT-2 take as reference an heterogeneous mix of different connection types and manufacturer-specific solutions. This partly explains the reduced consumption in the Swiss case, where the choice of more efficient meter products plays a role in the overall results. For the Austrian scenarios, the consumption remains almost the same as the status quo or tends even to increase.

### 5.5.1 Comparison of rollouts scenarios for Switzerland (CH-1 to CH-4)

Figure 37 shows the results of the own energy consumption for the four rollout scenarios with new smart metering systems for Switzerland, as well as the status quo.

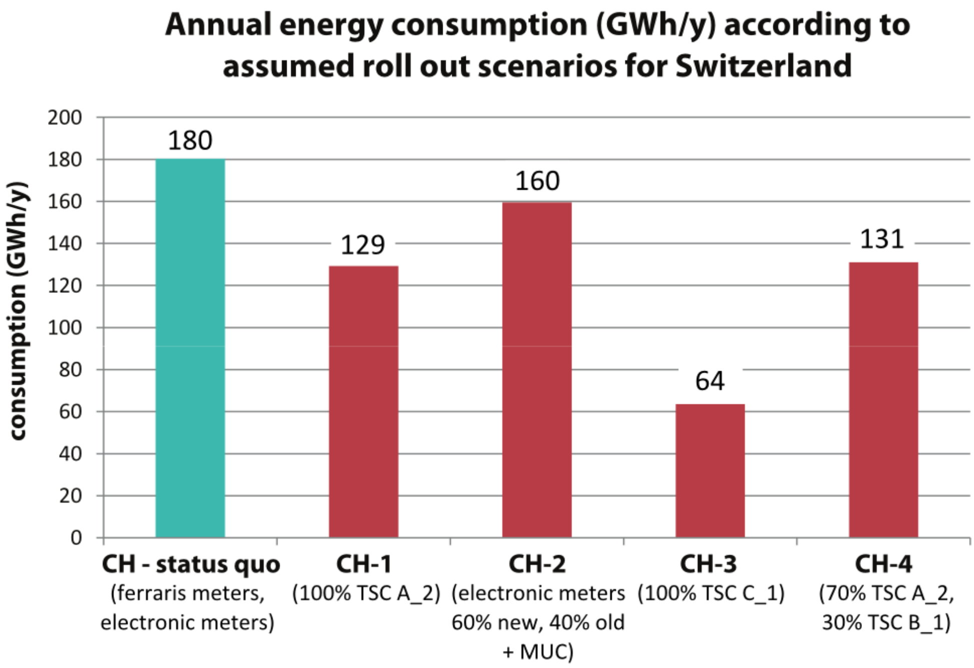


Figure 37: Own energy consumptions for the Swiss rollout scenarios CH-1 to CH-4 and the status quo (in GWh/y).

The devices at the metering point contribute the most to the overall consumption of the system. This is evident from the graphs of the different rollout scenarios (Figure 30 to Figure 34).

When the aim is to reduce the energy consumption of the whole system, the own consumption of smart meters should be considered a priority. This is the contribution with the highest potential for energy saving measures when setting the details of the implementation (Refer to section 4.2).

Many recent studies on IT devices show that the (permanent) standby power consumption of electronic devices with few volts, for the conversion of AC voltage of the mains (230 V) to the chip DC voltage, is critical. From this point of view, additional devices equipped with an own power supply unit (such as the MUC) have an adverse effect on the energy consumption of the whole system. However, when the MUC replaces the communication devices of several meters, the total consumption (including the MUC) might be lower as without it.

Nevertheless, for scenario CH-2 with MUC the estimates show a higher total consumption. This is because the installed generation of old electronic meters is not being replaced by new meters (with lower own consumption).
The scenario CH-3 considers meter solutions with possibly various internal, more energy efficient components. In addition, radio transmission, which is a lean proprietary system that saves energy, when compared to most PLC solutions.

Scenario CH-4 shows almost the same annual energy consumption as scenario CH-1. Although the meters from TSC B_1 consume less energy than those from TSC A_2, the savings in that case are comparable to the additional consumption at the side of the telecommunications provider.

### 5.5.2 Comparison of rollout scenarios for Austria (AT-1 and AT-2)

Figure 38 shows the results of the own energy consumption for the two rollout scenarios with new smart metering systems for Austria, as well as the status quo.

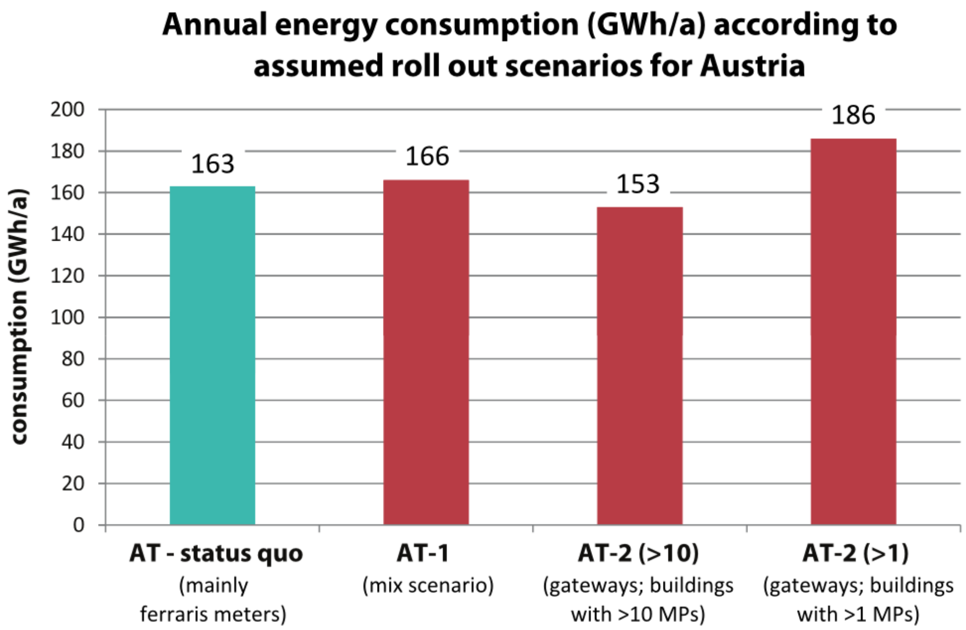


Figure 38: Own energy consumptions of the Austrian rollout scenarios AT-1 and AT-2 and the status quo (in GWh/y).

The annual energy consumption of the status quo scenario is lower in Austria than in Switzerland. The number of metering points in Austria is higher, but also the proportion of single-phase metering points considered in the calculation. Furthermore, the proportion of older generation electronic meters is almost negligible in Austria, while it accounts for 40% of the meters in Switzerland.

The rollout scenario AT-1 assumes a mixture of existing technologies, which included three different connection types and various smart metering solutions per connection type.
In addition to exploring the own energy consumption for this “base case scenario”, the rollout scenario AT-2 shows the extent of possible system-wide energy consumption savings when using gateways for reading data of several metering points in residential buildings. The two different cases for the scenario AT-2 show the the following results:

– It is useful to connect buildings with more than 10 apartments (Living units) with a common gateway. This measure can reduce the total consumption by -8% when compared to scenario AT-1 (See Figure 38, case AT-2 (> 10)).

– For the case of connecting all houses with one than one apartment (case AT-2 (> 1)) the gateways is no longer contributing to energy savings, but instead results in an additional system-wide consumption of +12% more.

### Comparison with results from to other studies

The cost and benefits study from Capgemini "*Studie zur Kosten-Nutzen Abschätzung zur Einführung von Smart Metern*" [Capgemini, 2010] shows that the total consumption of the network infrastructure for a full-scale rollout (Meter, data concentrators, and transmission equipment) increases by about +77%. A general statement is made that says "smart meters have a higher (own) energy consumption than the conventional Ferraris meters".

The average input power per metering point in scenario AT-1 within the project SMART METERING consumption project is 3.26 W, which is around 1.9% higher than the status quo value of 3.20 W.
The results of the modelling in the SMC project do not match with the 77% increase for systems-wide consumption mentioned above.
In the hypothetical case of a region-wide metering implementation with the most energy intensive technical scenario for Austria, the increase would be about 50% in the own system-wide consumption. Likewise, when considering the most energy efficient technical scenario nation-wide, the total own consumption is reduced by is 59%. Both are improbable cases for implementation.

The study "*Studie zur Analyse der Kosten-Nutzen einer österreichweiten Einführung von Smart Metering*" [PWC, 2010], conducted by the Austrian regulatoring agency E-Control, takes the British "*Impact Assessment of a GB-wide Smart Meter Roll Out for the Domestic Sector*" [DECC, 2009] as reference to set the own energy consumption per metering point.

The own consumption of an electricity smart meter is assumed with 7 kWh (note: This is "per year" and would be equivalent to 0.8 W average input power). The telecommunication (Modem) is balanced with additional 8.8 kWh consumption. This results in a total consumption of 15.8 kWh for the electricity smart meter.
This would be equivalent to a continuous power consumption of 1.8 W by the smart meter. The DECC impact assessment declares the following:

> "Energy cost
> The smart metering assets will consume energy and after discussions with meter specialists, we continue with the assumption that a smart meter would consume 1 W/h, and a display 0.6 W/h and the communication equipment 1 w/h. These assumptions are unchanged."

Presumably, values for power consumption (in units of W) would have been intended. The assumption in the DECC study would therefore be 2.0 W for a smart meter including the communication module (Modem). If this interpretation is correct, consumptions elsewhere in the system (e.g., data concentrators) are not included.
The measured power consumption of the meters in the SMc project is considerably higher for PLC solutions (See Table 17 and Table 18). Even in the case of a direct connection via mobile network provider, only the most efficient meter is below the value stated by DECC (see the corresponding technical scenario in Table 19 and Table 20). It improbable though the implementation of only this technology throughout Austria.

### 5.5.3 Allocation of the consumption to the technical components

**Metering equipment – Smart meter**

The example of the rollout scenario CH-1 for Switzerland illustrates the distribution of the energy consumption across the components of the system. Meters have the largest contribution with 98% of the total consumption (See Figure 30).

This is similar in the scenario CH-2 which includes the MUC. The power consumption for an independent MUC is approximately in the same order of magnitude as that of a three-phase smart meter. Still, building and housing statistics show that only every third metering point has a MUC. Thus, the share of the consumption of the smart meters is still 76% in this case (see Figure 32).

In our view, the consumption for the different arrangements would be generally applicable for most of the rollout scenarios in Switzerland and in Austria. With respect to the smart meter, it expected that these would have the highest contribution to the total consumption.

*Note:* This is valid when considering the systems in the non-metered area. Future scenarios with more complex home monitoring and home automation solutions would be an exception where the consumption of the in-home components might be more relevant than that of the meters. These scenarios were not included in this project.

**Data concentrator**

In general, the number of data concentrators within a typical smart metering grid is one hundredth of the number of metering points. The energy consumption of a data concentrator as such is approximately two to four times higher than that of a three-phase meter. From this, it is clear that the approximate contribution of the consumption of the data concentrator to the total consumption ranges between 1 to 4%.

The datasheets for PLC data concentrators show a maximum number of terminals (end-user equipment) as 1000 (or even the theoretical maximum of 1024). These maximum values were not present within pilot projects, and will not be present in large-scale rollouts with current technology.

Some network operators are installing PLC data concentrators in all existing transformer stations, in their efforts to deploy smaller sub-grids and guarantee greater availability of meters. This is at times necessary because of the topology of the existing grid, for example in the case of deep valleys, with long distances between individual meters. Network operators expect one data concentrators to 35 metering points for rural areas. Smart metering points set closely together have several connecting paths, via different repeaters (Redundant system), and therefore, more favourable conditions for transmission. In such a case one data concentrator for every 200 metering points (Or even more) is possible.
Most of the pilot projects operate in urban areas, and the current empirical values are 1:100 to 1:200 data concentrators to metering points.

**Energy consumption at the telecommunications operator side**

No reliable data was available on the energy consumption per metering point for the processes at the telecommunications operator side. Experts indicated that the energy consumption for the transmission equipment and facilities depends on the number of *active connections* (GPRS, GSM, and in some cases, SMS connections). Therefore, the consumption of each connection type also includes the corresponding consumption due to a specific number of data concentrators or gateways, or in the case of direct meter readout, the number of metering points.

Furthermore, it makes a significant difference whether the same transmission security performance is always guaranteed, or only at certain times. For daily readout the use of the infrastructure of mobile radio communication in phases with low usage frequency would be enough. Once a transmission channel is started up, it can read more than 500 connections. The transmission channel is once again available for mobile communications after this transmission is over. When the connection is time-critical, regarding its all time availability for grid applications, such a solution as described above would not be sufficient.

According to the opinion of a provider of meter data management services, a conservative approach is that the continuous power consumption per metering point, for the entire transmission chain of the operator, has the same value as that of the GSM/GPRS module of the meter. Therefore, a permanent value of 0.5 W is considered. This value is only relevant for the case of the metering points connected directly to the head-end (i.e., category B, see Figure 28), with a resulting proportion of more than 10% to the total own consumption.

### Central components of the head-end of the energy utility

No reliable data was available on the energy consumption per metering point for the IT processes at the energy utility side. Opinion of experts from medium-sized energy utilities, together with certain number of readout of metering points and servers form the basis for this discussion. With these information the estimated contribution of the IT at the utility side is about 1% to the total own consumption.

The amount of data processed through the transaction server, and the data availability for monitoring, has a direct impact on the energy consumption of the IT hardware. In contrast to the manual readout of the Ferraris meter (where a cumulative energy consumption value is recorded annually), a daily readout takes place in the smart metering system. The readout consists of the daily consumption value, but also may include the values every quarter of an hour, and even additional status data. This makes the dataset up to one hundred times bigger. This is especially true in the case of following the Austrian IMA regulations.

From the perspective of the data volume of today (Status quo), and for the purposes of metering, the assumption that the data volume would grow by a 36,500 fold with smart metering is a plausible one. Specific investigation on the corresponding system would be necessary for getting a more accurate picture of the energy consumption for the head-end processes. Data processing directly associated to real metering would need to be differentiated from all other head-end processes associated with the use of an expanded grid system.

# 6 Discussion and outlook

Electro-mechanical Ferraris meters were predominantly in operation in Switzerland and Austria during the course of the project SMART METERING consumption. The Swiss meter manufacturer Landis+Gyr - a major player within the European market - stopped its production of Ferraris meter in the middle of last year, to focus exclusively on a product portfolio with digital technology only. The regulations for smart meters entered into force on April 25th, 2012 in Austria, requiring a rollout of about 70% of smart meters by the end of the year 2017.

Under such circumstances it became clear that, instead of answering the question “How do the changes in technology influence the own consumption of electricity meters?”, the more important question to answer is “Which smart metering technology is the most efficient?”.

Results of the SMc project showed that the consumption of the meter primarily determines the energy consumption of the whole system, and therefore, the selection of the technical design of the meter and the information technology used would set (and possibly control) the system wide consumption.

### Standards

The limit for own consumption of electricity meters is defined as 2.0 W (10 VA) per phase in the international standard IEC62053-21 [IEC,2003]. For the case of a smart meter only the dedicated measurement part (“MID” part) of the meter would fall under this limit, but not the communication module. From January 7th, 2013 onwards, Germany also sets limits through the regulation VDE-AR-N4400:2011-09 [VDE, 2009], stating the limit (Maximum or peak value of the active power) for metering equipment outside the metered area. This definition of the system boundary around the metering point implicitly considers that this is the most consumption-intensive technical component of the smart metering system. However, in the interests of achieving higher energy efficiency, the regulation establishes limits on average power values preferably, as opposed to limits on peak values. This is especially important considering that today’s modular smart meters have typically 40 to 70% of the consumption due to the communication.

According to the opinion of some experts, the basic requirements for efficient and robust PLC transmission are still lacking. A frequency band of 150 to 500 kHz would be favourable, however, only the CENELEC A band is in use for PLC in Europe at this time. The implementation and usability of efficient radio network solutions depend on the regional approval of the particular frequency band.

### Methodology

The modelling approach developed within the methodology of the project allows for the inclusion of relevant parameters in a flexible way, for the input variables and the corresponding calculations of the total consumption. These variables include the number of one- phase and three-phase meters in a region, the equipment per metering point (Including interfaces), type of the connection between the meter and the data collection network, and the corresponding data nodes.

The more complex tasks within the application of the methodology included:

– Identification and mapping of specific features, such as the availability of the meter in the network and for particular functions. This requires basic understanding of the capabilities of various systems.

– Identification of a plausible mixture of technical scenarios, for example by using robust data on the available solutions on the market, combined with research data, as done in this project.

The calculation approach for the total consumption in this project can serve as basis to evaluate simplified components of the existing model. This would allow a more efficient and faster system evaluation. Still, in-depth studies would help clarify data uncertainties. Rough estimates were used for describing the key technical components of the head-end processes at the energy utility side, and at the telecommunications operator side. Real time measurements at several locations of the smart metering network would be important for understanding the sensitivity of the meters to different conditions of operation. The sample measurements conducted during the project are subject to considerable uncertainties.
The fact that the smart meter has a low own consumption even when it is measuring a high current flow through the phase line is a challenge for modern measuring technology. Under certain conditions in the field, the laboratory circuit constructed for this project operated inaccurately.

The methodology in the project SMc only analyzed the direct infrastructure needed to fulfil basic functions such as “measuring, logging, and transmitting”. Consequently, there was a clear system boundary set between metered and non-metered areas; directly defined at the metering point. Under this condition, the main contribution to the total energy consumption is due to the smart meter, because of the exclusion of additional devices, which are not in use for transmitting in the data collection network.

The situation regarding energy consumption could potentially change if the system boundaries expand to the metered area. Home monitoring and/or home automation systems would require further equipment, which also make use of communication technologies. The question of whether and if additional devices are part of the smart metering infrastructure would then have to be redefined. This important question is worth investigating in a follow-up project.

**Outlook for internationalization**

The methodology developed in the SMc project for the modelling of energy consumption is highly structured but also flexible in its application. The data structure allows for extrapolation and for making use of databases and scripts. The methodological requirements were fulfilled under the original project idea, for understanding the own energy consumption of the smart meter infrastructure in a transparent and visible way.

The project outcomes already fostered discussions at the international level. Further international work could lead to an enhancement of the existing methodology, in deriving strategies for the rollout of smart metering systems (or sub systems), based on the groundwork completed during this project.

The rollout of smart metering systems is also taking place in various countries worldwide. An internationally agreed and consistent methodology could support the assessment of different technologies, and their associated energy consumption. International cooperation within the framework of the International Energy Agency´s Implementing Agreement on Efficient Electrical end-Use Equipment (IEA - 4E) is a concrete option for furthering this work.

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