The Role of Advanced Metering Infrastructure for Greenhouse Gas Emissions Mitigation: A Brazilian Evaluation

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Abstract

This paper analyzes the capabilities of an Advanced Metering Infrastructure (AMI) roll-out for low voltage residential consumers as a tool for power load reduction and GHG emission mitigation. It was considered that load reductions could arise by three technical aspects: reduction of non-technical losses, demand-side management and efficiency improvement. Two scenarios were used to quantify the AMI roll-out benefits, the Business As Usual scenario based on the EPE projections and the AMI accelerated scenario, defined in this study. Evidences of previous national and international experiences were considered as references for the different estimations performed. It was concluded that AMI roll-out has the capability of reducing 0.79% of the total SIN consumption and 0.64% of the total SIN CO_2 emissions. Finally, a non-extensive estimation of AMI deployment costs was performed.

Keywords – Advanced Metering Infrastructure, GHG emissions reduction, load power reduction, smart grids.

1) Introduction

The Brazilian electrical power system is recognized internationally as one of the cleanest, mainly due to the large share of hydroelectricity production. According to the 2016 Statistical Yearbook for Electricity (base year 2015) (EPE, 2016), 61.3% of total installed capacity of the country (140 GW) corresponds to hydropower plants. The share of this resource in the country's electric mix leads to a relatively low contribution of the electricity sector to the country's total greenhouse gas (GHG) emissions, approx. 3.7% in 2015 (MCT, 2016 e SEEG, 2016). However, in the recent past, thermoelectric power plants have been growing in importance in the Interconnected Power System (SIN, in Portuguese). This represents an increasing emissions rate for the electric sector (MCT, 2016), which may have to be addressed in order to accomplish the GHG mitigation targets. Measures for GHG emissions mitigation became more relevant for the country after its ratification of the 2016 Paris Agreement. In this context, the formulation, study and implementation of GHG emissions reduction measures for the electricity sector are issues of high relevance.

The IPCC-2006 methodology establishes that the electrical sector's emissions evaluation must be counted by the emissions originated by the use of fossil fuels at generation (IPCC, 2006). In this context, initiatives focused on the decarbonisation of the power generation sector, through the increase in the participation of renewable energy sources (such as solar photovoltaic, concentrated solar power, wind, biomass, etc.) are the main envisaged actions for mitigation. However, it is also possible to contribute to GHG emissions reductions through improvements in the transmission and distribution segments, by means of load reduction. As such, this work aims at analyzing the role of Advanced Metering Infrastructure (AMI) systems as a tool for GHG emissions mitigation in Brazil.

An AMI consists in an integrated system of smart meters, bidirectional communication, smart control and data management in a metering structure that allows to meter, to collect and to analyze information of energy consumption for a massive number of consumers in an hourly or higher rate basis (FERC, 2013). Having a metering system with such features brings benefits not only in the modernization of the billing system (compared with the current one), but also opens the door for various demand management applications, which lie with the concept framed as Smart Grids (Mohassel et al., 2014). For example, through AMI it is possible to: i) define accurately the users' energy consumption profile; ii) detect energy disruptions quickly and inform precisely the affected region; iii) offer a good scenario for Distributed Generation integration; and iv) create value added services; among others (Ahmad, 2011).

Various AMI initiatives have been performed worldwide. In these experiences it can be observed that the motivations that have encouraged a country to invest in these systems vary accordingly to its particular characteristics. In the USA, for example, the main interest lies in the need for a modernization of the distribution system due to accelerated consumption growth. For various European countries, AMI systems are interesting for establishing better conditions for distributed generation integration. The Brazilian case appears to be more similar to the Italian and Spanish cases, where the reduction of technical and non-technical losses is the main motivator (Centro de Gestão e Estudos Estratégicos, 2012 e Mohassel et al., 2014). Nowadays Brazil is in an early stage of

AMI development. However, some experiences have been performed, mainly correlated with R&D ANEEL projects, as listed in (Centro de Gestão e Estudos Estratégicos, 2012).

This work aims to discuss the role of AMI systems roll-out and its correlated technical benefits in the reduction of the SIN electrical energy load. Since this saved energy would no longer be generated, it would represent a reduction in GHG direct emissions from the power sector. Two scenarios were created, a business as usual scenario (BAU) and a hypothetical scenario, in which the Low Voltage (LV) residential Brazilian consumers experiment an accelerated increase of the mentioned technology, reaching a high penetration level by 2025. For simplify, this scenario is called AMI scenario.

This paper is organized as follow: Section 2) exposes the main segments of the electric power sector in which AMI systems could contribute with load reductions and therefore, GHG emissions reductions. Section 3) describes the methodology used in this study and presents the results for AMI scenario evaluation. Finally, a non-extensive estimation of AMI deployment costs is performed in section 4) and the overall conclusions are presented in section 5).

2) Load power reduction due to AMI systems.

Academic literature and previous experiences have shown that AMI systems could cause load power reductions in the aspects listed below.

a) Reduction of non-technical losses

An AMI system can easily identify fast and illogical deviations in power consumption, helping in the combat of non-technical losses. Smart meters usually have anti-theft sensors that allow transmitting alarms to the control center in case of any anomaly (McLaughlin et al., 2010). Additionally, a suitable data management of the meter readings would identify suspicious changes in the consumption patterns of a particular region. Reductions on energy load are justified since it is expected that a percentage of the energy that was previously counted as non-technical losses will no longer be consumed, because of rationalization (Simanoggio, 2009).

b) Demand-Side Management

AMI systems can offer additional value services which have the potential of modify the habits of the residential consumers and gradually lead to a decrease in the electrical energy consumption as well as peak power reduction. Examples of actions and technologies that may lead to such reductions are:

i) Voluntary reductions

According to Darby (2016), just the replacement of current meters by smart meters with easy access In-Home Displays (IHD), which allow consumers to have a near real-time feedback of their consumption and the applied rate, can be a mechanism that drives behavioral changes, since IHDs create a better awareness of patterns of energy use. It had been reported that about 60–70% of British Gas customers with smart meters had made behavioral changes and that 45% use or refer to their IHD at least once a day (HC, 2016). Naturally, the voluntary reductions will depend on the subjectivity and socioeconomic condition of the specific consumer. In (Hunn, 2016) is argued that even though the consumer could present an immediate change in his behavior, it can slips back within about six months. Nonetheless, Smart Energy GB affirms that energy saving appear to become more prominent the longer a consumer has had their smart meter installed, since behavioral changes in the energy use are more likely to adjust gradually (HC, 2016).

ii) Time varying rates

AMI deployment represents an opportunity to improve over traditional fixed rates, since it facilitates the implementation of the value-added service of variable hourly rates. This means the establishing of a billing system where the cost of energy for low voltage residential consumers varies according to the time of the day and / or day of the week. The most common types of time varying rates are: Time of Use rate (TOU), Critical Peak Pricing (CPP), Critical Peak Rebates (CPR), and Real Time Pricing (RTP) (Faruqui et al., 2012).

As can be seen in Figure 1, the residential energy consumption has a high concentration during few hours of the day. Since the power system must be sized to meet the maximum demand, this behavior causes the system to be in a partially idle state most part of the day. The implementation of differentiated hourly rates is an attempt to improve the use of the power system infrastructure, encouraging, with and economic signal, the electrical energy consumption outside the peak hours. Two results are expected from time- varying rates: i) peak load shifting and ii) consumption reduction (Faruqui et al., 2012).

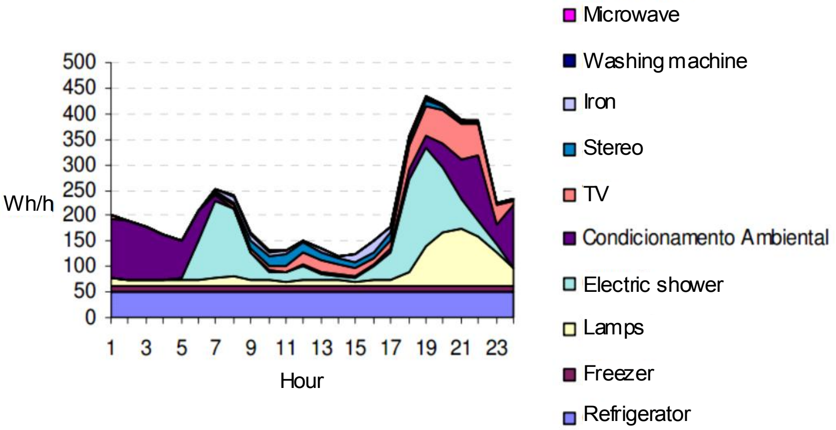

Figure 1 – Average load curve for Brazilian residential consumers, year 2007. Source: (PROCEL; Eletrobrás, 2007).

iii) Demand Response

Demand Response is understood as an advanced application of smart grids, in which Home Area Networks are used to control home appliance electronics equipment that would become programmable and/or remotely controllable (Albadi; El-Saadany, 2007). Traditionally, generation plants increase the overall power output at peak demand hours in order to keep the system stable and balanced. Demand Response works with the oppositely concept, it recompenses users for reducing their consumption when required, for example during peak load (Palensky; Dietrich, 2011).

c) Efficiency Improvement

The load reductions obtained in sections a) and b) lead to a lower system loading and to peak load shifting for LV residential consumers. Therefore AMI causes improvements in the power system efficiency. In other words, it also could contribute with technical losses reduction (Hayt et al., 2007). On the other hand, an AMI system roll-out requires the introduction of new electronics components as sensors, communication devices, management tools, etc., which could be considered as new sources of technical losses or efficiency reduction, since they were not part of the power system previously. However, according to the Brazilian Mines and Energy Ministry report on smart grids (MME, 2012), an smart meter consumes about 30% of an traditional electro-mechanic meter does. Therefore, in this work it is considered that the additional load due the introduction of new devices is compensated with the improvement in the efficiency of the smart meters in comparison with electro-mechanic meters.

d) Others GHG emissions reductions due AMI systems.

As explained in section 3), the approach used in this study to estimate the reduction on GHG emissions caused by AMI systems for the Brazilian case considers only the power load reduction by means of the items described in sections a), b) and c). This load reduction is converted into avoided GHG emission using the 2015 "Interconnected Power System CO_2 Emission Factor". Nonetheless, there has been reported additionally ways in which AMI systems could contribute with GHG emissions reductions, for instance:

i) Operational improvement for Distribution System Operators (DSO)

The communication system implemented or upgraded for the application of AMI systems will allow that several operational and maintenance actions, which were traditionally carried out locally (in the field), to be carried out remotely. Some actions examples are: monthly energy measurement, connection and disconnection of consumers and some technical operations. The results of an AMI project from US utility Center Point with a coverage of 2.2 million meters highlight that after the system was implemented, about 97% of the service orders have been met electronically (Hackney, 2012).

Performing operational actions remotely has repercussions on the number of vehicles used for maintenance, kilometers travelled, fuel consumed and, consequently, GHG emissions. In an AMI project of US utility Central Maine Power, with coverage of 600,000 consumers it was argued that the miles traveled reduction after the development of the system was 2 million (Brown, 2012). In this sense, the US Department of Energy's report on the initial results of 15 AMI projects shows that the vehicle fuel consumption suffer reductions between 12% to 59% (US Departmet of Energy, 2012). Since this benefit depends of the internal management system of each DSO it is not consider for this study.

ii) Modification of the SIN CO_2 emission factor

The procedure performed to calculate the SIN CO_2 emission factor takes into account the hourly dispatch data of the SIN, considering the historical data of the power plants used (MCT, 2007). It is well know that the dispatching process is ruled by the load profile curve. In the Brazilian case, hydro-electrical power plants, under normal conditions, represent the main based-load power plants and the intermediary and peak-load usually tends to have relevant participation of thermal electrical power plants. In this context, it is clear that if the deployment of AMI systems can modify the load profile curve into a flatter one, fast thermo electrical power plant units that are normally used to cover the peak-load will most likely be used less – under normal dispatch conditions –. Consequently, the CO_2 emission factor of the SIN would be reduced, or in other words, this would lead to additional GHG emission reductions. However, there is high level of uncertainty in this approach, and therefore it is not considered in this study.

3) Brazilian Evaluation: Methodological aspects and Results.

Considering the segments in which AMI systems deployment could cause load power reductions, mentioned in the previous section, this work aims to estimate the possible GHG emission diminutions in the a hypothetical scenario with high AMI penetration .

In order to perform the estimation, some considerations were taken:

- Eventual GHG emissions reductions associated with DSOs operational improvements are not considered, since they depend of each distribution management characteristics.
- During all the analyzed period (2015 – 2025) the SIN CO_2 emission factor is considered constant, the emission factor for the year of 2015 was used as reference (124,4 tCO_2/ GWh).
- Eventual reductions or increases in the SIN CO_2 emission factor are unconsidered, due the large uncertainties associated with an estimate regarding this fator.
- This study focus only in AMI systems for low voltage residential consumers with monthly average consumption higher than 100 kWh, therefore this set is considered as the target group. In 2015 the target group represented a total consumption of 116,898 GWh (EPE, 2016).
- The penetration of AMI systems through 2015- 2025 follows a logistic function in which by 2025 it is assumed that 90% of the target group would have replaced the traditional meters by smart meters.
- It is assumed that Consumer Premises (CP) with smart meters are charged with a Time-of-Use (TOU) rate, similar to ANEEL's White Tariff (ANEEL, 2013). Additionally, CPs benefits from implemented demand response management control strategies are considered.

As mentioned, the main objective of this paper is to quantify the potential annual power load reduction by the use of AMI installations and then estimate, through the use of the "Interconnected Power System CO2 Emission Factor" published by Brazilian Science and Technology Ministry (MCT, 2016), the avoided GHG emissions. To do this two scenarios were established, the BAU scenario and the AMI scenario.

a) BAU scenario

This scenario represents the expected projection of energy consumption and total load (consumption + losses) until 2025. Table 1 shows such estimates according to indicators obtained from the Brazilian energy research company (EPE). It was used data from the ten-year expansion plan (MME; EPE, 2015) and from the 2015 Statistical Yearbook of electricity (EPE, 2016). By comparing the SIN total load and the SIN total consumption it is possible to note that losses reduction are considered in the projection.

Table 1- Projection of SIN total energy consumption and load for base scenario.

Period	**LV Target group consumption**	**SIN Total consumption**	**SIN Total load**
	Variation (% a.a.)		
2014-2019	3.4%	2.6%	2.6%
2019-2024	4.8%	5.2%	5.1%
2025	4.1%	3.9%	3.8%

Year	GWh		
2015	116.898	461.761	578.011
2020	140.039	538.298	673.175
2025	175.852	685.016	852.582

The base scenario for CO_2 emissions is obtained by multiplying the yearly SIN total generation by the SIN CO_2 emission factor (124.4 tCO_2/ GWh) of 2015. As mentioned, this paper does not consider a variable emission factor due to the level of uncertainty that it entails. According to this methodology, the SIN GHG emission is 71.9 $MtCO_2$ in 2015 and 105.4 $MtCO_2$ in 2025.

b) AMI scenario

This scenario represents an accelerated penetration of AMI system into Brazilian distribution grid. It is considered that this study is focused in the AMI roll-out for Brazilian LV residential consumers with average monthly consumption higher than 100 kWh. This section presents estimations regarding the amount of annual electrical energy generation that could be avoided by means of the AMI technical benefits described in Section 2).

Figure 2 shows the AMI penetration curve that this scenario assumes, from 2015 until 2025. The percentage penetration of this Figure is given in terms of consumers units of the target group. As shown, the penetration curve follows a logistic function that is used to calculate the potential yearly load reductions

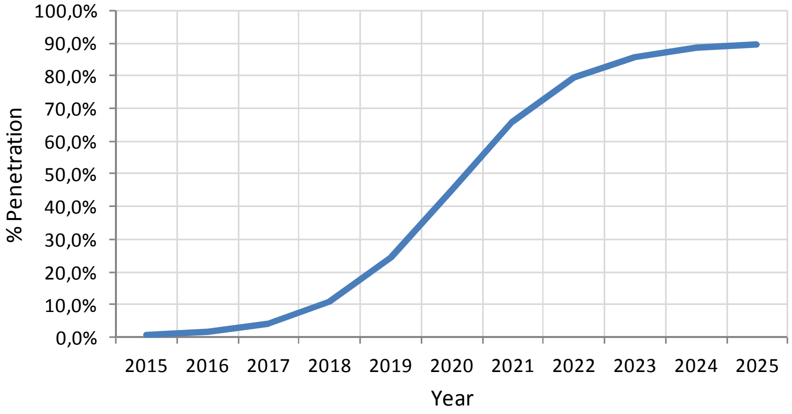

Figure 2 – Evolution of AMI penetration in the AMI scenario.

i) Reduction of non-technical losses

Reduction of non-technical losses could be a true driver for AMI deployment in Brazil. Figure 3 shows a data collection regarding the percentage of energy losses in the power systems of Brazilian DSOs in 2015 (ANEEL, 2016). As shown, there are cases in which the losses reach levels higher than 40% of the total injected energy. In contrast, some others DSOs have losses levels smaller than 5%. In (Villar et al., 2009) it is shown that there is a strong direct correlation between the socioeconomic complexity index and the non-technical losses level. The socioeconomic complexity index considers variables as violence, percentage of low income families, Gini coefficient and availability of public services in order to catalogue the complexity of each city or concession area. It is used by ANEEL to define the regulatory non-technical losses limits (ANEEL, 2015). From the information of Figure 3 the equivalent Brazilian non-technical losses level was estimated in 6.1% in 2015 that represented 33,745 GWh. According to (ANEEL, 2016), this meant an overall cost of BRL$ 8,152 million in 2015.

A Brazilian DSO – Ampla – implemented a pilot project, during 2003-2008, focused on the reduction of non-technical losses. The concession area of Ampla includes nearly 70% of the state of Rio de Janeiro, including some regions with a really high non-technical losses level. In 2003, it was verified that in an area with 30% of the clients, the energy losses accounted for 52% total market losses. Motivated by this situation, Ampla performed a series of actions to reduce these losses; including the implementation of AMI systems, in the most critical areas up to 50% of the consumers has replaced their traditional meter system by smart meters. According to its results, the non-technical losses of these critical areas reduced up to 37% in term of the initial value. By the end of the study, the global losses index of Ampla changed from 23.64% to 18.7% (Villar et al., 2009).

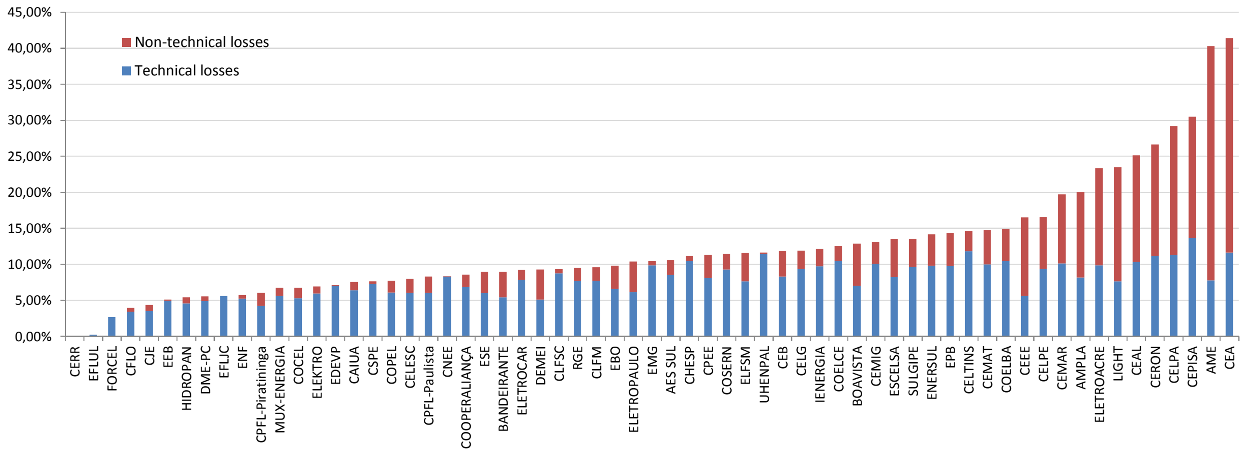

Figure 3 –Total losses in the distribution systems. Self-elaboration with data from (ANEEL, 2016).

In order to estimate the capability of AMI systems to reduce non-technical losses in the Brazilian power grids it was adopted a methodology based in the Mines and Energy Brazilian Ministry Smart Grid Report (MME, 2012), in which the diversity of Brazilian DSOs was considered by classifying the main 63 DSOs into 7 groups, according to their non-technical losses levels in 2015, as shown by Table 2. For each group, a new non-technical losses percentage was specified. It was considered that the AMI capability of losses reduction was higher for DSOs with higher levels of current non-technical losses. Based in the background of Ampla's results, it was supposed that for the DSOs with non-technical losses levels superior to 15% it is possible to achieve up to a 40% reduction after full AMI systems deployment.

Even though in this work it is considered the logistic curve of Figure 2 to represent the penetration of AMI systems along the 2015-2025 period, the Table 2 also shows the energy losses that could be reduced if the AMI roll-out had finished by 2015. This analysis has the purpose of giving an idea, with the current load levels, of how much energy would be saved, 8,634 GWh in total.

Table 2- Prevision of non-technical losses reduction after full AMI deployment

Current non-technical losses	**Non-technical losses after AMI roll-out**	**Number of distributor operators**
Below 3.5%	It maintains equal	39
Between 3.5% and 5%	3.50%	10
Between 5% and 6%	4.50%	2
Between 6% and 8%	5.50%	1
Between 8% and 10%	7.00%	1
Between 10% and 15%	9.75%	4
Above 15%	Reduction of 40% of current non-technical losses	6
Current Brazilian non-technical losses level	**Brazilian non-technical losses level after complete AMI deployment**	**Losses reduction [GWh/ 2015]**
6.1%	4.5%	8,634

Using the previsions of Table 2 and considering the penetration behavior of Figure 2 the load reductions for each year were estimated. As previous experiences have shown, when fraudulent installations are regularized there is a tendency of average consumption reduction for these installations (Simanoggio, 2009). In other words, some of the energy previously accounted as non-technical losses will not be consumed any more. This consumption rationalization is the focus of the current work, because it represents effective load reduction and GHG emission mitigation. In this work it is adopted the prediction of (MME, 2012) in which it is establish a 15% cut on top of losses reduction. Figure 5 shows the results obtained through the analyzed period.

One aspect that it would be interesting to include into the prevision of the Table 2 is the effect of the socioeconomic complexity index of each DSO, since as larger this index it is most likely that actions against the installed AMI units could be performed, as shown in (Villar et al., 2009). Unfortunately, to the best of the knowledge of this paper authors, there are not available results of a studies in which similar combating actions against non-technical losses have been made considering regions with high and with low socioeconomic complexity index. From the results of a study as the one mentioned, it would be possible to perform extrapolations to determine how the previsions of Table 2 could be affected by the complexity of each concession area. Therefore, this aspect is a recommendation for future developments in this area.

ii) Demand-side Management

Estimations of the load reductions that could be achieved by means of demand-side management actions have a large uncertainly associated since it is linked to the behavioral characteristics of the consumers. There are studies that have shown that even in projects with similar characteristics regarding the actions performed and the consumers profiles, it is possible to obtain much different results in terms of load reduction (University of Ulster, 2013). Considering the Brazilian pilot projects, the COPEL DSO used a sample of 230 low voltage consumers to test TOU rates. However since all consumers where notified that they would pay the lower tariff (between normal or TOU) the changes in their behavior were slight (Camargo, 2000). In other experience, the Banderiante DSO employed TOU rates on 2300 consumer premises, achieving a load peak shifting of 1.1 MW (MME, 2012)..

Regarding voluntary reductions, the British project "Smart Meter Early Learning" found, by detailed in-home surveys, that 60% of consumers with an IHD still had it in use when they were interviewed between 6 and 24+ months after the installation and that the energy rationalization activities appear to become more prominent the longer a consumer has had their smart meter. According to the experience, 36% of the consumers that had a smart meter for seven months or more said they had searched for more energy efficient appliances against 19% of the consumers that own smart meters less than six months (HC, 2016). This evidence opposes the idea that people would rarely make drastic behavioral changes in their energy use since energy is highly embedded in routine and key domestic activities, according with these results consumers are more likely to adjust gradually (Liddell, 2016).

Regarding electrical energy saving, a survey performed by (Covig et al., 2014) establishes that an average value of 2.6% (deviation of ±1.4%) has been reported, considering all EU Member States roll-out plans, and 3% (±1.3 %), considering only the countries that have already proceed or are proceeding with a wide scale deployment of smart metering systems. Additionally in (VaasaETT, 2011) a review of 100 pilots projects by the European Smart Metering Industry Group suggests savings of around 5-6% from interventions without an IHD, and an average of 8.7% in the cases of IHD usage. Similarly, an impact assessment of the roll-out of smart meters in Great Britain analyzed results of projects and trials and took a conservative approach by assuming a 2.8% reduction in domestic electricity consumption (DECC, 2014). Finally, (HC, 2016) presents a summary of results from a selection of smart meter studies relevant to Great Britain, these studies indicate that a load reduction of around 2–3% might be expected.

Regarding peak load shifting, an EU cost and benefits analysis due to nation-wide roll-out of smart electricity systems reflected that this is subject to considerable variation from less than 1% to 9.9 % (Covig et al., 2014). In contrast, a summary of the major trials regarding the UK smart meter projects shows that the general consensus appears to be that TOU tariffs can shift 8–10% of peak demand (HC, 2016). On the other hand, a survey of 24 residential pricing pilots between 1976 and 2011, in the USA, Europe and Australia, performed by the Brattle Group, found that TOU rates could lead to a reduction in peak demand between 3 and 10%; that Critical Peak Pricing (CPP) tariffs could lead to a drop in peak demand of between 13 and 20% (with maximum cases with peak reduction up to 50%); and that demand response technologies such as remotely controlled air conditioning units and other appliances in combination with CPP could drive to a reduction in the peak load between 27 and 44% (with some extreme cases reaching reductions higher that 50%) (Faruqui et al., 2012 e Faruqui; Sergici, 2010).

Taking into account the aforementioned findings, the AMI scenario uses the considerations of Table 3 as the goals to be reach by the end of the analyzed period (year 2025), when the AMI roll-out is completed. Figure 5 shows the behavior of the load reductions obtained.

Table 3- Assumptions used regarding benefits obtained by demand-side management actions

Load Reduction in 2025	**Peak load shifting in 2025**	**% of consumer target attended in 2025**
2%	5%	90%

iii) Efficiency Improvement

As mentioned before, the load reductions and peak load shifting obtained by items i) and ii) affect the charging level of the distribution power system. Regarding to load diminution, it can be noted from the results of Figure 5 that the reduction estimated for the year of 2025 by item i) and ii) sum 5,042 GWh; if compared with the BAU consumption projection for the LV target group in that year (see Table 1), it can be identified an 2.87% reduction.

In regard to load peak shifting, Table 3 established an estimate of 5% for the LV target group. In order to consider both effects into the efficiency improvement evaluation it was supposed that in the AMI scenario consumers are charged by an energy rate similar to ANEEL "white rate" which has the structure described in Table 4 (ANEEL, 2013).

Table 4- "White rate" composition and assumed periods

Rate applied	Definition	Schedule assumed
Peak rate	A consecutive period of three hours	7pm to 10 pm
Intermediate rate	Period formed by the immediately preceding hour of the peak period and by the immediately following hour of the same period	6pm to 7pm and 10pm to 11pm
Out of peak rate	Period formed by the complementary hours to peak and intermediate periods	Remaining hours

Taking into account Table 4, it is assumed that the load profile curve of Figure 1 is reduced in 5% during the peak rate period and by 2.5% during intermediate rate period. It is also assumed that the displaced energy is allocated in the following two hour intervals: 4pm – 6pm and 23pm – 1am. In addition to this load shifting, the total energy of Figure 1 is decreased by the previously cited 2.87% factor. The resulting average load profile curve under these considerations is shown in Figure 4. This curve is used as reference to estimate the potential technical losses reductions caused by AMI deployment.

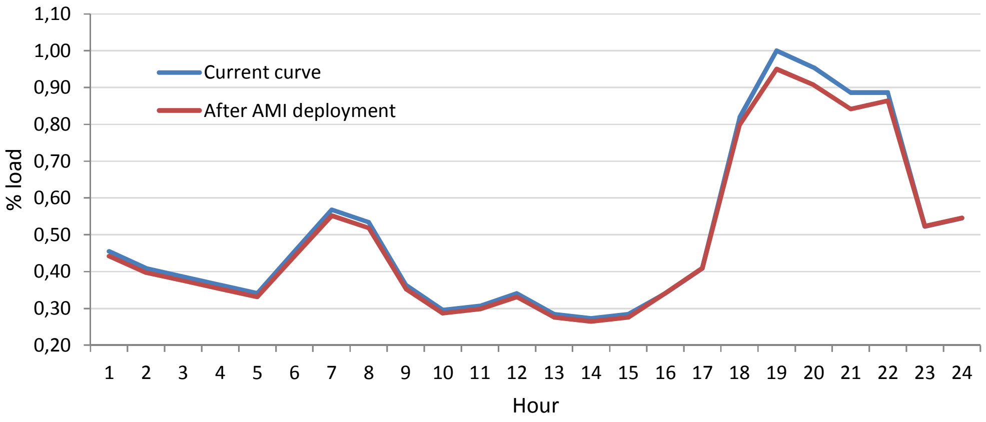

Figure 4 – Average load curve after AMI deployment.

In this paper it is considered that the modifications of the daily load profile for the LV target group of Figure 4 affect only low voltage and medium voltage power grids. With the aim of taking into account the characteristics of the Brazilian distribution systems, regarding technical losses, into the estimations made in this study, it was used actual data from five of the most important Brazilian DSOs. This information consist of the injected energy into the grid, energy supplied to the consumers, technical and non-technical losses and losses in each segment of their power system (high voltage grid, HV/ MV transformers, medium voltage grid, MV/LV transformers, low voltage grid, meters, etc.). This information was submitted by the DSOs to ANEEL (Brazilian regulation body) as a part of the periodic rate review process. The list of the companies considered is shown in Table 5.

Table 5-Distribution system operators considered in the analysis

DSO	2015 market [GWh]	Reference
Aes Eletropaulo	54,543	ANEEL Technical note 0018/2012
CEMIG	52,679	ANEEL Technical note 0053/2013
CPFL Paulista	35,985	ANEEL Technical note 0051/2013
COPEL	34,700	ANEEL Technical note 0036/2016
CELESC	26,935	ANEEL Technical note 0072/2016

In this evaluation it was considered that the technical losses of LV grids depend in a quadratic way of the circulating current (losses caused by Joule effect). Under this assumption, the modified average curve of Figure 4 will cause a diminution of 6.3% in the technical losses. Considering that the average relation between the target consumption group and the overall low voltage consumption is 53.1% (EPE, 2016), the equivalent LV grid technical losses reduction was estimated in 3.39%. Using the DSOs data cited in Table 5 it was possible to extrapolate this estimation to determine the average reduction in the cases of MV/LV transformers and the MV grids, as shown in Table 6.

Table 6 – Medium technical losses reductions in Brazilian DSOs due to residential AMI deployment.

Segment	**Segment's energy that is injected into the low voltage grid [%]**	**Losses reduction [%]**	**Relation between Segment's losses and total SIN losses [%]**	**Equivalent SIN technical losses discount [%]**
Low Voltage grid	100%	3.39%	6.10%	0.21%
transformers (MV/LV)	74%	0.79%	24.95%	0.19%
Medium Voltage grid	45%	0.70%	25.77%	0.18%
Total Expected Reduction				**0.58%**

From Table 6 it can be seen that the equivalent 3.39% technical losses reduction of the LV grids represents a discount of 0.21% in the Brazilian total technical losses, since the technical losses in LV grids represent 6.10% of the overall SIN losses. According to Table 6, AMI systems deployment could reduce the total technical losses by 0.58%, this would represent a reduction of 253 GWh in 2015 in the hypothetical case that the AMI deployment had already been performed and finished by this year. For the AMI scenario studied in this work, the reductions follow a logistic behavior, as shown in Figure 5.

i) Total Load Reduction and Emission Mitigation

The sum of the reduction estimates performed in the previous sections is presented in Figure 5. It shows the total load reductions achievable through AMI deployment for the target group, identifying the aspect that originated each discount. According to the results obtained in 2025, when the roll-out of this technology was totally performed, it is possible to obtain a load reduction of 5,412 GWh, which is equivalent to 0.79% of the projected SIN's consumption for this year. It could be noticed that, for the current analysis, the area that mainly contributes with the load reductions is demand-side management, however it is highlighted that if the consumption rationalization of previously fraudulent installations, established in section 3 as 15%, would be equal or superior than 25% (in other words, considering a less conservative scenario) then the non-technical losses combat, which normally is considered the main economic incentive, would represent the main driver for load reductions.

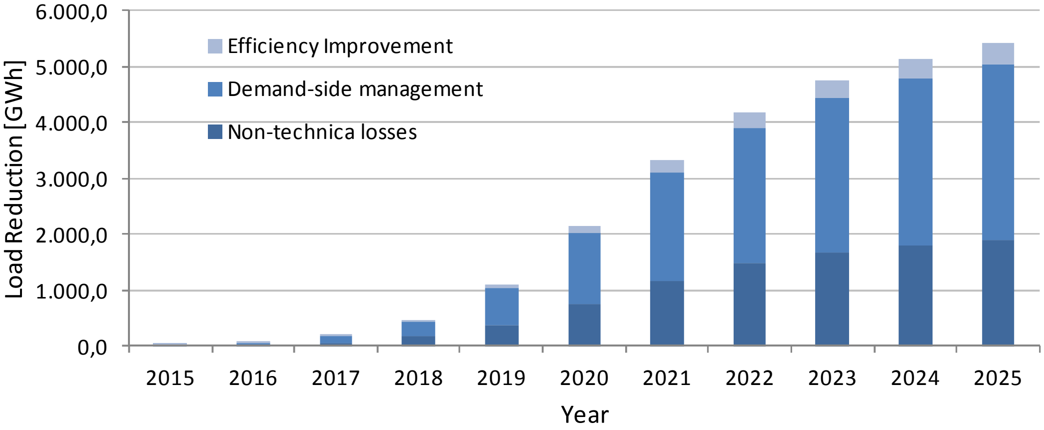

Figure 5 – Annually load reductions due AMI between 2015-2025.

In relation to the avoided GHG emissions, the methodology applied considers that the 2015 SIN´s CO_2 emission factor will remain constant through the whole period of analysis (124.4 tCO2/GWh) (MCT, 2016). The obtained results are shown in Figure 6 in which it is possible to identify an annual mitigation of 0.64% of the total interconnected electrical system direct emission by the time the AMI roll-out is finished. Regarding to the accumulated reductions, it was found that it would be possible to avoid a total of 3.3 MtCO2 emissions during the 2015-2025 period.

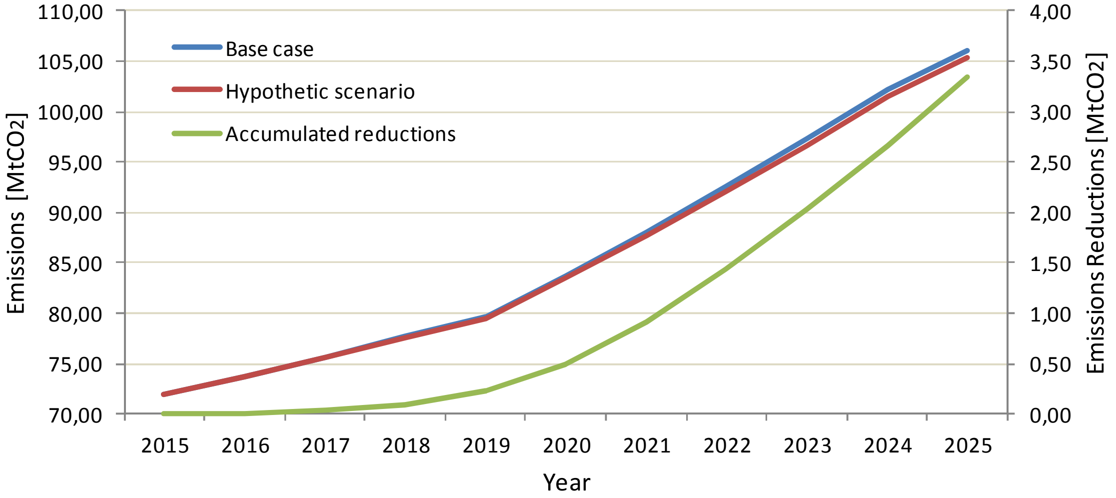

Figure 6 – Annually CO_2 emissions in BAU and AMI scenarios. Accumulated CO_2 emissions reductions until 2025.

4) Cost Estimation of the AMI scenario

This section looks at the likely deployment cost of the AMI scenario. This evaluation is based on the conclusions of the cost analysis of previous experiences from countries that have already implemented large smart metering installation projects. All the evidence reports analyzed reach the same conclusion, capital and operational costs of the smart meters are the major expenses in an AMI roll-out, followed by the capital and operational cost due to data communication (Covig et al., 2014 e DECC, 2014 e Kemp et al., 2008 e MME, 2012).

In (DECC, 2014) the cost of AMI systems roll-out was categorized as follow: i) Meters & IHDs (*capex* and *opex*): 42% of the total cost, ii) installation of the metering system: 16% of the general cost, iii) infrastructure improvements related to communication systems, data management and upgrades to the distribution network: 30% of the total cost and vi) other costs such as disposal costs and costs associated with consumer engagement activities: 12% of the costs.

For (Kemp et al., 2008) the meter cost and its installations represent the first and second larger cost for a smart metering system roll-out. According to that analysis, the estimated cost of both items accounts for 71-80% of the total transitional cost. The third most important cost is the one related to upgrades in the distribution network and, the fourth most important cost category is the provision of communications. On the other hand, according to a survey made by ERSE, the Portuguese regulatory agency, the necessary investments for upgrade the information and communication system would be 30% of the investment need it for purchase the smart meters (MME, 2012).

A Brazilian pilot project implemented by Cemig DSO analyzed the technical and economic viability of the value chain involving smart grid technology. According to the information provided by Cemig, the costs of the network automation and adaptation corresponded to 49,2% of the purchase and installation cost of the smart meters (MME, 2012). In the report on smart grids of the Brazilian Ministry of Mines and Energy was considered that, based on the characteristics of the Brazilian infrastructure, it more suitable to consider the values presented by Cemig as the reference for the Brazilian cases i.e. that the necessary investments for network upgrading represent 50% of the smart meters cost (MME, 2012).

In the current economic evaluation it was adopted the Ministry of Mines and Energy consideration in which network improvement costs account for 50% of the smart meters costs (meter acquisition + installation costs). Additionally, it was supposed that the sum of both costs (smart meters investments and network improvement) represents 80% of the total roll-out expenses. In order to develop this approach it was adopted an average smart meter cost of R$278.50, as indicated by (MME, 2012), this value was corrected to current prices by the use of the accumulated consumer price index for the correspondent elapse period (2012-2016) (BCB, 2017), the resulting cost is R$380. This data treatment was performed in the absence of more recent data of smart meter prices from official sources; however it is possible that the evolution of the smart meter industry into a more mainstream and mature one lead to a price drop, counteracting the inflation effects. Nonetheless, this assumption is not considered in this study.

Under the aforementioned considerations, the average cost per consumer premise (CP) of the full AMI roll-out is R$713. According to the 2016 Statistical Yearbook for Electricity, the number of residential CPs in 2015 was

67.7 million. In this study it was estimated that 31.9 million CPs fit into the target group of LV residential installations with monthly consumption superior than 100kWh in 2015. Furthermore, it was extrapolated that in 2025 the number of CPs with AMI installations would be of 43.3 million. In this sense, the overall cost of AMI roll-out was estimated in R$30.8 billion.

5) Conclusion

AMI systems aim to modernize traditional electric metering systems through the introduction of communication and management technologies. Besides their technical improvement virtues, AMI systems can be seen as a measure for GHG emissions mitigation.

Using data from academic literature and from previous experiences, this work sought to estimate the role of AMI systems in GHG direct emissions reduction for the Brazilian interconnected power system, considering two scenarios, BAU scenario and a hypothetical scenario with an accelerated AMI penetration in residential consumers with monthly average consumption higher than 100 kWh. Initially, it was quantified the potential annual power load reduction as a result of three technical benefits of an AMI roll-out: i) Reduction of non-technical losses, ii) Demand-side Management and iii) Efficiency Improvement. Then, the total energy reduction was transformed into avoid GHG emission through the use of the "Interconnected Power System CO_2 Emission Factor" published by Brazilian Science and Technology Ministry (MCT, 2016).

The final estimation of the load reduction for the target group, considering that by the year of 2025 90% of the target group consumers would have been incorporated into the AMI system, is of 5,412 GWh, which is equivalent to 0.79% of the projected SIN's consumption. Regarding CO_2 emission mitigation, it was estimated an accumulated reduction of 3.3MtCO_2 during the 2015-2025 period. The cost estimation resulted in a total investment of R$ 30.8 billion (present value of 2016).

The findings obtained in this work can be added to the known technical benefits of AMI systems as information that can be useful for decision makers in order to evaluate the viability of AMI deployment. It is important to mention that this paper does not intend to present AMI systems only as a measure of GHG emission mitigation but rather to show an additional advantage of the technical benefits of the AMI roll-out in an electrical power system. Since the approach used in this study determines the GHG emissions reductions in terms of a reduction in power load, the results depend directly on the SIN CO_2 emission factor, which is ruled by the share of renewable or no-renewable energy sources in the power mix of the country.

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