Colombia AMI

System Design:

Initial hypothesis report

August 2016

The Carbon Trust wrote this report based on an impartial analysis of primary and secondary sources. The Carbon Trust's mission is to accelerate the move to a sustainable, low carbon economy. It is a world leading expert on carbon reduction and clean technology. As a not-for-dividend group, it advises governments and leading companies around the world, reinvesting profits into its low carbon mission.

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Acronyms

AMI – Advanced Metering Infrastructure

ANM – Active Network Management

CREG – Comisión de Regulación de Energía y Gas

DA – Distributed Automation

EPM – Empresas Públicas de Medellín

EPSA – Empresa de Energia del Pacifico

EV – Electric Vehicles

FCO – Foreign & Commonwealth Office

GSM – Global System for Mobile Communications

GPRS – General Packet Radio Service

LAN – Local Area Network

NEP – National Expansion Plan

PLC – Power Life Carrier

PV – Photovoltaic

RF – Radio Frequency

TC – Telecommunications

UPME – Unidad de Planeación Minero Energética

WAN – Wide Area Network

Introduction

Overview of project

This report was written by the Carbon Trust to provide a framework for selecting an Advanced Metering Infrastructure (AMI) system in Colombia. This output forms part of a larger body of work in collaboration with UPME and FCO Colombia with the goal of: "Structuring a programme for the implementation of AMI, including its associated ownership structure, for the Colombian electricity sector in order to facilitate integration of renewable energy technology at optimal cost, provide new services to customers and further the development of smart cities". Overall the project is split into four discreet outputs which together will help achieved its stated aims. The four outputs are:

- **Output 1:** Map AMI key functionality, assess Colombia's desired AMI outcomes, and develop an initial hypothesis
- **Output 2:** Recommend an AMI Roll-out Strategy for Colombia
- **Output 3:** Perform a high level Cost Benefit Analysis to assess financial requirements of the roll-out
- **Output 4:** Coordinate workshops to promote UK-Colombia ties regarding AMI.

This report forms the basis for the first of these outputs. The aim of the report is to introduce the options for AMI system design, assess the specific needs of AMI in Colombia, and ultimately to formulate an initial hypothesis on the question of 'which AMI system would be best suited to Colombia's needs?' The report is largely be a qualitative assessment of options and concludes by highlighting the specific questions that will need to be answered in the next phase(s) of the project to test this initial hypothesis. It is hoped this approach will help tie the findings of this report directly into the next phase of the project and make it relevant for accomplishing the continued aims of the project.

Overview of the Colombian market

Electricity grid

Colombia has an advanced energy system with an annual energy demand of around 66.2GWh. Electricity demand in the country is expected to grow at a rate of around 4.6% (per year) out to 2030, in line with strong GDP and population growth over the same period. The majority of this electricity comes from hydroelectric dams (~64%), though there are currently plans to diversify the energy mix of the country. Thermal generation, such as natural gas and coal, make up the majority of the remaining energy supply (~31%), with a small amount from other sources, like micro-scale generation and combined heat and power plants (~5%), making up the rest.

The energy network in Colombia is split between a transmission and a distribution grid. The transmission grid operates at the National Transmission System level (>220kV) and the Regional Transmission level (>115kV and <220kV). The transmission network is owned and managed by seven public companies with one central network operator.

The distribution network on the other hand is operated by more than 30 utility companies, each covering a distinct region (see figure 2 of Colombian regions on next page). The five largest of these utilities (Codensa, EPM, Electricaribe, Emcali, and EPSA) together supply more than two-thirds of the market.

Electricity metering

The transmission companies mentioned have already installed an advanced metering system to help monitor and control the electricity system at this level and, for this reason, the transmission network is out of scope for this report.

Almost 60% of the ~12.1m meter points across the country are still using analogue/mechanical or electromechanical (i.e. ‘dumb’) metering technology (see figure 1). Moreover, even the electronic meters in place do not, in most instances, have the digital hardware necessary to communicate as part of an AMI system. Also, the distribution network in Colombia continues to face several major challenges. For example, Colombia has a high rate of both technical and non-technical losses in the distribution network, with non-technical losses at around 12% nationally (and rising to over 20% in some regions).

There is growing consensus that implementing an AMI system in Colombia could help reduce costs significantly by identifying where these losses occur in the system. In fact, AMI could also provide a series of other benefits to Colombia, such as reducing power outage times, improving network planning, and helping integrate distributed generation, among other things (see ‘Benefits of AMI systems’ below). With this in mind, several of the Colombian utility companies have begun conducting pilot projects to test AMI system designs in the field, many of which are showing initial success (see Appendix 1). Having said that, there is no one-size-fits-all model for AMI systems, with many different technology and communication options offering a range of functionalities at varying costs. Resultantly, there is currently no national roll-out plan for AMI in Colombia, with multiple discussions still in progress on which AMI systems to support, and how best to implement an AMI roll-out plan. With that in mind, the next section of this report is aimed at assessing what AMI system design options are available for the Colombian market.

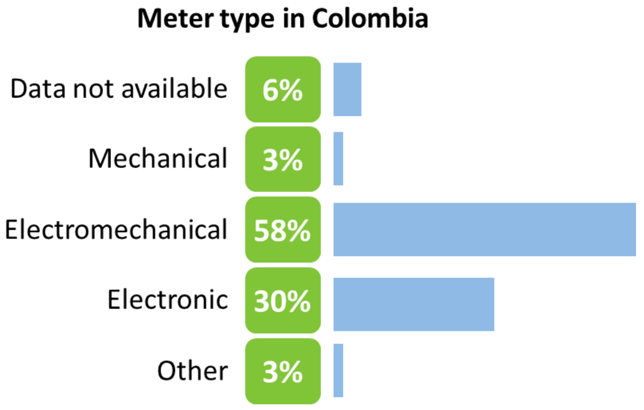


Figure 1: CREG, Smart meter pilot

Figure 2: Maphill, Political map of Colombia (2016)

1 AMI system design options

At a high level, AMI systems monitor (and help control) grid activities, ensuring the efficient and reliable two-way flow of electricity information between consumers, utilities, and generators[1]. AMI systems are often promoted as a route for energy saving, real-time pricing, automated data collection, avoiding the human errors and costs from manual reading, and as a method of diagnosing network issues and detecting network faults virtually. However some AMI systems also allow commands to be sent to operate grid infrastructure devices, such as distribution switches and distributed generators in real-time.

As figure 3 highlights, typically, AMI communications have multiple layers. Smart meters collect data locally and transmit via a Local Area Network (LAN) to a data collector. The collector retrieves the data and may carry out processing of the data on site or transmit it directly via a Wide Area Network (WAN) to the utility central collection point for processing and assessment. The communication method used at the LAN level does not have to be (and often is not) the same as that chosen for the WAN level. It is important to state here that the scope of this work is only to select an AMI system design for the meter itself up to the collector, often known as the 'last mile' (i.e. the LAN communication system). Communication options beyond this point (i.e. WAN communication systems) are generally less complex to design and have less trade-offs because of the nature of the data (e.g. aggregated and compressed into larger packets) and the network (e.g. fewer nodes) past this point. For this reason it is usually effective and inexpensive to transfer this data to the utility via a cellular or Ethernet (e.g. fibre optic internet connection) service. However, as stated, this level of the design is not part of the scope of this project.

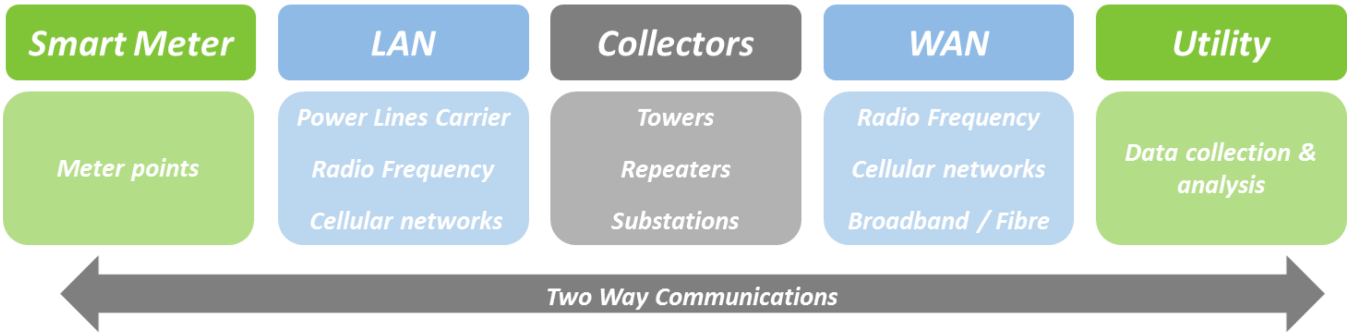


Figure 3: AMI communication layers, Carbon Trust analysis

At the LAN level, there are a variety of different metering technologies and communication options available which could constitute an AMI system. The chosen communication option used to send/receive metering data has a significant impact of the rest of the system design, as without sufficient communication capabilities then much of the potential functionality in a meter may be redundant[2]. For example, while meters may be capable of sending and receiving information on the spot pricing for electricity (based on real-time supply and demand metrics), without a low latency communication system to allow this information to be transmitted in real-time, the information cannot be utilised effectively by consumers to optimise their energy use. The communication platform is also the true enabler of the smart grid system as it provides two-way communication capabilities for moving data between the utility and individual meter points, without which utilities could not understand and improve the energy network at such a granular level. With that in mind, this report has adopted a 'communication-led' approach, whereby the AMI system designs are primarily categorised and evaluated based on the functionality that different communication options can support.

Types of AMI system design

In line with the communication-led approach outlined above, the following section provides an overview of the three major communication options available for AMI systems at the 'last mile' of connection. Each technology is described briefly along with some of the key advantages and disadvantages of each.

[1] Ping, Y (2010), Wireless Mesh Network, IETE Technical Review, Vol.27, Issue 1
[2] Budka, KC (2010), Communication network architecture and design principles for smart grids, Bell Labs Technical Journal, Vol.15

Power Line Carrier

I- Description:

i. Power Line Carrier (PLC) systems enable data to be transmitted from the meter through pre-existing electricity wiring and up the power line directly to a collection point, usually in the distribution substation feeding the meter. The data is then delivered to the utility data systems for processing at a central location.

II-Pros:

i. Can use the **existing utility infrastructure** of poles, wires, and sub-stations. This ensures that PLC systems have high penetration while also being highly cost effective for most functionality requirements (e.g. meter reading and limiting non-technical losses).

ii. Has been **installed in many other countries** (especially in Europe) and is the most established of the AMI communication technology types. This not only means that PLC systems tend to be the cheapest, but also that they have a mature markets with developed supply chains for components and services.

iii. Generally the most reliable and **effective in challenging terrain**, with improved cost effectiveness for rural lines. PLC systems also have the capability to work over long distances as long as electricity infrastructure is in place.

iv. **Offers most of the benefits of an AMI system** at a generally low price, including granular data collection to help identify non-technical and technical losses, as well as improve network planning.

v. PLC systems are also beneficial from the perspective of distribution utility operators as upgrades **remain in control of the utility** and add to their asset base. This may help make operations of the PLC system more efficient as construction, maintenance, and upgrades are carried out by the same company.

III- Cons:

i. Tend to have **longer data transmission times (higher latency)** than other options as data is not generally transmitted in real-time but in larger 'packets' (usually once a night).

ii. Generally has **less functionality due to having less bandwidth** and throughput than other systems. For example PLC systems tend to have limited ability to interface with distribution automation (DA) devices and real-time management of distributed generation (DG).

iii. The **economics are highly dependent on the architecture of the energy system**. For example, if the distribution network is not designed with each transformer servicing many meter points then PLC systems quickly become cost prohibitive.

iv. There may also be relatively **higher costs in suburban or rural areas** due to the relative number of transformers per meter point.

v. PLC systems also have the **potential for network interference,** (e.g. large industrial customers may introduce noise and harmonics on the power line that may affect system performance and distort communications).

IV- Additional information:

i. PLC systems have already been established in numerous countries, including parts of North America and numerous countries in Europe (e.g. Italy, Sweden, and Hungary).

ii. Although the basic design is the same, in reality PLC is available as either narrowband or broadband PLC. Broadband PLC is generally a more expensive system design but can deliver some additional services (e.g. limited real-time services such as 'last gasp' outage warnings).

Radio Frequency

I- Description:

i. Radio Frequency systems (RF) transmit data by wireless radio frequency. Meter points can connect to other nearby meters to form an RF ‘mesh’ of network coverage which then uses points closest to the collector to transmit data from multiple meters. Alternatively meters can talk directly to the collector in a ‘point-to-point’ RF design. The collector itself is usually a radio tower which is either purpose built, or can be leased from existing infrastructure operators. Data is then packaged by the collector and sent to the utility for processing at a central location.

II- Pros:

i. Has **lower latency data transfer and higher bandwidth** than PLC systems, meaning it can send and receive information in near real-time. This is often crucial for advanced AMI functions such as Active Network Management (ANM) and integrating intermittent DG sources.

ii. Most RF systems are **self-healing.** If one module loses communication with the network, the system is capable of automatically findings another path to bring communications back to the collector. This significantly reduces the chance of the system going offline.

iii. Most arrangements are also **self-forming**, meaning they can find the optimal route back to the collector. This is particularly important as it means the **system can function in areas with many obstructions**, such as mountains or high-rise buildings.

iv. Generally systems **can be deployed regionally**, meaning the operator can target and install RF mesh services in specific (e.g. high DG deployment) areas without the need for national roll-out.

v. RF systems are also beneficial from the perspective of distribution utility operators as upgrades **remain in control of the utility** and add to their asset base. This may help make operations of the PLC system more efficient as construction, maintenance, and upgrades are carried out by the same company.

III- Cons:

i. **Cannot be installed without a clean available radio frequency** to transmit on. In many countries viable frequencies have already been utilised for other services, or there have been serious concerns that unlicensed frequencies could interfere with transmission.

ii. Generally the need for the construction (or leasing) of collection point infrastructure means that RF mesh systems **tend to be more expensive** to install than PLC systems

iii. **Costs also rise quickly as customer density falls** as increasing amounts of infrastructure need to be installed per meter point in rural areas with large distances or difficult terrain between metering points.

iv. RF mesh systems **need to be installed at a large scale** to ensure there are sufficient devices to create an effective network, meaning that RF systems cannot be used for single meter installations.

IV- Additional information:

i. RF systems have already been established in some countries, including North America in particular where RF mesh systems are the predominant AMI option currently.

ii. In real terms the difference between ‘RF mesh’ systems and ‘RF point-to-point’ systems is that the former has added benefits (e.g. better self-healing), while the latter tends to be cheaper as less infrastructure is required.

Cellular networks

I- Description:

ii. Cellular AMI systems transmit data using the mobile telecommunications network (e.g. GSM/GPRS). In most cases this means using a commercial cellular network to connect smart meters to the network, which then transmit information either to a collection point or directly to the utilities data processing sites.

II- Pros:

i. Have **very low latency data transfer and very high bandwidth**, meaning they can send and receive information in near real-time. Due to this cellular systems are best placed to deliver advanced AMI functions such as Active Network Management (ANM) and integrating internment DG sources.

ii. Cellular systems can be rolled out quickly with coverage to the majority of customers because they can **leverage existing infrastructure and customer coverage** from establish telecommunications networks.

iii. Can be **optimal for targeted applications** as they can be deployed cost-effectively to support small groups (or even single) customers by using the pre-existing mobile network.

iv. Generally **very reliable, with good integration with other devices** because of the established nature of the mobile communications network.

III- Cons:

i. Serious **concerns over technology obsolescence,** as cellular networks tend to roll over to new technologies (e.g. 3G to 4G) quicker than AMI systems need to be replaced, creating a risk that cellular systems will be left unsupported by telecoms companies (or that companies will charge high costs to keep the service operating). Alternatively AMI systems will have to be upgraded before they would otherwise need replacing.

ii. Generally cellular systems have proven **more expensive** than other options, especially because in some cases collector head-ends may need to be changed to be made compatible with cellular transmissions

iii. The pricing of data communication in cellular systems is generally controlled by telecom companies and there are **concerns over future price** hikes (see above).

iv. Cellular networks **may not be able to provide full coverage**, with remote areas out of mobile reception range or prone to connectivity outages unlikely to be able to use the system effectively.

v. They may also be **unreliable** with network congestion or connectivity issues in some areas causing potential problems for cellular systems (e.g. natural disasters or large public gathering causing mobile network congestion).

vi. From the perspective of electricity distribution utility operators, cellular systems are an issue because they are **out of the direct control of utilities**. This may could make operations less efficient as construction, maintenance, and upgrades of communications assets may not align well with plans from owners and operators of the AMI system.

IV- Additional information:

i. Cellular systems are already in widespread deployment around the world for large scale industrial customers, though they have had limited testing at the domestic level.

ii. Some countries, such as Australia, however have established cellular systems at the domestic scale, with several others countries currently in the process of implementing similar systems (e.g. the United Kingdom).

Other system options

Whilst the three AMI communications options discussed above are unambiguously the leading archetypes for AMI system design, it is important to note that several other communications options are available. For example, it has been suggested that AMI data could be transferred directly via home internet connections. In this framework, smart meters would communicate via home wireless (or Ethernet cables) with individual modems, which would then route the data directly to the utility via broadband or fibre optic cables used for internet connections. The large advantage of this system is that it could have extremely high bandwidth and near real-time latency by piggy-backing off home internet connections. It would also be relatively cheap as there would be limited need to install additional infrastructure. Having said that, the biggest down side for a system like this is that it relies on near 100% internet connection to meter points, which most countries is simply not a reality yet. Moreover, much of this technology has not yet been tested on a national scale and could have unseen risks or costs when in operation. For these reasons, alternative systems such as this have not been considered explicitly in the rest of this report. However the potential for an Ethernet (fibre optic) system in Colombia is discussed (and ultimately dismissed) in the final section of the report.

It is also important to mention here that, while this section represents AMI communication options as discrete options, in reality hybrid systems are possible. For example Germany has an 80% GPRS (cellular) system design, with 20% PLC services used in areas where this was more feasible. Moreover, it is also possible to install and upgrade different systems in different areas according to the specific needs of that area - though there may be associated cost inefficiencies with doing so.

The Role of the Meter

At the time of writing this report the Universidad Nacional de Colombia (UNC) is undertaking a separate study focusing on the appropriate meter functionality for Colombia and we have been working closely with the UNC to ensure this project is complementary. Whilst the UNC project will provide far more detail, below we present some of main considerations for at-the-meter functionality. Given the global market for smart meters at present, we do not consider the functionality below to add significant cost to potential AMI system for Colombia.

Component	Question	Considerations for Colombia
Clock	What minimum time intervals should the clock have?	• Hourly readings as a minimum for residential customers • Extra energy efficiency benefits could be realised through more granular reading for non-domestic customers
Data storage	What data storage capability should it have and for how long should data be stored?	• The meter should store one year's consumption data
Data display	What should be displayed by the meter?	• The meter should display simple consumption data • Customers should be able to access more detailed information from their energy supplier via a smart phone or PC • We do not see any need for an in-home display
Payment mode	Should the meter be capable of operating in credit and pre-payment mode	• The meter should be capable of switching between credit and pre-payment mode remotely
Pricing & billing	Should the meter be able to calculate pricing based on the customers tariff?	• The meter should be able to calculate energy costs based on hourly consumption and the tariff

Security	How will the meter secure the data it transfers?	• The meter should encrypt data before it is transferred
Energisation	Should the meter be capable of remote (de) energisation?	• The meter should have remote energisation and de-energisation
Interfaces	**Question**	**Considerations for Colombia**
HAN interface	Should the meter have a HAN interface?	• At this stage we see no need for a HAN interface as demand side response is not a significant need in Colombia
Gas interface	Should the meter have a gas interface?	• We see no need for a gas interface in Colombia given the relatively poor cost-benefit analyses for gas metering infrastructure across the world
Water interface	Should the meter have a water interface?	• We see no need for a water interface in Colombia given the relatively poor cost-benefit analyses for gas metering infrastructure across the world

AMI system costs, benefits, & functionality

AMI systems have a wide variety of potential functionalities which can produce an equally wide variety of benefits. However different systems also have varying costs associated with this functionality. This section will first describe the indicative costs and benefits of archetype AMI systems, before discussing how some of these benefits may be limited by the communication system elected.

Indicative costs

While the exact cost of AMI systems can vary significantly due to location specifics (see 'Risks and complexities'), general global experience suggests that PLC systems can be the least expensive. This is primarily because they can harness pre-existing electricity infrastructure, reducing the large installation (capex) costs required for systems such as RF networks, which require the installation of radio towers. Moreover, PLC systems generally also have relatively low operational (opex) costs due again to their ability to piggy-back on existing infrastructure. This differs significantly from cellular systems, which require the overlay of an entirely new communications layer to operate. In reality this can usually be leased from established telecommunications companies, although such leasing is itself often a key component driving up the operational cost of cellular systems. Moreover, because PLC systems have been established in numerous countries already (see 'Power Line Carrier' above), the cost of equipment and services for PLC is generally lower than other systems because of the mature nature of the market and established global supply chains. Although a full cost-benefit analysis for Colombia will only be carried out in the second stage of this project, it seems reasonable to initially categorise PLC as a generally low cost system.

RF mesh is generally considered the second most established AMI communication technology, having also been deployed in numerous countries (see 'Radio Frequency' above). Again this means that decades of learning have helped bring down the cost of RF technologies and create an established supply chain of RF components for AMI systems. Once again however, the exact costs of an RF system depends on local conditions and, critically, may not be possible at all in certain situations (see 'Risks and complexities' below). Having said that, if RF is possible then the costs are fairly straightforward, with well-established knowledge internationally on the volume and cost of infrastructure upgrades needed per meter point. For these reasons, RF systems have been indicatively categorised as having medium costs.

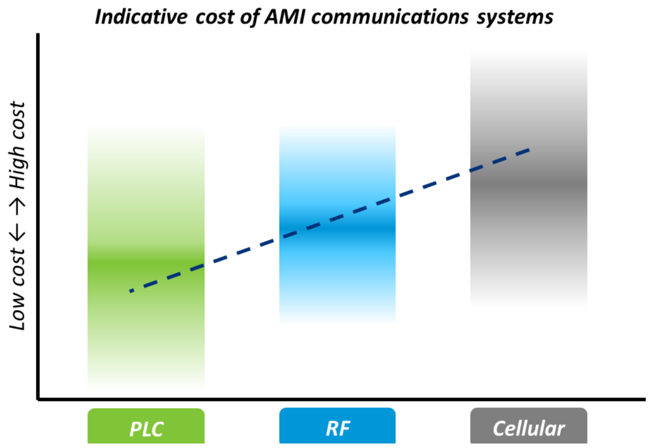


Figure 4: Landis+Gyr (2013), communication component of smart grid solutions & Carbon Trust analysis

Finally cellular AMI systems are thus far the least tested of the three options. Although they have begun to be rolled out successful in several major countries (see 'Cellular network' above), current experience suggests that these systems are the most costly. This is partly due to the lack of a mature market for all the necessary components needed for cellular AMI systems, and partly because cellular systems generally have higher component and operational costs. Once again, it is important to say here that the exact costs of a cellular system will vary due to local setting and a full cost-benefit analysis in the Colombian context has not yet been carried out. However, all things considered, it seems reasonable for this report to initially categorise cellular systems as relatively high cost.

Indicative benefits

Numerous benefits from AMI systems are possible, with many able to be broken down into further sub-benefits (e.g. reduction of CO_2 can be broken down into different direct and indirect sources). However to help establish a framework for assessing AMI system design in Colombia, this report has categorised AMI benefits into 12 distinct categories[3]:

1. **Reduce non-technical losses:** One of the key functions of AMI systems is their ability to identify and alert utilities to non-technical losses. Non-technical losses (sometime called 'electricity theft') can be carried out either by directly tampering with the meter (e.g. rolling the meter back) or through illegal connections onto the powerline itself. In many countries both these issues are a key drain on the energy system and create a significant additional cost to utilities and consumers. AMI can reduce this through 'tamper detection' services, as well as triangulating data on unexpected losses from the system.

2. **Enhance retail competition**. Retail competition has largely been delivered in Europe via the unbundling of network and retail activities. This has proved to be an expensive method with unproved success. If Colombia wishes to pursue further retail competition, making hourly consumption data available (with the customers permission) to alternative suppliers will help spur the market and the development of more sophisticated tariffs.

3. **Improve network planning:** The volume and granularity of AMI data allows utilities and network operators a much better picture of the current network, including areas reaching maximum capacity or suffering from reduced power quality issues. This data can be used to plan network expansion and upgrades in a much more cost effective manner, reducing the overall installation and operational cost of the network.

4. **Reduce technical losses:** Technical losses from inefficient or damaged network infrastructure also creates serious additional costs for countries. AMI systems can help accurately identify where these losses are occurring to help them be repaired in a cost effective manner. AMI data can also be used to predict where technical losses are likely to occur in the future (e.g. strained parts of the network) allowing problems to be prevent before their cause outages or damages to the network.

5. **Provide consumer information:** AMI systems can be connected to in-home displays to give consumers real-time metrics on their electricity usage and consumption habits. Customers can have daily or on demand reads and this can also be linked to the cost (per kWh) of the electricity they are using, helping drive behaviour change as consumers are more aware of their consumption habits and energy wastage.

6. **Reduce meter reading costs:** The cost for utilities companies to physically come and read meters individually is currently a large part of total meter operational costs. AMI systems allow meters to be read virtually through the communications systems, reducing the cost of meter readings and improving the accuracy of these readings.

7. **Decrease operating costs:** AMI systems may also help reduce a range of other operational costs to the network, such as a reduction in call centre/customer care transactions, reduced back office billing (and re-billing from estimation and billing errors), as well as employee training and safety incidents from meter reading call-outs.

8. **Allow smart tariffs:** AMI systems can be used to create 'smart tariffs' which vary in line with the time of the day. This should help drive energy efficiency and peak load reduction through consumer behaviour change.

[3] These categories were established by synthesising AMI benefits from: Landis+Gyr (2013) Evaluating the communication component of your smart grid solution; Budka, KC (2010), Communication network architecture and design principles for smart grids, Bell Labs Technical Journal, Vol.15; EEI (2011) Smart Meters and Smart Meter Systems: A Metering Industry Perspective; EPRS (2015) Smart electricity grids and meters in the EU Member States; and Carbon Trust analysis.

9. **Reduce CO_2 emissions:** AMI systems may have a significant indirect impact on reducing greenhouse gas and air pollutant emissions. This is because they should reduce the amount of physical meter reading call-outs (with associated fuel costs), as well as improving the overall efficiency of the energy network and, in some cases, allowing higher deployment of intermittent renewable energies such as wind and solar.

10. **Reduce outage times:** Many AMI systems can give outage notifications to the utility in real-time, reducing the time it takes to identify and repair network issues. Some systems can also provide detailed data schematics to help identify the exact cause of the issue. Typically a real-time system is required to deliver this but even non real-time systems (e.g. PLC) can sometimes provide a 'last gasp' mechanism to inform utilities before going offline.

11. **Allow active network management (ANM):** AMI systems with low latency are also crucial to actively manage the network. This may include monitoring and controlling smart grid infrastructure (e.g. using AMI data to control automated "reclosers" [4] which improve service continuity), or turning off devices with high inertia (such as fridges) remotely at periods of peak demand to reduce load. However, ANM is also essential for managing systems with high levels of intermittent DG sources (such as solar PV and wind) because these devices may need to be curtailed remotely in real-time to stop them overloading the system, or integrated with controllers on storage units to prevent dips in supply. These systems also allow networks to integrate with real-time big-data platforms to increase data insights in the system.

12. **Automate demand side response (DSR).** AMI systems can support automated demand side response by switching down (or off) appropriately enabled "Smart" devices in the home or business (such as lifts, freezers, air conditioners, washing machines, etc.) on a signal from the electricity system. Demand side response is a growing type of flexibility in modern electricity systems and serves to avoid very expensive peak generation or network upgrades being built which are only used a few time per day or even per season. The savings from demand side response are normally passed onto customers that participate in a DSR programme.

It is important to note that the recipients of these benefits will differ depending on the exact nature of the benefit (e.g. providing consumer information will mostly benefit the customer themselves, whilst others may be of most benefit to the utility, or to the wider system). Whilst this attribution of benefit will be crucial when assessing the final cost-benefit analysis for AMI systems in the final stage of this project (see 'Overview of project'), it has not been considered in this report. At this stage, AMI system design options for Colombia will first be agnostic of the beneficiaries, before adding this layer of complexity in proceeding work.

Differing functionality

All AMI systems help provide many of these benefits regardless of the communication platform. For example all systems can help utilities increase the granularity of their network data, helping identify non-technical and technical losses, and improving their ability to plan the network efficiently. All AMI communication systems also allow the option of interfacing with an in-home display to provide consumers with information on their energy consumption (though the actual ability to interface will depend on the meter hardware selection itself). All AMI systems reduce the need for physical meter reading and operational costs such as re-billing services. A further benefit of all AMI systems is the influence they can have on retail competition, energy companies can use the data to offer a competitive tariff for customers. Finally, all AMI systems will to some extent help reduce greenhouse gas emissions and air pollution by making the energy system more efficient and reducing the number of physical call-outs needed from service personnel.

Having said that, some AMI communications systems will not be capable of providing all of the benefits listed above. The big divide here is whether an AMI system can communicate in near real-time (i.e. with low latency). Most PLC systems for example could be considered non-real time systems, as data is transmitted from meter to collection points frequently, but is then packaged and sent less frequently (usually overnight) to the utilities. This means the utility gets the same level of data granularity but will only be updated on changes once every 24 hour cycle.

[4] A "recloser" is a circuit breaker that can open the circuit when there is a fault and can automatically close it again once the fault has been resolved.

Other AMI designs on the other hand, such as RF mesh and cellular systems, allow the utility be updated in (near) real-time to changes in the network. This low latency is key for capturing some of the more advanced benefits of AMI. For example, without real-time communication it is not possible to provide customers with electricity prices that vary according to the spot price of electricity (based on the supply and demand of electricity at that time). Often called 'smart tariffs' these should, in theory, reduce the pressure on the electricity system at peak load times, with consumers financially incentivised to use electricity (such as charging their electronic devices or EVs etc.) at off-peak hours. Having said that, even non real-time AMI systems will increase the level and granularity of data available to utilities, which could then be used to create hourly 'smart' tariffs based on predictive modelling instead of real-time data (e.g. assuming consumption will be similar to how it was on the same day last year, or to a day with similar temperature and other factors); though this is of course not as robust as having the real-time data itself.

Moreover, without real-time communication systems, it is also not possible to harness AMI to actively manage the network. ANM describes a system whereby the utility (or local aggregator) can monitor the system using smart metering data, and then adjust and control the components of that system to ensure maximum network efficiency. This could mean turning off devices with high inertia (such as fridges) remotely at periods of peak demand to reduce load. However, ANM is also essential for managing systems with high levels of intermittent DG sources (such as solar PV and wind) because these devices may need to be curtailed remotely in real-time to stop them overloading the system. ANM can also be used here to manage electrical storage effectively in tandem with DG devices, remotely activating storage units to compensate for dips in output from intermittent DG sources, therefore effectively balancing the system. Finally, real-time systems also allow networks to be integrated with big-data platforms (such as weather data to allow real-time dynamic lining rating etc.).

Finally real-time systems are also more effective at identifying outages. RF mesh systems for example can notify the utility immediately if any meter point goes offline or flags an outage, with repair services being sent accordingly. Non-real time communication systems such as narrowband PLC on the other hand have to continue to rely on customers to phone up in order to identify outages. Having said that, many forms of broadband PLC do allow a 'last gasp' function, whereby information on outages can be transferred down the power line and sent from the collector in near real-time, whilst other more routine information (e.g. power consumption data) is saved for slower, overnight packages.

It is also important to mention here that the added benefits of real-time systems may in turn have some impact on secondary benefits of AMI systems, such as the amount of CO_2 emissions reduced (as distributed generators can be used more efficiently through an ANM system, therefore effectively reducing the amount of fossil fuel sources required to supply the network). As such, these additional emissions savings may not be possible without a real-time AMI system.

Figure 5 summarises the capacity of different AMI communication systems to deliver key benefits. Benefits that systems are able to provide have been given the symbol '✓' and shaded in green. In general only PLC has limitations, and this is only for benefits that require real-time data exchange (i.e. smart tariff and ANM systems – including integrating DG sources). The benefits that PLC systems are not capable of providing have been denoted with a 'X' symbol and shaded in red. In principle this also means that PLC systems are also not be able to identify and reduce outage times (benefit 8), though, as described above, some PLC systems may have 'last gasp' capabilities which allows real-time identification of outages even if the rest of the system has a higher latency. For this reason PLC's ability to reduce outage times has been indicated with a '½' symbol and shaded in yellow. In the same way, PLC is also likely to have some impact on CO2 reduction, but this is unlikely to be as much as real-time systems with ANM capabilities; justifying PLC's partial functionality in this category too. Having said that, PLC systems are generally much cheaper than alternative systems and have several key advantages that may make them preferential even with this limited functionality. This will depend heavily on the needs and capacity of Colombia itself, which is the topic of the next chapter.

	PLC	**RF**	**TC**
Indicative cost	LOW	MED	HIGH
Functionality			
1 Reduce non-technical losses	✓	✓	✓
2 Enhance retail competition	✓	✓	✓
3 Improve network planning	✓	✓	✓
4 Reduce technical losses	✓	✓	✓
5 Provide consumer info	✓	✓	✓
6 Reduce meter reading costs	✓	✓	✓
7 Decrease operating costs	✓	✓	✓
8 Allow smart tariffs	✓	✓	✓
9 Reduce CO_2 emissions	½	✓	✓
10 Reduce outage time	½	✓	✓
11 Allow ANM	X	✓	✓
12 Automate DSR	X	✓	✓

Figure 5: AMI functionality, Carbon Trust analysis

2 Key functionality for AMI in Colombia

As the preceding section highlights, AMI systems can provide a plethora of benefits to the energy network, though this may come with an associated range of costs. To understand what AMI system design option best suits Colombia, it is therefore crucial to next understand what Colombia most needs an AMI system for. It is also important here to understand *when* Colombia will need these benefits, as some services may be important but only near (or after) the end of the lifetime of the first round of AMI units deployed (i.e. in 10-15 years[5]). This section sets out to answer these questions by first assessing the top priority needs for AMI in Colombia:

Colombia's top priorities

This report suggests that the top priority, short-term benefit for an AMI system in Colombia is to address non-technical losses from both meter tampering and illegal connection. UPME secondary top priority is to ensure the growth of retail competition to reduce consumer's electricity tariffs. Reduction in technical losses and improved network planning are also assessed to be strong, immediate priorities in Colombia. These priorities were derived by assessing both official documents on the topic[6] and secondary sources[7], as well as several first-hand interviews (see Appendix 3).

Non-technical losses

Several studies have highlighted the identification and reduction of non-technical losses as one of the clearest benefits of installing an AMI system[8]. Colombia has a high rate of non-technical losses in the distribution network, at around 12% nationally, rising to over 25% is some region of the country[9]. Although these figures have been slowly declining over the past decade, non-technical losses are still estimated to cost Colombia millions of dollars per year[10]. Deploying a national AMI system is likely to reduce these losses significantly. Indeed, numerous companies have already began installing smart meters for this reason (see Appendix 1). In this sense Colombia is well positioned to benefit rapidly from non-technical loss reduction from a nationwide AMI rollout.

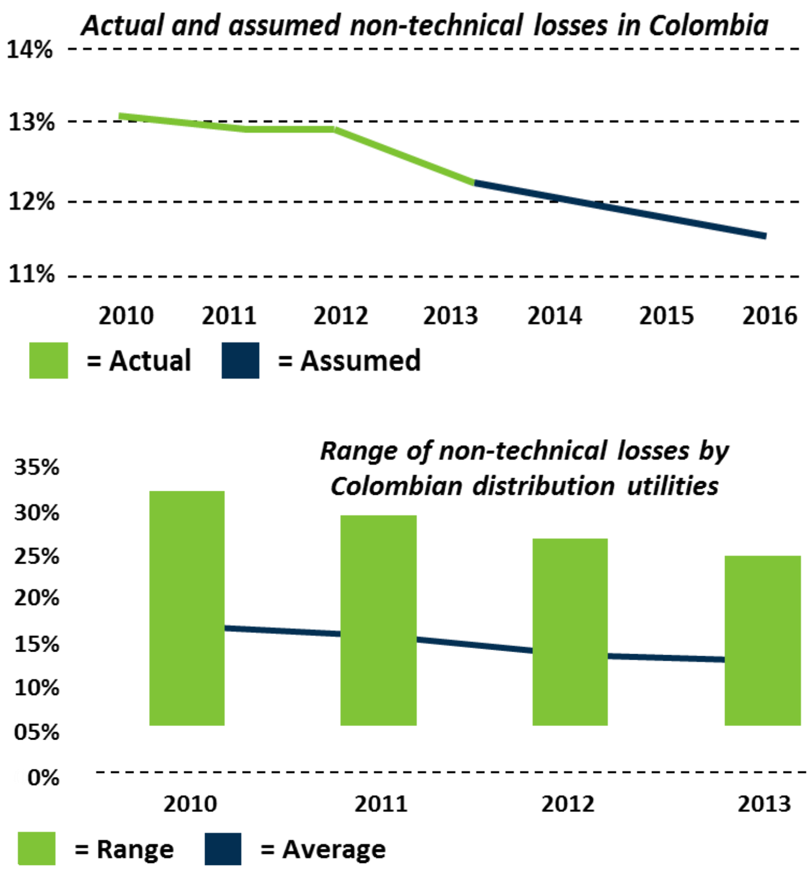


Figure 6: ASOCODIS (2013), Energy Sector in Colombia & Carbon Trust analysis

It is also important to consider here that, although national losses have been on a downward trajectory in the last years (see figure 6), the difference between utility companies remains large. For example utilities like Electricaribe, Cedenar, and Emcartago still have non-technical losses of around 19-26%. Indeed as figure 7 highlights, the range of losses between utility companies is consistently large. With this in mind it seems

[5] Electa (2010) Study of Smart Meter lifetimes; Frontier Economics (2008) Research into the cost of smart meters
[6] CERG (2015) Pilot for Smart meters, Objectives and Goals; ASOCODIS (2013) Energy Sector in Colombia; UPME (2015) National Expansion Plan
[7] NEG (2015) South America: Smart Grid Market; Jarmilla, N (2014), Smart meter adoption, recent advances and future trends
[8] EEI (2011) Smart Meters and Smart Meter Systems: A Metering Industry Perspective; NEG (2015) South America: Smart Grid Market
[9] ASOCODIS (2013) Energy Sector in Colombia
[10] ASOCODIS (2013) Energy Sector in Colombia

clear that combating non-technical losses should be one of Colombia's top priorities when considering AMI system functionality.

The main counterargument against this priority is that electricity consumption in Colombia is still relatively low by global standards. This means that even if the percentage amount of electricity saved by AMI through reducing non-technical losses is high, the gross electricity and costs savings may still be fairly small compared to the cost of the AMI system itself (which has a similar price independently of where it is deployed due to the cost of globally-traded components). Having said that, Colombia has enjoyed several years of strong economic growth and is expected to continue to grow quickly both in terms of GDP and associated energy demand. Resultantly, the ability to identify and reduce non-technical losses will likely have an increasing impact over the coming decade, providing an increasingly strong incentive for installing an AMI system in the country.

Growing Retail Competition

In theory, retail competition can help reduce prices and increase choice for consumers, especially in the non-domestic sector. In most jurisdictions, but especially Europe, this has been achieved through the unbundling and strict separation of regulated network activities (transmission and distribution) and liberalised activities (generation in retail). In the UK, these activities have been separated for more than 20 years and regulated network assets are now owned and run in the main by completely different companies to generation and retail. The idea behind this form of market liberalisation is allow free and fair "third party access (TPA)" to network infrastructure to competing generators and retailers. The ability of this form of retail competition to provide the expected benefits to customers is unproved due to:

- A lack of customer engagement in the competitive market;
- An inability on behalf of energy suppliers (with very similar input costs and a lack of information on their customers) to differentiate their offer;
- The cost of sector restructuring; and
- The relatively high transaction costs for switching

An alternative approach to retail competition would be via an AMI system, which would provide alternative retailers with far richer information about potential customers than is currently available, allowing them to develop a tariff based on customer behaviour. If consumption data is held by an independent third party data manager and provided to accredited, alternative suppliers which the customer's permissions it may service to help develop a competitive market as long as some of fair TPA can be delivered.

Network planning & technical losses

At the transmission level (>115kV) Colombia already has advanced metering infrastructure system in place, which is used as part of the inputs to produce a 'National Expansion Plan' for the transmission grid[11]. At the distribution level however, Colombia currently has no systemic method for networking planning, with each utility making its own expansion plans. There have been several criticisms about the effectiveness of this mechanism focused on a lack of timely maintenance and updates to the network (and the consequent outages of the service in several regions) as prime examples.

Part of the reason behind this is limited availability of accurate information about the network, especially at a granular level. AMI systems could therefore greatly increase Colombia's ability to plan the distribution network in a cost effective way by providing high volumes of meter by meter data on the network. This data can then be analysed to support rational network planning and provide key insights to network engineers when designing or renovating the system. For example, AMI data could be used to predict where the network will become strained and allow upgrades or repairs to be carried out before serious outages occur. Furthermore, data can be utilised to predict where DG sources are likely to be installed and if network upgrades will be necessary to incorporate these, avoiding delays and increasing the utilisation of the grid.

AMI data can also be used to identify areas with high technical losses (e.g. degraded cabling, faulty sub-stations, or areas damaged from exceeding maximum capacity), allowing utilities to reduce losses and make the network more efficient. Indeed, predictive modelling can even be carried out on this data to estimate where and when areas are likely to experience technical losses before they have happened, helping put in place cost effective contingency plans. Overall, cost reductions through

[11] UPME (2015), National Expansion Plan

improved networking planning seems a clear short-term priority for Colombia, with benefits realisable rapidly and with impacts throughout the lifetime of the AMI system.

Longer term priorities

The reduction of non-technical losses and improved network planning (with associated reductions in technical losses) are highlighted in this report as some of the key short-term objectives for AMI in Colombia. This is because they need addressing immediately, and can provide tangible paybacks in a relatively short period of time. Having said that, it is important to make clear that many of the other potential benefits of AMI do remain important for Colombia, though they are likely to become most important over a longer time frame.

Consumer information & operational costs

One clear example of longer term priorities is providing better consumer information of electricity consumption. This benefit should still be considered an important goal for AMI deployment in Colombia, although its importance will increase in line with energy consumption, meaning it is less important now than it will be in the future. Moreover, compared with the immediate and potentially large benefits of reducing both technical and non-technical losses in the system, providing consumer information (which may in turn reduce consumption through behaviour change) has a more ambiguous return on investment in the short-term and should therefore be considered a longer term priority.

The same in true for a number of other AMI benefits too. Reducing operational cost in Colombia for example (e.g. from reducing call-out frequencies or back-of-office administration costs from reading disagreements or rebilling). Whilst this is still a key benefit of AMI, it is likely of less immediate priority than loss reduction which can show cost reductions to the system over short time period. The same is true for outage reduction and emissions reductions which would undeniably be a benefit in Colombia, but will not in themselves dramatically improve the electricity system in the short-term. The key distinction to make here is that the top priorities (above) must be addressed by any system installed in Colombia, whilst many of these other benefits could be considered desirable extras rather than necessities.

ANM & DG integration

Perhaps the best example of these longer term priorities however is the need for an AMI system that can support ANM processes, and especially the integration and control of high levels of DG. Although the integration of distributed generation such as wind and solar has been flagged as a key goal for Colombia, the context and timescales for this need to be considered carefully. Firstly, real-time monitoring and control of DG sources only becomes a serious need for countries once large volumes of intermittent generation are coming online. Whilst Colombia has high levels of solar and wind resource potential (especially in the north east of the country), it currently has a low level of DG penetration, at around 20-60MW. Looking forward, the Smart Grids National Policy document itself predicts that Colombia will have only around 90-120MW of distributed energy capacity by 2025, and between 240-600MW by 2030 (as shown in figure 8). Indeed, even the official scenario supported by the government in the National Expansion Plan (NEP) predicts only around 1,200MW of wind and 500MW of solar by 2029/30 (scenario 12)[12]. Whilst this would be a large increase in deployment in relative terms, it would still only represent a small fraction of Colombia's total energy demand[13]. Moreover, the important point to draw out here is that AMI systems typically have a design life of 10-15years[14]. For most of the lifespan of an AMI installed in Colombia now therefore, real-time integration of DG into an ANM system is likely to

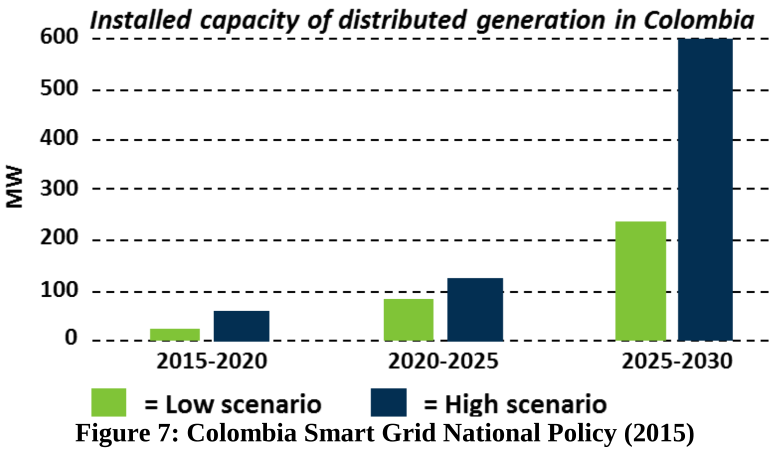


Figure 7: Colombia Smart Grid National Policy (2015)

[12] National Expansion Plan (2015)

[13] It should be noted however than the highest renewables scenario in NEP (scenario 11) does predict 3,000MW of wind and 500MW of solar by the same date (see Appendix 2).

[14] Electa (2010) Study of Smart Meter lifetimes; Frontier Economics (2008) Research into the cost of smart meters

be a fringe issue in most regions until near the end of that AMI unit's lifespan.

Moreover, even if there are high levels of DG deployed in Colombia, real-time ANM services to coordinate and control these sources are only likely to become a top priority if there is insufficient dispatchable storage to offset the intermittency problems associated with large amounts of wind and solar. Colombia has a high level of hydro energy resources, with around 64% of its electricity currently coming from hydroelectric sources. More than 10GW (i.e. the vast majority) of these hydroelectric dams are large, dispatchable units which build up potential hydro energy over many months[15]. Effectively this means that they have a large capacity to offset any intermittency issues in the future. Having said that, the location of these hydro plants is important, as they must be near potential sites of DG deployment if they are to effectively act as a balancing mechanism for the network. One way to assess this is to map the location of hydro plants in Colombia onto wind and solar resource maps available for the country, as has been done in figure 9:

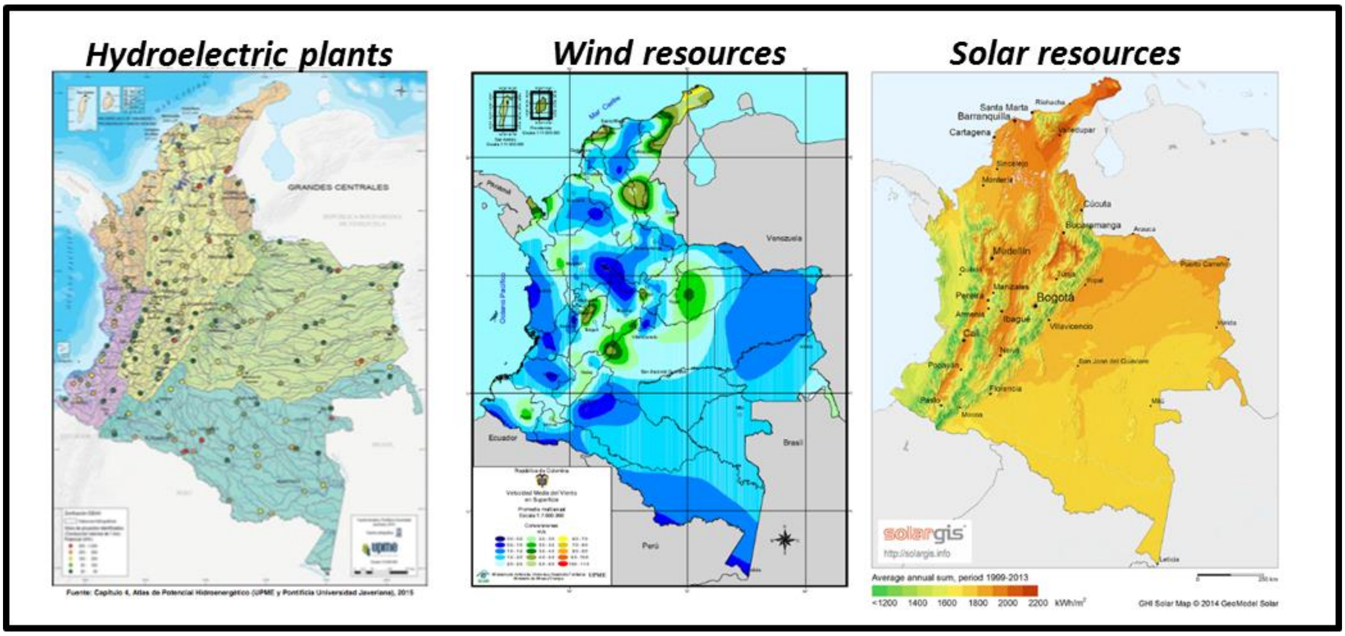


Figure 8: UPME (2015) Hydropotential; UPME (2015) Wind potenital ; SolarGIS (2016) Solar potential in Colombia

As figure 9 shows, the only major region with high solar and wind resources that is not likely to have access to dispatchable storage in la Guajira region on the Atlantic Coast. In this case it may be prudent to consider installing a real-time AMI system capable of ANM and integrating high levels of DG as a short-term priority (see 'Risks and Complexities'). However, in the majority of other cases, a strong argument can be made that these benefits can either wait until the AMI system needs replacing (i.e. in 10-15 years), or can rely on hydroelectric storage options to help balance the system, making real-time AMI communications systems less vital.

Smart tariffs

Smart tariffs are another example of a benefit which can likely be considered longer term in Colombia. Although smart tariffs which can provide real-time electricity prices are still desirable, there are three key reasons to not consider them as top priorities currently. Firstly, because Colombia still has relatively low electricity consumption patterns by global standards, the expected gains from behaviour changed based on smart tariffing is likely to be somewhat limited in the short-term. In the longer-term however it could become increasingly important, though again, this is likely to fall near the lifetime end of an AMI system installed before 2020 (i.e. around 2025-2030). Secondly, because Colombia is supplied largely by hydroelectricity at current, it has less severe problems managing peak load variation than in other countries (i.e. the peak demand can be

[15] UPME (2015) Hydro-potential in Colombia

partially offset by dispatchable storage from hydro dams). This reduces the priority for smart tariffs as it decreases the incentive to reduce consumption as peak times. Finally, it is also important to restate that, even without full real-time data, most AMI systems will be able to provide some kind of smart tariff based on predictive modelling data (e.g. pricing based on similar days in the previous year). Although this is not as desirable as real-time data, it does decrease the priority of smart tariffs through AMI data in Colombia, as decent alternatives can be achieved before a more sophisticated replaces the system in 10-15 years.

Returning to AMI system designs, it is therefore possible to map the indicative costs, benefits and limitations of the AMI systems (as previously defined in this report) onto an indicative timescale for the priority needs of AMI in Colombia – as figure 10 demonstrates.

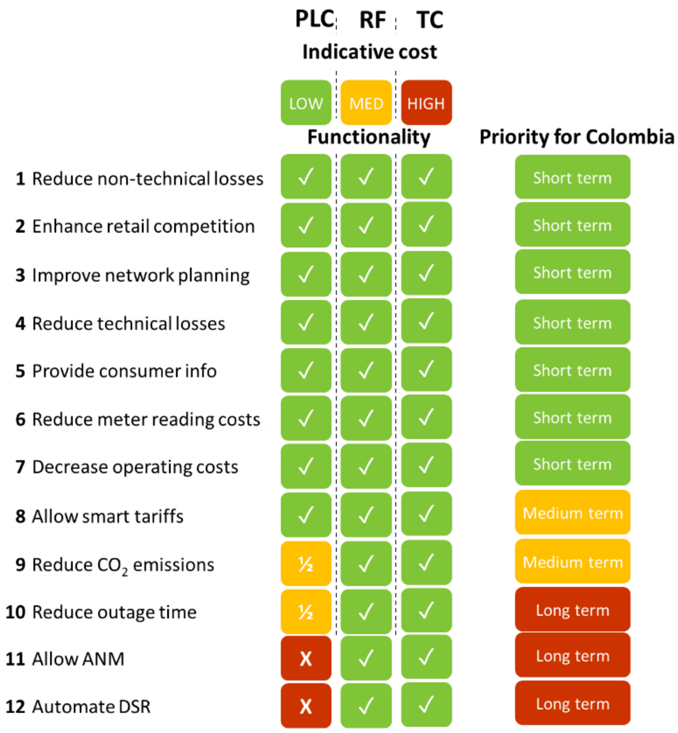


Figure 9: AMI functionality & Colombia's AMI priorities, Carbon Trust analysis

3 Initial hypothesis

This section will draw together all the initial findings provided as part of this report to develop an initial hypothesis in answer to the question of ‘what AMI system design is most suitable for Colombia?’

Early conclusions

PLC system with ‘last gasp’ options

One key early conclusion of this report is that **a real-time (i.e. low latency) AMI system is likely to not be necessary for *most of* Colombia in the short-term.** Actively managing the network and integrating large volumes of intermittent DG are the key benefits of a real-time system, both of which seem likely to become a high priority for Colombia only near the lifetime end of an AMI system installed in the next few years (i.e. around 2025-2030). Moreover, in specific regions where this may not hold true (i.e. high DG areas) it is hypothesised that a non-real-time system could be replaced with a real-time system in manageable pockets (see ‘Risks and complexities’).

With that in mind, this report’s initial hypothesis is that **a PLC system could meet Colombia’s top needs at least cost.** There are several key reasons for thinking this:

- PLC is generally much cheaper than other AMI systems and already has an established market from its development in numerous other countries. This not only makes PLC technology cheaper, but also means there is a developed supply chain and expertise which Colombia could effectively utilise.
- Most of the priority issues that Colombia needs AMI for can be solved with a PLC system, especially the top priority issues of resolving non-technical losses and improving network planning (and associated technical losses).
- Finally, under certain system designs, PLC should also be able to still improve outage times in Colombia with a ‘last gasp’ function even if it does not have real-time capabilities in other areas.

As figure 11 summarises, a PLC system would likely be able to address all of Colombia’s top priority, short-term needs, as well as all or almost all of the secondary order priorities, whilst providing the lowest cost of system design. Having said that, it is important to state **several key risks and complexities surrounding PLC still remain to be tested**. These are explored in the following section.

It is also the case that certain regions of Colombia (particularly the Caribbean coast) may have different needs from Colombia as a whole and may prefer a different technology design that better suits its needs.

Whilst having different technologies across Colombia may more closely meet different regional needs, it could increases the interoperability risks faced by the system and overall cost, and so will need careful design.

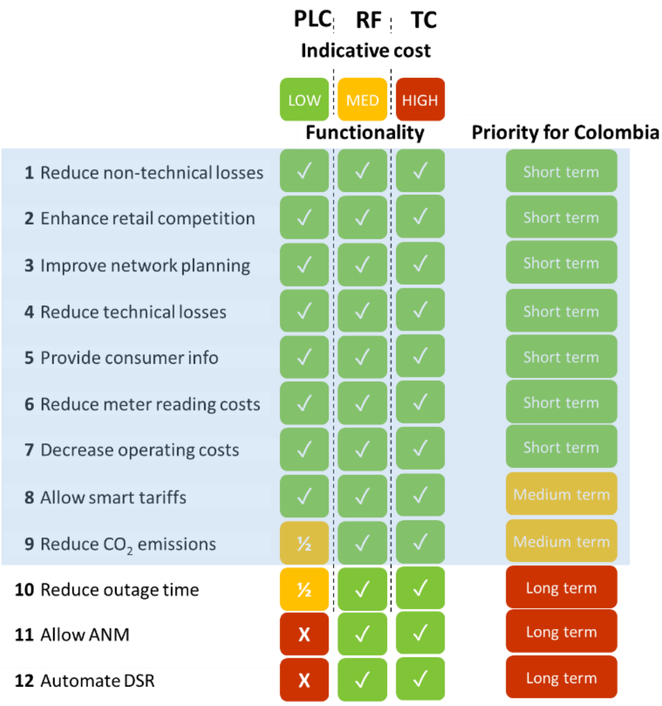


Figure 10: AMI functionality, Colombia’s & AMI priorities with PLC functionality highlighted, Carbon Trust analysis

Risks and complexities

Local feasibility of PLC

The economics of PLC systems are highly dependent on the architecture of the energy system. For PLC systems to be cost effective they need to installed in a 'radial' electricity system. In real terms this means that many meters need to be serviced by a small number of sub-stations and transformers. Indeed, as figure 12 illustrates, the meter/transformer ratio drastically impacts the cost of a PLC system. Initial research undertaken by the Carbon Trust indicates that the meter/transformer ratio in Colombia could be between 20 and 60 at a national level[16], which is mid-range in terms of feasible PLC systems.

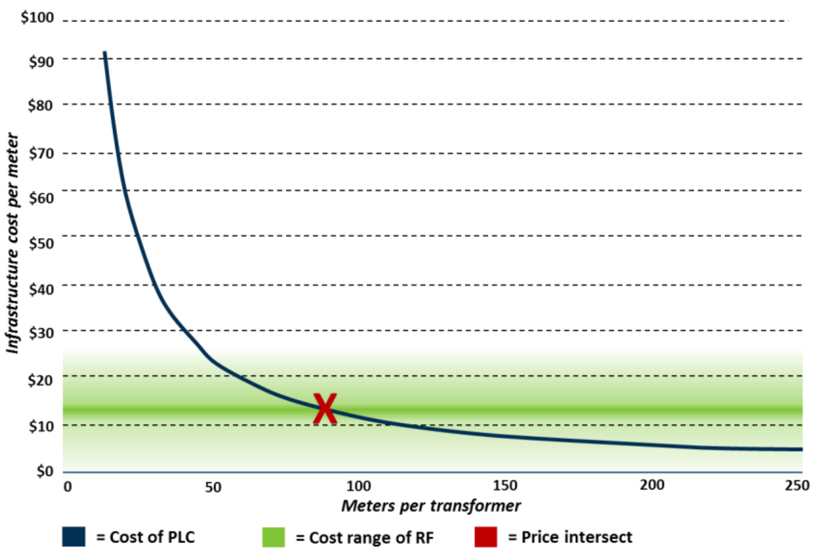


Figure 11: Carbon Trust analysis

Another potential issue for PLC in Colombia is compatibility. Whilst PLC systems generally have an established supply chain, there is some concern that exact conditions in Colombia may mean components are not compatible with the network. For example, international meters could have poor interoperability between meter and the wider energy systems. Simply put, there may be restrictions with using some PLC equipment in the Colombian context.

With both of these concerns in mind however, first hand interviews conducted with key experts at Colombian utility Condensa seem to reduce this risk (see Appendix 3): Condensa is currently carrying out a pilot programme of 40,000 smart meters based on PLC communications and confirmed that initial results were positive. They were confident that the Colombian network was adequate to implement PLC technology, with one of the key motivations of the pilot scheme being to evaluate any technical problems with integrating PLC into the Colombian network. They were also confident that PLC would likely be the cheapest system for Colombia and would be a good initial AMI system to solve some of the top priority issues before a more sophisticated system was put in place next decade. The final results of the Condensa PLC project will be available in May 2017.

Applicability of PLC in high DG scenarios

Although PLC is likely to be a sufficient AMI system in most regions, there is still some risk that some areas will require ANM services or integration of significant volumes of intermittent DG in much shorter time frames than expected (see 'Longer term priorities: ANM & DG integration'). This is particularly true from regions like La Guajira region on the Atlantic Coast, which has high wind and solar resources (and can therefore reasonably expect to see large growth in wind and solar farms in the coming decade), but which is situated far from hydroelectric storage with large enough dispatchable capacity to balance the network. In these cases it may be prudent to consider installing an alternative AMI system which is capable of offering real-time response benefits in these area.

RF mesh systems could work well here if it the alternative is rolled out across the entire region (as RF systems need a critical mass of metering points to work effectively). Alternatively, cellular systems can be rolled out on a much smaller scale and do not need additional infrastructure building in most cases; though they have their own associated risks (see 'Cellular networks' above). Either way, it seems a clear argument can be made than in areas of potentially high DG uptake (with low storage) a

[16] CREG (2015) Smart Grid Pilot Project

more advanced AMI system should be considered. More work needs to be done here on how to define where this could be deployed and what system should be used.

Related to this, it is also important to consider the fact that – depending on the cost of renewable technologies and Colombia's policy framework – there are scenarios whereby DG uptake and the need for ANM services could be much higher than anticipated in this report. In response, it is recommended that the final cost-benefit analysis for this project uses a scenario based approach to capture this complexity. The National Expansion Plan scenarios (Appendix 2) could serve as a good basis for this type of scenario modelling for DG uptake in Colombia.

Fibre optic penetration

Finally, it is worth mentioning that there are plans in Colombia for a national rollout of fibre optic cabling[17]. An AMI system that could piggy-pack on this infrastructure could be able to provide full AMI functionality at a very low cost and is therefore worth considering. However, there are serious concerns that – unless this rollout reaches near 100% penetration then it will not be suitable as an AMI system, which needs to connect the vast majority of meter points to be effective. Typically near 100% penetration is only achieved when connection to the fibre optic network is mandatory rather than optional, but this approach to broadband roll-out is rare. Moreover, there is some concern that pegging AMI deployment plans to a fibre optics plan that has yet to come to fruition increases the risk of delays and issues if the broadband deployment come behind schedule. Having said that, more research is required on the specifics of this programme in Colombia before ruling it out completely.

Alternative plans

The initial findings of this report suggest that PLC would be the optimal system design for AMI in Colombia. However if PLC becomes unviable, it is important to finally consider an alternative plan:

Radio Frequency

This report finds that, in the absence of a PLC option, an RF mesh system would also meet Colombia's need at a reasonable cost. This will be especially true if there are feasibility issues with PLC (see 'local feasibly of PLC' above) which make RF cheaper, or only marginally more expensive. This is because RF mesh provides many of the benefits that PLC has to compromise on (e.g. smart tariff and ANM services) and yet is still likely cheaper and has less associated risks than a cellular system.

Having said that RF systems are critically dependant on the availability of a clean radio frequency to transmit on. Initial research indicates some frequencies are available in Colombia, though results are still inconclusive as to whether this could be used for an RF-based AMI system. The issue is therefore still under assessment by the Carbon Trust and will be resolved in the second stage of the project.

[17] Oxford Business Group (2014) The Report: Colombia

4 Conclusions

From a communications perspective there are **three archetypal options for AMI system design**: power line carriers, radio frequency, and cellular network systems. These systems have differing indicative costs, benefits, and functionality; with the most important difference being that PLC is usually a less expensive system, but has some limits to its functionality – particularly in terms of active network management capabilities and the real-time control of distributed generation.

Colombia's top priority for AMI is reducing non-technical losses and growing retail competition. Reducing technical losses and helping better plan the network are also key priorities. Together these improvements could bring significant benefits to Colombia, helping to make the grid more efficient and reduce the cost of the entire network. Whilst other benefits, such as active network management and smart tariff systems would also be of use in Colombia, it appears the most value will be attained from this in 10 – 15 years, by which time an AMI system installed today would need to be replaced anyway.

A real-time (i.e. low latency) AMI system is therefore likely to not be necessary for Colombia in the short-term, apart from certain regions. With that in mind, this report's initial hypothesis is that **a PLC system could meet Colombia's top needs at least cost**. PLC systems are generally much cheaper than other AMI options and yet can meet most of Colombia's key needs, especially if a 'last gasp' function can also help reduce outage times.

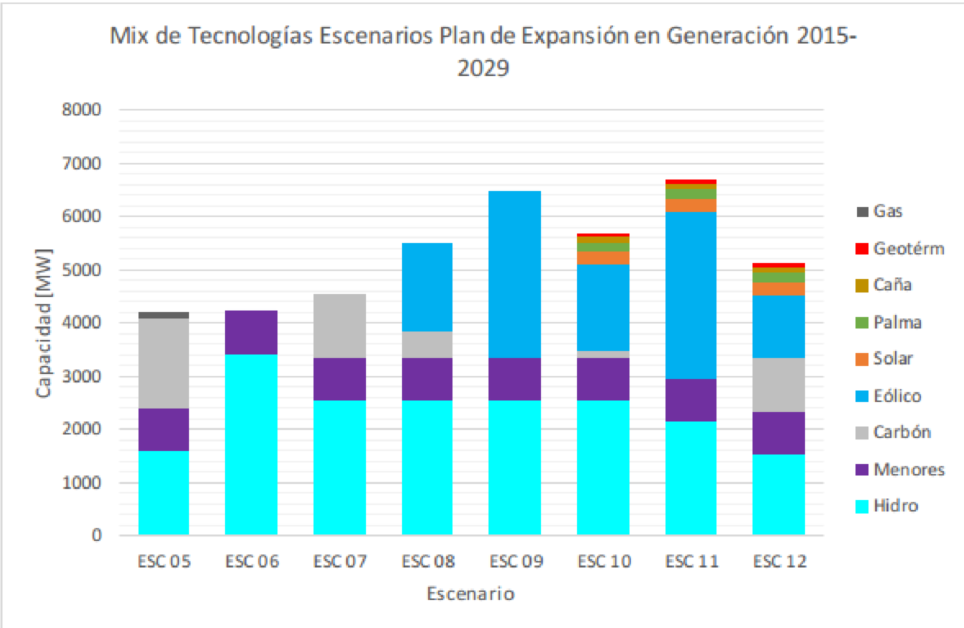
Local studies now need to be carried out to assess the feasibility of PLC in the Colombian context, though initial results from utilities piloting AMI in the country seem to suggest PLC is a viable option. Moreover, there may be some locations – such as rural areas or regions with high distributed generation potential (e.g. la Guarjira) – where PLC remains uneconomical, or where real-time functionality is more urgent than in the rest of the country. **Colombia should consider rolling out bespoke AMI systems in these special cases**, either using RF or cellular technology to ensure these challenges are overcome at solved at least cost.

Appendix 1 – Current Utility Activities

- **Codensa:** AMI project in Bogota, expanding out to 66,000 meters, with plans to deploy AMI meters to all customers consuming than 300 kWh per month (estimated at around 300,000 customers)
- **Electricaribe:** Installing two-way communication meters with theft control sensors. Currently has 60,000 customers with centralized metering and has seen return on investment from AMI project already.
- **Emcali:** Deployed 14,000 AMI meters and plans to deploy 70,000 more. Emcali's AMI projects used Aclara PLC-based communications for all customers, and tested a number of other smart meter hardware providers (e.g. Elster, Imet, Itron, Landis+Gyr, Lin Yang, Nasen, Wasion) in the process. Emcali's main aim was to reduce non-technical losses.
- **ESPA:** Deploying smart meters in targeted regions to reduce non-technical losses. They were able to reduce losses from 28% to 3% in some cases, showing nearly 90% effectiveness. EPSA is currently studying additional potential AMI projects, though the utility's challenging geographic terrain has made it difficult to find a suitable large-scale solution.

Appendix 2 – DG deployment scenarios

National Expansion Plan Scenarios



National Expansion Plan Goals

Objective	Phase 1	Phase 2	Phase 3
AMI (Advanced Metering Infrastructure)	58-70% energy Remote lecture, losses management, demand knowledge.	65-88% energy Hourly tariffs and distributed generation	73-100% energy Demand Response
ADA (Advanced Automated distribution)	2,7-3,3 interrupters per circuit.	4,2-5,7 interrupters per circuit.	Self-healing in the interrupters from phase 2.
DER (Distributed energy resources)	0,1-0,2% of the whole power. 20-60 MW Intermittent distributed generation in low voltage.	0,4-0,5% of the whole power. 90-120 MW Intermittent distributed generation in low voltage.	1-2,5% of the whole power. 240-600 MW. Storage units.
VE (Electric Vehicles)	1-1,2% of the total number of vehicles.	3-4% of the total number of vehicles.	9-14% of the total number of vehicles.

Appendix 3 – Interview list

Date	Event	Subject	Assistants
June 21/22	Smart Meters Functionality Workshop	National University Project	Energy Companies, Meters Producers, Government Institutions
July 17	Meeting Location: UPME	Technical Codes in Smart Metering	Siemens, UPME
July 22	Meeting. Location: CRC	Communications Regulatory issues	Communications Regulatory Commission, CRC, UPME
July 26	Meeting. Location: ANE	National Spectrum issues	National Spectrum Agency, ANE
July 27	Meeting. Location: UPME	Communications Policy issues	Telecommunications and Tecnology Ministry, Mintic, UPME
August 18	Meeting. Location: Codensa	PLC and RF experiences in Codensa Market	Codensa and ENEL