THESIS WORK

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Decarbonisation of The Argentinian Transport Sector by The Introduction of Battery Electric Vehicles

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Buenos Aires, 14/09/2018
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Abstract

During the past decades, there has been a dramatic increase on the average temperature worldwide, and it is nowadays undeniable the fact that we are going through a warming process and experiencing irreversible climate changes. In line with the target set in the Paris Agreement to limit global warming well below 2°C above preindustrial levels, Argentina has launched as from 2016 several measures in the electricity sector oriented to carbon dioxide (CO_2, the main greenhouse gas) emissions reduction, but there is still a lot of work to be done in the transport one, the second largest CO_2 emitting sector. This work projects the effect of the battery electric vehicles' introduction in the carbon footprint of Argentina. This is done by mapping, along with their specific emissions, all the operating, planned and projected electricity plants, together with the light duty transport fleet and its growth projection as well. The evolution of these variables is simulated up to year 2050 in a time series under three different scenarios. The inputs for these are the controlled charging, efficient usage of electricity, and the grade of penetration of this technology. The emissions of battery electric vehicle are assessed in a time-dependent average, this means, weighting the emissions according to the specific daily load profile. The overall emissions result, both on the electricity and the transport sector, is compared to a baseline scenario in order to prove that the introduction of this technology following certain guidelines brings important benefits. Nevertheless, if this technology would be introduced in an uncontrolled and disordered way, the negative effect on emissions reduction and the shortfalls on the electricity system would also be contrasted.

Resumen

En las últimas décadas ha habido un notorio aumento en la temperatura media global, y hoy en día es indudable el hecho de que se está atravesando un proceso de calentamiento global acompañado por cambios climáticos irreversibles. De acuerdo a los lineamientos establecidos en el Acuerdo de Paris de limitar el calentamiento global a 2 °C por encima del nivel preindustrial, Argentina ha comenzado a trabajar desde 2016 en las medidas necesarias para atacar este problema desde el sector eléctrico con el objeto de reducir las emisiones de dióxido de carbono (CO_2, el principal gas responsable del efecto invernadero). Sin embargo, aún queda un largo camino por recorrer en el sector de transporte, el segundo mayor responsable de emisiones de CO_2 de Argentina. En este trabajo se proyecta el efecto que tendrán los vehículos eléctricos a batería (excluyendo los híbridos e híbridos enchufables) en la huella de carbono en Argentina. Esto se realiza en primer lugar mapeando las emisiones específicas de todas las centrales eléctricas, operativas y planificadas, más una proyección de la evolución del sector, junto con la del crecimiento en el sector de transporte. La evolución de dichas variables es simulada en una línea de tiempo bajo 3 escenarios hipotéticos. Las entradas para plantear estos escenarios son la carga controlada de baterías, el uso eficiente de la electricidad de la red y el grado de penetración de esta tecnología en el sector de transporte. Las emisiones de los vehículos eléctricos son calculadas teniendo en cuenta el momento de la carga y las emisiones específicas del momento en el que se carga el vehículo de acuerdo al patrón de consumo. Los resultados totales, tanto en el sector eléctrico como en el de transporte, son comparados con un escenario base para probar que la introducción de dicha tecnología bajo ciertas consideraciones traerá importantes beneficios. Sin embargo, si esta tecnología se introdujera de una forma descontrolada y sin planificación, sus consecuencias también se verían contrastadas a la luz de los resultados.

Zusammenfassung

In den letzten Jahrzehnten ist die Durchschnittstemperatur weltweit dramatisch angestiegen und es ist heutzutage deutlich, dass wir einen Erwärmungsprozess und unumkehrbare Klimaänderungen erfahren. In der Pariser Vereinbarung gesetzten Ziel (die Erderwärmung deutlich unter 2 °C über dem vorindustriellen Niveau begrenzen) hat Argentinien ab 2016 mehrere Maßnahmen im Stromsektor eingeleitet. Die wurden auf

Kohlendioxid (CO_2, das wichtigste Treibhausgas) Emissionsreduktion ausgerichtet. Im Transportsektor, der zweitgrößte CO_2-emittierendene Sektor, gibt es noch viel zu tun. Diese Masterarbeit projektiert die Auswirkungen der Adoption von Elektrischefahrzeuge auf den CO_2-Fußabdruck Argentiniens. Zu diesem Zweck werden alle betriebliche, geplante und projektierte Stromswerke zusammen mit der leichten Transportflotte, ihrer Wachstumsprojektion und spezifischen Emissionen kartiert. Die Entwicklung dieser Variablen wird bis zum Jahr 2050 in einer Zeitreihe unter drei verschiedenen Szenarien simuliert. Die Inputs für diese Szenarien sind das kontrollierte Laden, die effiziente Nutzung von Strom und der Grad der Durchdringung dieser Technologie. Die Emissionen von Elektrofahrzeugen werden in einem zeitabhängigen Durchschnitt bewertet, das heißt, die Emissionen werden ab dem Zeit der Ladung des Fahrzeugs entsprechend den spezifischen Werten gewichtet. Die Gesamtemissionen, sowohl im Strom- als auch im Verkehrssektor, werden mit einem Basisszenario verglichen, um zu beweisen, dass die Einführung dieser Technologie nach bestimmten Richtlinien wichtige Vorteile bringt. Wenn diese Technologie jedoch unkontrolliert und ungeordnet eingeführt würde, wären auch die negativen Auswirkungen auf die Emissionsreduktion und die Defizite des Stromssystem gegenteilig.

Executive Summary

According to IEA statistics [1], [2], the transport sector is in the second place of energy consumption worldwide, 99% of it coming from combustion processes, right below the electricity generation one and the second largest carbon dioxide (CO_2) emitter. Projecting a business as usual (BAU) scenario, greenhouse gases (GHG) emissions will increase its amount, saturating the atmospheric concentration before exhausting petroleum reserves, leading to an irreversible climate change, like the global warming that has been experienced lately. Declared this one to be the most critical topic to address in the 21st Century by United Nations Environment (UNE), in 2015 it was committed the Paris Agreement by the United Nations Framework Convention for Climate Change (UNFCCC), which set the objective of limiting the increase in the global average temperature to well below 2°C above preindustrial levels [3].

Argentina is one of the 3 countries integrating G20 who presented no 2020-pledges to the UNFCCC, but did presented post-2020, conditionally on how would the energy sector evolve [4]. In 2016, this one demanded a total primary energy of 89 megatons of oil equivalent (MTOE), from which the transport sector demanded 20% (18 MTOE). This represented almost 50 megatons (Mt) of CO_2 emissions on that year [5]. The rest was demanded by the electricity generation (including transformation loses), 40%; industrial and commercial activities, 19%; heating gas, 14%; and non-energy related sectors, 7%. In developing economies with unsaturated transport markets such as Argentina's, it is expected an annual growth in vehicles' registration between 4% and 7% [6], which following a BAU scenario projected emissions by 2030 would climb up to 75 Mt CO_2 yr^{-1}.

In the electricity generation sector, there is a target set by law 27.191 of integrating 20% renewable energies mix in the electricity grid by 2025 [7], by a pack of measures already launched like renewable energies auctions "*Renovar*" rounds 1 & 2, *MATER* (Private Market for Renewable Energies), and a normative for producing distributed energy (law 27.424). In the transport sector, so far it was only announced in 2017 a reduction in the import duties for hybrid, battery electric (BEV) and hydrogen fuel cell vehicles for local automakers [8] towards net emissions cutoff, with no visible impact so far. Anyhow, the impact of this measure from an environmental point of view is always in the eye of discussion, as BEVs are well known for being eco-friendly due to its zero emissions, but this is only true from the tank-to-wheel (TTW) perspective. When assessing from the well-to-wheel (WTW) one, there are specific amounts which could vary under certain assumptions.

In this work it will be explained the main benefits that BEVs have against internal combustion engine vehicles (ICEV) in terms of CO_2 emissions reductions, and it will be projected the introduction of them into the light duty transport (LDT) sector under different scenarios. It will be arranged a time-series simulation model, responding to the necessary energy supply and its specific CO_2 emissions to attend projected demand from the already existing electricity sector, plus the added one from the transport sector with the introduction of BEVs. Among the main factors that will impact on this analysis, renewable energies generation and other clean energy sources will play a key role, the effect of introducing a more efficient technology could intensify the usage, and controlled charging strategies could take advantage of the idle capacity of the grid. It will be left out of scope how will BEVs penetrate in the transport market, instead it will be assumed that this is done based on other projections. In this basis, the objective of this work is to assess whether BEVs represent a benefit in terms of emissions comparing to ICEV's state-of-the-art and how could this help to achieve the objective set in Paris Agreement.

List of abbreviations

ADEFA	Argentina's Automakers Association (from Spanish: Asociación de Fabricantes de Automotores)
BAU	Business as Usual
BEV	Battery Electric Vehicle
CAMMESA	Argentina's Administrating Company of The Wholesale Electricity Market Inc. (from Spanish: Compañía Administradora del Mercado Mayorista Eléctrico Sociedad Anónima)
CCS	Combined Charging System
CDF	Cumulative Distribution Function
COP	Conformance of Production (when referred to vehicle emissions' assessment)
COP	Conference of The Parties (when referred to UNFCCC)
DNRPA	National Directorate of Motor Vehicle Registration (from Spanish: Dirección Nacional de Registro de Propiedad Automotor)
DSM	Demand Side Management
EVSE	Electric Vehicle Supply Equipment
GHG	Greenhouse Gas
GWP	Global Warming Potential
ICCT	International Council of Clean Transportation
ICEV	Internal Combustion Engine Vehicle
INDC	Intended Nationally Determined Contributions
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
IEA	International Energy Agency
LCA	Life Cycle Assessment
LDT	Light-Duty Transport
MATER	Term Market of Renewable Energies (from Spanish: Mercado a Término de EERR)
MEM	Wholesale Electricity Market (from Spanish: Mercado Eléctrico Mayorista)
MINEM	Argentina's Energy and Mining Ministry
MY	Model Year
NEDC	New European Driving Cycle
NPV	Net Present Value
PDF	Probability Density Function
SAE	Society of Automotive Engineers
SSN	Superintendence of National Insurances (from Spanish: Superintendencia de Seguros de la Nación)
TCO	Total Cost of Ownership
TIS	Time in Service
TTW	Tank-to-wheel
ULEV	Ultra-low Emissions Vehicle
V2G	Vehicle to Grid
UNE	United Nations Environment
UNFCCC	United Nations Framework Convention for Climate Change
VER	Vehicles Exposed to Risk
WLTC	World Harmonized Light Duty Vehicles Test Cycle
WLTP	World Harmonized Light Duty Vehicles Test Procedure
WTT	Well-to-tank
WTW	Well-to-wheel
YIS	Years in Service

Nomenclature

Units Conversion Prefixes:

Multiplier	Prefix	Multiplier	Prefix
10^{-12}	pico (p-)	10^{2}	hecta (ha-)
10^{-9}	nano (n-)	10^{3}	kilo (k-)
10^{-6}	micro (μ-)	10^{6}	mega (M-)
10^{-3}	mili (m-)	10^{9}	giga (G-)
10^{-2}	centi (c-)	10^{12}	tera (T-)
10^{-1}	deci (d-)	10^{15}	peta (P-)
1	unit	10^{18}	exa (E-)
10	deca (da-)	10^{21}	zetta (Z-)
		10^{24}	yotta (Y-)

Units System: SI (Système International)

Physical Quantity	Name of SI Unit	Symbol for SI Unit	Definition of Unit
length	meter	m	
mass	kilogram	kg	
time	second	s	
thermodynamic temperature	Kelvin	K	
amount of substance	Mole	mol	
force	Newton	N	kg m s^{-2}
pressure	Pascal	Pa	kg m^{-1} s^{-2} (= N m^{-2})
energy	Joule	J	kg m^{2} s^{-2}
power	Watt	W	kg m^{2} s^{-3} (= J s^{-1})
frequency	Hertz	Hz	s^{-1} (cycles per second)

Decimal Fractions and Multiples of SI Units Having Special Names

Physical Quantity	Name of SI Unit	Symbol for SI Unit	Definition of Unit
time	hour	h	3600 s
time	year	yr	3153600 s = 8760 h
mass	ton	t	10^{3} kg
mass	gram	g	10^{-3} kg
volume	Cubic decameter	dam^{3}	10^{3} m^{3}
volume	liter	l	10^{-3} m^{3} = 10^{3} cm^{3}
pressure	bar	bar	10^{5} N m^{-2} = 10^{5} Pa
pressure	millibar	mb	10^{2} N m^{-2} = 1 hPa
energy	Watt-hour	Wh	3600 J = 3.6 kJ
energy	Tons of Oil Equivalent	TOE	11.63 MWh = 41868 MJ

Substances Abbreviations:

CO	Carbon Monoxide
CO_2	Carbon Dioxide
H_2O	Water
HC	Hydrocarbons
NMHC	Non-methane Hydrocarbons
NO_x	Nitrous Oxides
PM	Particulate Matters (soot)
PN	Particle Number
SO_x	Sulfur Oxides
THC	Total Hydrocarbons

Vehicle Categories (according to Directive 2007/46/EC):

Category	Description
M	Motor vehicles with at least four wheels designed and constructed for the **carriage of passengers**.
M1	Vehicles used for carriage of passengers, comprising **not more than eight seats in addition to the driver's = 9** (Car, Van).
M2	Vehicles used for the carriage of passengers, comprising **more than eight seats** in addition to the driver's seat, **and** having a maximum mass **not exceeding 5 tons**. (Van, Mini-Bus)
M3	Vehicles used for the carriage of passengers, comprising **more than eight** seats in addition to the driver's seat, **and** having a maximum mass **exceeding 5 tons**. (Bus)
N	Power-driven vehicles having at least four wheels and used for the **carriage of goods**.
N1	Vehicles used for the carriage of goods and having a maximum mass **not exceeding 3.5 tons.** (Pick-up Truck, Van)
N2	Vehicles used for the carriage of goods and having a maximum mass **exceeding 3.5 tons but not exceeding 12 tons.** (Van, Small Truck)
N3	Vehicles used for the carriage of goods and having a maximum mass **exceeding 12 tons.** (Commercial Truck)

Defined constants

Name	Symbol	Value
Planck	h	$6.62 \cdot 10^{-34}\ \frac{kg \cdot m^2}{s}$
Speed of Light	c	$3 \cdot 10^8\ m/s$
Boltzmann	κ	$1.38 \cdot 10^{-23}\ \frac{kg \cdot m^2}{K \cdot s^2}$
Stefan-Boltzmann	σ	$5.67 \cdot 10^{-8}\ \frac{W}{m^2 \cdot K^4}$

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1. Introduction

1.1 CO_2 emissions and the greenhouse gases effect

The greenhouse effect in the simplest way can be explained as the rebound of the heat emitted by the Earth, which came in the first place from the Sun power. This heat that is radiated by the albedo (Earth's surface) and bounds against the barrier of the greenhouse gases (GHG), present in the atmosphere, is sent backwards, modifying the heat balance of the Earth's system and increasing its temperature.

According to Planck's law of black body [9], the radiation energy depends on the temperature at which a black body is emitting by integrating the spectral emission through the whole range, given by the following expression:

$$E_{\lambda,s}(T) = \frac{2\pi hc^2}{\lambda^5\left(e^{\frac{hc}{\lambda kT}} - 1\right)}$$

Where h is Planck's constant, c is the speed of light, λ is the wavelength, k is the Boltzmann constant, and T is the temperature, expressed in *K*.

A mass particle emits radiation, not as a black body but as a gray body, so there is a spectral emissivity factor that is a function of the wavelength, $\varepsilon(\lambda) \leq 1$, which indicates the ratio of emissivity when compared to a black body. And according to Kirchhoff's law, the spectral emissivity is equal to the spectral absorptance. It can also be deduced by differentiating this expression that the wavelength at which the emissivity is maximum varies with the black body temperature, and so it does the emissivity. This is known as the Wien's displacement law, shown in Figure 1. The total emitted radiation can be calculated out from the temperature of the gray body with Stefan-Boltzmann's law:

$$E(T) = \varepsilon \cdot \sigma \cdot T^4$$

Where ε is the emissivity factor (assumed to be constant in this case), σ is the Stefan-Boltzmann constant and *T* is the temperature expressed in *K*.

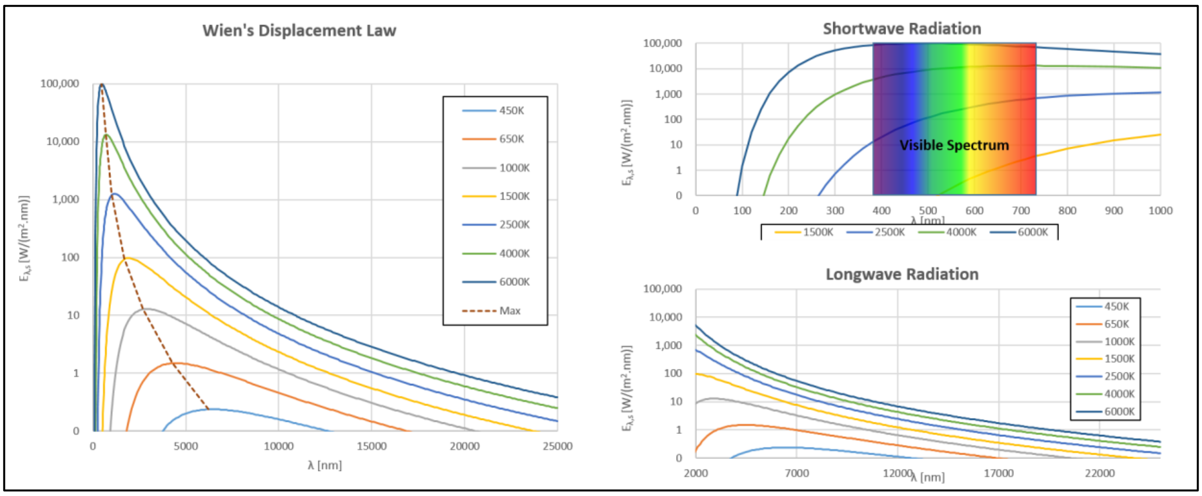

Figure 1: a (Left) - Wien's Displacement Law; b (Upper Right) - SWR; c (Lower Right) - LWR.

The Earth's climate system is powered by solar radiation, a system where the Sun behaves as a black body $(\varepsilon \approx 1)$ that irradiates at its temperature, calculated in 5778K. So, about half of its energy is supplied in the visible part of the electromagnetic spectrum $(390\ nm < \lambda < 730\ nm)$. The generally accepted mean value of the total solar irradiance before entering into the atmosphere is 1361 W m^{-2} [10]. This solar radiation is partially absorbed and reflected by the atmosphere and troposphere (ozone absorbs 97-99% of UV rays at $\lambda < 390\ nm$). The rest of it is the incoming solar shortwave radiation (SWR) transmitted to the Earth (Figure 1-b). The incoming SWR can be decomposed in the following way: 50% is absorbed by the Earth's surface, 30% is reflected back to space by gases and aerosols, clouds and by the albedo, and the remaining 20% is reflected in the Earth's surface and re-absorbed in the atmosphere.

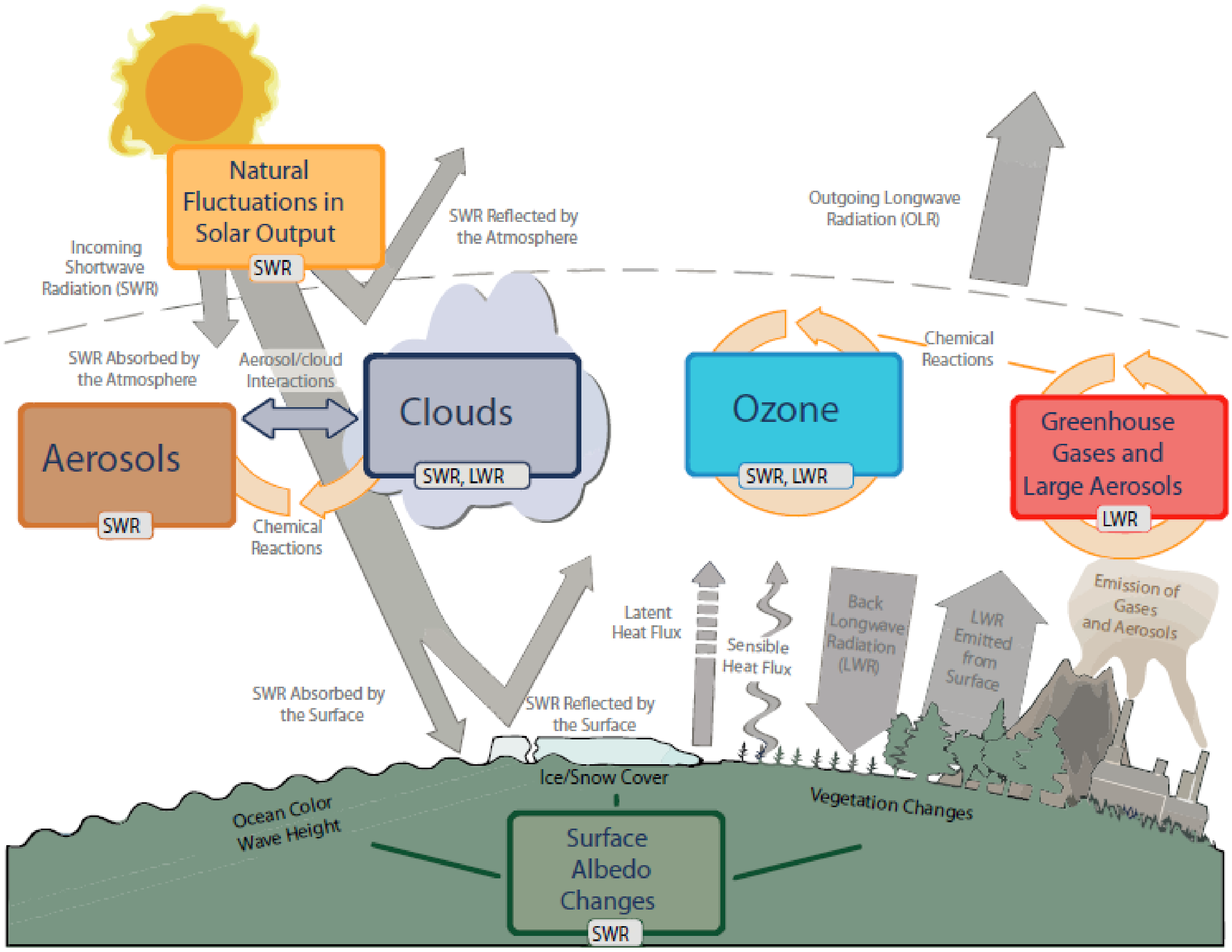

Figure 2: Main drivers of climate change.
The radiative balance between incoming solar shortwave radiation (SWR) and outgoing longwave radiation (LWR) is influenced by global climate 'drivers'. Anthropogenic changes in GHGs (e.g., CO_2, CH4, N2O, O3, CFCs) and large aerosols modify the amount of outgoing LWR by absorbing outgoing LWR and re-emitting less energy at a lower temperature. (Source: IPCC, AR5 [10])

Based on the albedo's temperature, which may roughly vary between 250K and 350K, the majority of the outgoing radiation energy flux emitted by the Earth is in the infrared part of the spectrum (Figure 1-c). The longwave radiation (LWR, also referred to as infrared radiation) emitted from the Earth's surface is largely absorbed by certain atmospheric constituents —water vapor, CO_2, CH_4, N_2O and other GHGs— and clouds, which themselves emit LWR as well, into all directions: the downward directed component of this LWR adds heat to the lower layers of the atmosphere and to the Earth's surface **(greenhouse effect)**, while the upward layers of the troposphere emit the dominant energy loss of the infrared radiation portion. An illustration of such effect is in Figure 2.

Changes in the global energy balance derive from either changes in the net incoming solar radiation or changes in the outgoing LWR. The solar radiation variation over time is negligible and the radiative energy budget of the Earth is almost in balance, but there is evidence of a small positive imbalance that is consistent with the rapid changes in the atmospheric composition and the consequent temperature rise in the past years. There are different mechanisms of climate forcing that may impact on the climate system and contribute to this imbalance. It is not the object of this study to analyze the impact of each into global warming effect, but just to mention the existence of complex Earth System Models (ESM), which model these interactions and are capable to predict the climate response over time on the Earth System.

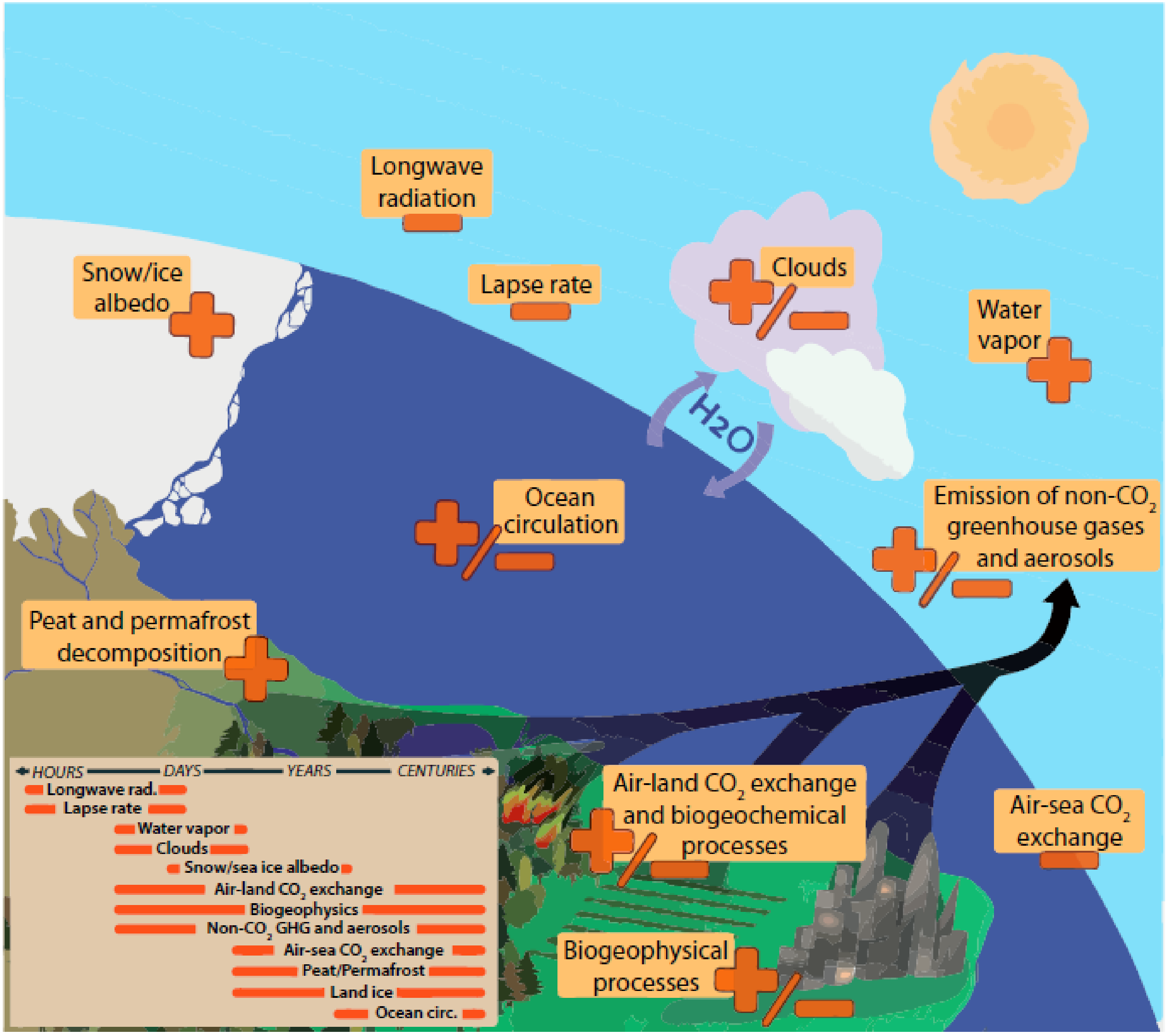

Figure 3: Climate feedbacks and timescales.
The climate feedbacks related to increasing CO_2 and rising temperature include negative feedbacks (–) such as LWR, lapse rate, and air–sea carbon exchange and positive feedbacks (+) such as water vapor and snow/ice albedo feedbacks. Some feedbacks may be positive or negative (±): clouds, ocean circulation changes, air–land CO_2 exchange, and emissions of non-GHGs and aerosols from natural systems. In the smaller box, the large difference in timescales for the various feedbacks is highlighted. (Source: IPCC, AR5 [10])

A positive feedback is a mechanism that can amplify the effects of a change in climate forcing, while a negative one is the opposite. An example of a positive feedback is the water vapor feedback whereby an increase in surface temperature enhances the amount of water vapor present in the atmosphere. Water vapor is a powerful GHG: increasing its atmospheric concentration enhances the greenhouse effect and leads to further surface warming. Figure 3 summarizes the feedback of each subsystem and the timescale for a forcing to make effect on it. Melting of land ice sheets can take days to millennia, while LWR will dissipate in a matter of hours or days in the worst scenario. In the same way, certain gases reflect radiation in a more intense way than CO_2. The reflection intensity plus the living time is resumed in one parameter called global warming potential (GWP), which assesses the GHG effect when comparing to CO_2 (reference value of 1). Table 1 summarizes the GWP of different gases. CO_2 is not a severe GHG compared to the same mass of other GHGs like CH4, for example. Yet, it lives for a long period and its rapid atmospheric concentration increase due to all the carbon intensive activities sounds an alarm of worry on global climate change and how to reduce its impact.

GAS	GWP-20	GWP-100
CO_2	1	1
CH_4	84	28
N_2O	264	265
NO_x	19	-11
CO	11.4	3.3
CFC-11	6.900	4660
HFC23	10.800	12.400
SF_6	17.500	23.500

Table 1: Greenhouse warming potential of main gases participating in combustion process and some other examples of harmful gases (Source: IPCC 2013, AR5 [10]).

CO_2 stock

Global CO_2 emissions from fossil fuel combustion and cement production were 20200 Mt CO_2 yr^{-1} on average during 1980–1989, 23500 Mt CO_2 yr^{-1} during 1990–1999 and 28600 Mt CO_2 yr^{-1} during 2000–2009. Global fossil fuel CO_2 emissions increased by 1.9% yr^{-1} on average during the decade 1980-1989 compared to 1.0% yr^{-1} in the 1990s and 3.2% yr^{-1} in the 2000s, a high annual growth rates were registered in 2010 and 2011 of 5.1% and 3.0%, leading to fossil fuel and cement CO_2 emissions of 34000 Mt CO_2 and 35000 Mt CO_2, respectively [10]. Global net CO_2 emissions from land use change are estimated at 5100, 5500 and 4000 Mt CO_2 yr^{-1} for the 1980s, 1990s and 2000s, respectively.

Since the beginning of the Industrial Era (1750), the concentration of CO_2 in the atmosphere has increased by 40%, from 278 to 390.5 ppm in 2011 (Figure 4), corresponding to an increase in CO_2 of **880,000 Mt CO_2** in the atmosphere. Atmospheric CO_2 grew at a rate of 12,500 Mt CO_2 yr^{-1} in the 1980s, 11,400 Mt CO_2 yr^{-1} in the 1990s and 14,700 Mt CO_2 yr^{-1} in the 2000s.

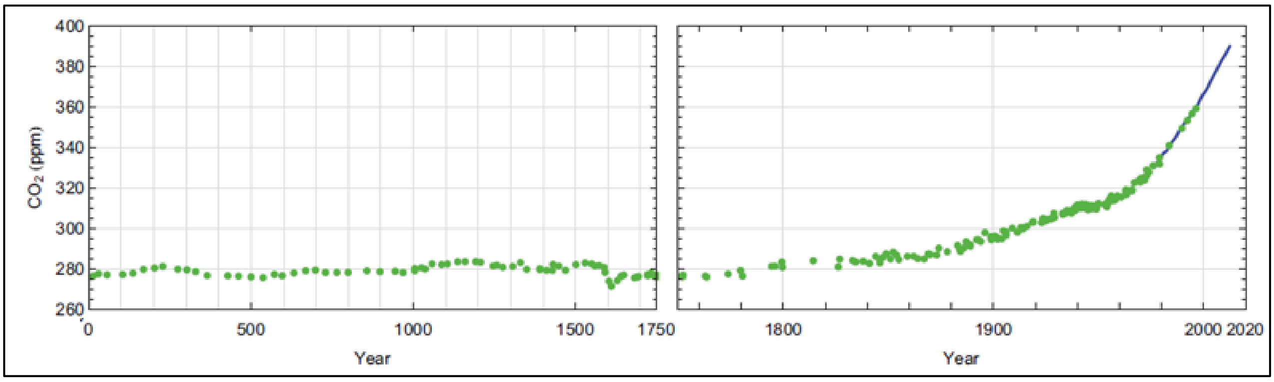

Figure 4: CO_2 historical atmospheric concentration evolution. (Source: IPCC 2013, AR5 [10]).

CO_2 emissions from fossil fuel burning and those arising from land use change are the dominant cause of the observed increase in atmospheric CO_2 concentration. There has been a 25-year fairy tale since the 1970s regarding the exhaust of petroleum reserves. But recent upstream technologies and new resources exploitation keep rolling those 25 years forward, putting in evidence that the petroleum reserves will not be the problem of the 21st Century. As shown in Figure 5, current unexploited petroleum reserves are equivalent to potential emissions of 11 Tt (millions of Mt) CO_2 emissions, 12 times more than current CO_2 concentration in the atmosphere, which is nowadays being deemed as an atmospheric saturation level. CO_2 atmospheric concentration seems to be reaching its saturation limit, forcing to find an alternative way of generating energy transversal to every demanding sector from that of fossil fuels in order to reduce the GHG effect.

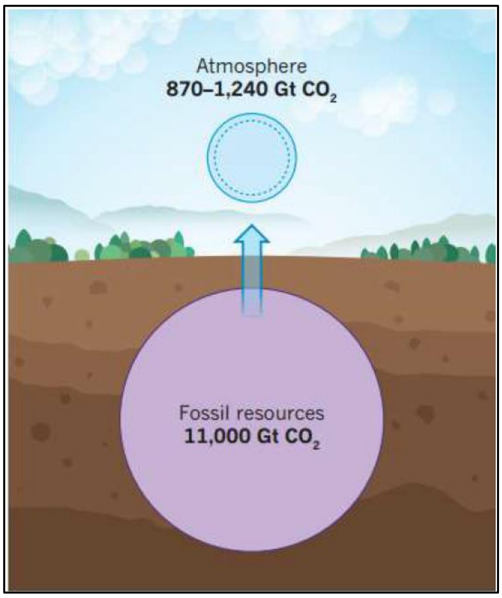

Figure 5: The geographical distribution of fossil fuels unused when limiting global warming to 2 °C. (Source: Nature, 517, 187-190, McGlade, C, and P. Ekins, 2015).

1.2 Emissions regulations of the transport sector and test procedures

In order to understand the reason behind the rapid increase of CO_2 in the atmposhere, a brief explanation of a combustion process is that when a combustion occurs, a chemical reaction takes place, releasing energy from the chemical bonds and the product gases of the oxidized fuel. These are carbon dioxide (CO_2) and monoxide (CO), water vapor (H_2O), nitrogen oxides (NO_x), unburnt hydrocarbons (non-methane: NMHC; total: THC), and soot (particulate matter: PM; particulate number: PN), among others (there can also be intermediate reaction species, sulfuric acid, metals, and other oxides as well). As stated in 1.1, CO_2 is the main contributor to the GHG effect, the main cause of the temperature rise and global warming, because of its high concentration and long living. Yet, together with water vapor, it is the most desirable product to obtain out of a hydrocarbon fuel combustion, as all the other gases are the result of an incomplete combustion or unwanted by-products, which deteriorate air quality. So, how can we reduce the GHG effect? By burning less fuel. In that sense is that the European authorities started treating vehicular emissions since the 1990s.

There are mainly two classes of emissions regulated by different commissions in Europe. On the one hand, there are CO_2 tailpipe emissions, strictly tied to energy efficiency and fuel consumption, as this is the main product of the fuel combustion together with water vapor. These emissions regulations do not apply to Latin American market yet, although most of the fuel efficiency technology is carried over from European Union (EU) market where these regulations are already mandatory since 2012. Brazil, for example, has implemented labelling of efficiency data on their vehicles; it is expected that Argentina will follow the same practice by 2020.

On the other hand, there are the Euro regulations which establish the tailpipe emissions limits for pollutants in order to regulate the air quality: these are CO, NOx, NMHC (only for direct injection gasoline engines), THC, PM, and PN, and are mostly abated with in-board after-treatment systems, like two- and three-way catalytic converters, particle filters, urea systems with selective catalytic reduction, among others. Euro regulations are not correlated with energy efficiency and do not establish CO_2 limits, but do regulate the limits to ensure good air quality and establish limits for the aforementioned pollutants. In fact, CO_2 emissions compete in certain way with pollutant emissions as, for example, increasing thermal efficiency of an engine reduces fuel consumption but comprises higher temperature, which is a favorable condition for NO_x generation. So, there is a trade-off at some point, between complying Euro norms and reducing CO_2 emissions. Latin America follow this normative in terms of emissions but is always behind latest one. At the moment of writing this work, Argentina follows Euro 5 normative while in Europe Euro 6d-temp has already come into force.

Directive Text Number		Euro 1 93/59/EEC		Euro 2 96/44/EC		Euro 3 2003/76/EC		Euro 4 2003/76/EC		Euro 5 715/2007/EC		Euro 6 715/2007/EC	
Combustion Type	-	SI	CI	SI	CI	SI	CI	SI	CI	SI	CI	SI	CI
THC	mg/km	-	-	-	-	200	-	100	-	100	-	100	-
NMHC	mg/km	-	-	-	-	-	-	-	-	68	-	68	-
NOx	mg/km	-	-	-	-	150	-	80	250	60	180	60	80
HC + NOx	mg/km	970 (1130)	970 (1130)	500	700	-	560	-	300	-	230	-	170
CO	g/km	2,72 (3,16)	2,72 (3,16)	2,20	1,00	2,30	0,64	1,00	0,50	1,00	0,50	1,00	0,50
PM	mg/km	-	140 (180)	-	80	-	50	-	25	4,5*	4,5*	4,5**	4,5**
PN	N/km	-	-	-	-	-	-	-	-	-	6,0E11*	6,0E11	
EOBD	-	NO		NO		YES		YES		YES		YES	

* Applicable only to Euro 5b (Euro 5a: 5,0)
** Applicable to gasoline DI engines

Table 2: Euro Emissions Standards Summary. (Source: Delphi Handbook [11])

In 1992, the transport sector had already become massive and Euro 1 regulation came into force, setting limits for the first time to CO, THC, NOx, and PM (this one only for diesel vehicles at that moment) emissions in order to reduce smog and improve cities' air quality. This regulation required also the switch to unleaded gasoline, as lead was found to provoke cancer, and the universal fitting of catalytic converter in order to attain CO limits. It was established at this point the new European Driving Cycle (NEDC) to standardize measurements across different vehicles. Table 2 presents the evolution of Euro limits.Following the same objective of reducing combustion emissions, efficiency became also an important subject, moreover considering that a reduction would impact in fuel consumption and cost of ownership. In 1995, automakers committed to a voluntary CO_2 emissions reduction to 140 g/km (TTW) by 2008, starting in 1995 with 186 g/km average starting point. That would have meant an average reduction of 2.1% yr^{-1}. By 2005, an average reduction of about 1% yr^{-1} was registered and was clear that the target would not be achieved. Hence, the European Commission started the treatment of a mandatory procedure, which came into force in 2009 by the regulation **EU 443/2009 [12]**, and established a maximum CO_2 emissions of 130 gCO_2/km for vehicles of 1372 kg, a weight slope establishing 0.0457 gCO_2 per kilogram difference on gross weight compared to the reference value and a penalty for every gCO_2 exceeded, phased-in progressively from 2012, applying in a certain proportion of the manufactured fleet, to 2015, applying to 100% of the fleet. This changed the target to an achievable one, and meant a continuing net reduction of 1.7 % yr^{-1} average as from 1995. In case of non-compliance of this regulation, a penalty of 95€ for each gram above the limit (averaged value for the whole fleet) was applied to the total fleet. This policy was successful and overachieved by 2015. The over-achievement of this regulation can be appreciated in Figure 6, where by 2013 most of the European fleet had already overachieved the target.

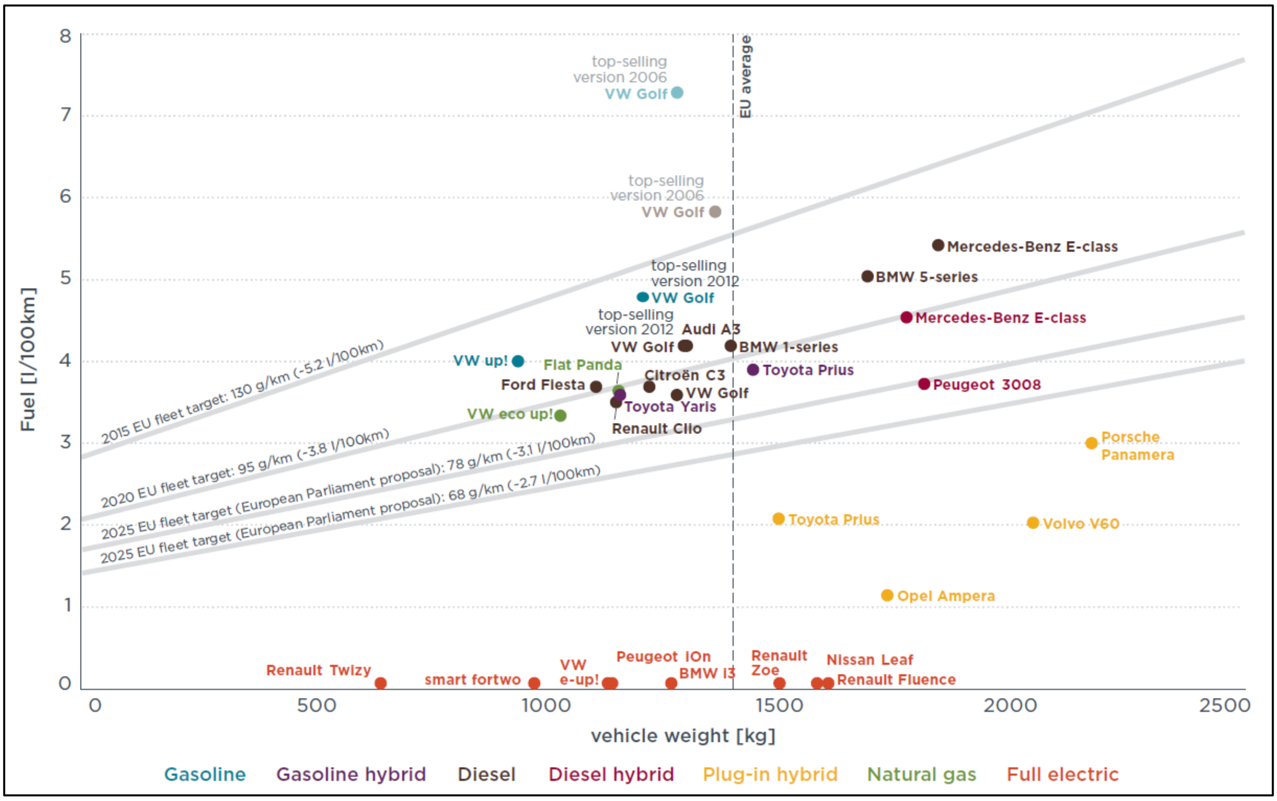

Figure 6: CO_2 emissions of selected commercially available passenger car models in the EU in 2013. (Source: ICCT [15])

In July 2012, the European Commission put forward two regulatory proposals to update mandatory CO_2 standards for new cars and vans in 2020. On October 4, an agreement was reached on the regulation for vans, followed by an agreement on passenger cars on November 29. For the final agreement on cars, **EU 333/2014 [13]** amended EU 443/2009 regulation, establishing a target of 95 gCO_2/km for 2021 (initially was set for 2020), phased-in progressively from 2020 for 95% of the manufacturer's fleet, which means a steep reduction slope of 5.1% yr^{-1} on gCO_2/km. The evolution of projected emissions from 1995 up to 2020 compared to actual ones from 1995 up to date is shown in Figure 7.

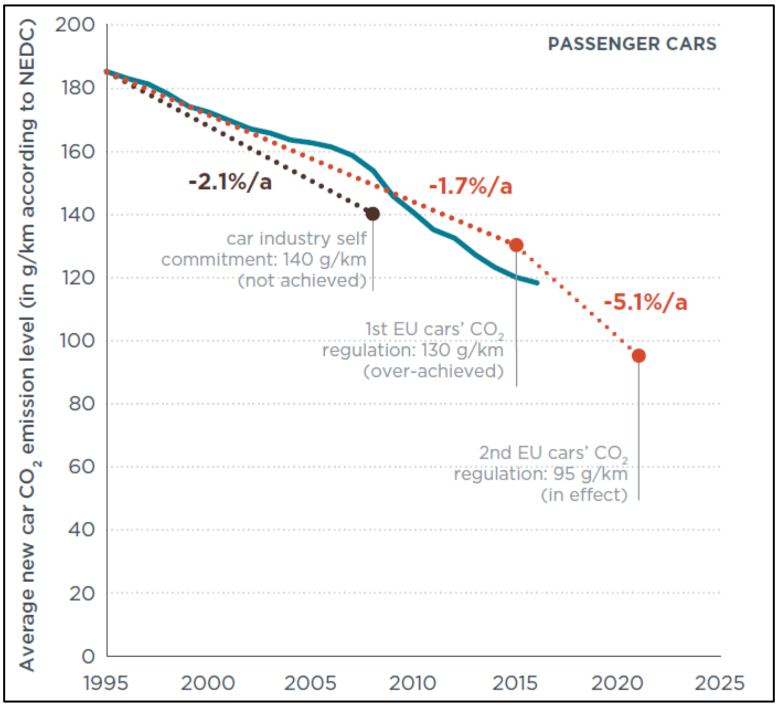

Figure 7: The Role of Emissions Standards in European Fleet. (Source: ICCT [14])

In both emissions measurements (Euro and CO_2) there exist statistical evidence that the "real-world" emission levels of vehicles are significantly higher. According to the ICCT, comparisons of laboratory-based test results with those from on-road testing show a significant and growing gap between reported and actual fuel consumption and CO_2 emissions in the vicinity of 40%, with actual NOx emissions at much as seven times greater. That is why it was replaced by the world harmonized light duty vehicle testing procedure (WLTP), phased-in for new vehicle platforms from September 2017, mandatory for new vehicles from September 2018, and becoming mandatory for the whole fleet and both regulations, Euro and CO_2, in 2020. This procedure intends to represent in a more realistic way the "real world" emissions. The new cycle is also complemented by real driving emissions (RDE) measured on the road and not in a lab by a portable emissions measuring system (PEMS) in order to keep a good track of lab – "real-world" correlation.

CO_2 equivalent emissions

Equivalent emissions are obtained by considering the GWP from Table 1 of the combustion gases. These are mainly NOx, CO, and THC (a mix of hydrocarbons, assumed to be CH_4 in this analysis).

THC formation is given when the reaction between hydrocarbons and oxygen is elapsing faster the higher the combustion temperature. The combustion chamber temperature has a substantial influence on the so-called quenching effect. This effect describes the stopping of the combustion at the cold walls of the combustion chamber and therefore the emission of unburned hydrocarbons from this zone during the charge cycle. The surface/volume ratio of the combustion chamber has a strong influence on this phenomenon. The combustion chamber temperature strongly depends on the air/fuel equivalence ratio, increasing progressively with lean mixtures.

CO formation is given mainly when there is not enough oxygen to burn the fuel, so the result is an incomplete combustion and, conversely to unburnt hydrocarbons, it is given at rich air/fuel mixtures.

NOx formation, on the other hand, is present when N_2 reacts with O_2, both present in the air. In order to break the triple bond of the N_2 molecule and to allow the NOx formation, gas temperatures above 2000 K must be reached. This means that this process mainly takes place during the hot phase of the combustion. However, once this temperature is reached, the NOx formation increases exponentially with temperature [16]. There must be enough oxygen for both, to burn the fuel and release as much as heat as possible and to allow the N_2 to react with free O_2. This happens in gasoline engines with slightly lean mixtures and in diesel engines -mostly- because of the excess of air present in the combustion chamber.

Normally the balance of all these effects tends to reach to a trade-off, keeping in mind that NOx formation is given when the engine tends to operate at its highest thermal efficiency, while the other 2 effects are the result of not releasing all the heat from the fuel to the combustion chamber under different conditions. So, it wouldn't be possible to have all 3 effects releasing maximum pollutants at the same time and, in order to improve fuel efficiency, cycles are generally optimized to achieve NEDC limits at the test bench, but releasing higher NOx in "real-world" emissions because they are operating at higher temperatures.

Therefore, considering a Euro 5 vehicle with specific CO_2 emissions of 186 g/km, that has real-world NOx emissions 3 times above the limit measure in NEDC, as stated by ICCT, while CO and THC remain at half the limit value, then CO_2 equivalence taking GWP values from Table 1 for 20 years will be:

$$CO_{2,eq} = 186\frac{g}{km} + 0{,}05\frac{g}{km}\cdot 84 + 3\cdot 0{,}06\frac{g}{km}\cdot 19 + 0{,}5\frac{g}{km}\cdot 11{,}4 = 199\frac{g}{km}$$

This value is 7% higher than direct CO_2 emissions. Euro limits will get tighter in the region with Euro 6 normative, even more when the new WLTP cycle (WLTC) will come into force, that intends to correlate in a more realistic way the lab emissions with "real-world" ones. And considering GWP for 100 years, CO_2 direct and equivalent values will converge, even leading to lower CO_2 equivalent emissions if NOx were higher, as this gas will have a negative warming effect [10].

The importance of setting mandatory policies

Before 2008, annual CO_2 reduction rates for cars were in the range of 1%, but increased to about 4% with the introduction of a mandatory Europe-wide CO_2 regulation and CO_2 based vehicle taxation in a number of EU member states. For light-commercial vehicles, historical trend data is available to a very limited extent only. 2021 objective seems far away from current level, a similar scenario as the one from 2005 against 2008 objective, with the only difference that ICEVs seem to be close to their technological efficiency limits.

Nevertheless, on the CO_2 abatement race, different technologies became more popular lately, and alternative propulsion systems such as PHEV, BEV, and other ultra-low emissions vehicles (ULEV) are rapidly gaining popularity to become the next standard of automotive industry.

The particular case of Latin American market is that fuel consumption is an important marketing aspect that customers consider when evaluating a purchase and, as explained, strictly tied to CO_2 emissions, while pollutant emissions (Euro) are not. That explains why there is such delay in complying latest Euro norms, but being close to same CO_2 compliance than developed markets. Nonetheless, alternative vehicles such as electric and hybrid still don’t have the same market acceptance as internal combustion engine propulsion systems. In Argentina for example, it came into force in 2016 the Euro 5 norm, which was mandatory in Europe in 2010. Nowadays, Euro 6 diesel and gasoline engines is required in Europe, for which expensive technology must be installed in the vehicle, something that does not pay off for Latin American market.

1.3 Motivation of this work

GHG emissions have had since the beginning of the Industrial Era (1750) a rising trend, increasing steeply since the beginning of the 20th Century, consequently becoming global warming a critic topic to be addressed in the 21st Century. Following current trend, atmospheric saturation will occur before exhausting petroleum reserves, continuing with a temperature rise up to the point of reaching an irreversible climate change. Many countermeasures are being undertaken in order to mitigate this effect (or at least reduce its impact). In this line, United Nations Environment (UNE) has launched United Nations Framework Convention for Climate Change (UNFCCC), and set in 2015 the Paris Agreement in the COP21 (21st session of the Conference of the Parties) to limit global warming well below 2°C above preindustrial level, and pursuing efforts to limit the temperature increase to 1.5°C above preindustrial levels, by the end of 21st Century [3]. According to 2017 Emissions Gap Report [4], in order to reach this objective with a confidence level above 66%, there should be a 10% reduction by 2030 and a 50% reduction by 2050 of CO_2 annual equivalent emissions compared to 2016 baseline, as depicted in Figure 8.

Argentina is one of the 3 countries of the G20 who presented no pledges for UNE’s unconditional intended nationally determined contributions (INDC) for 2020, but submitted post-2020, depending its yield mostly on the results of measures taken on the electrical energy sector. Moreover, it is one of the few countries who has increased its INDC targets since the Paris Agreement, which are currently being rated as highly insufficient. According to *Second Biennial Update Report* [17], its GHG are mostly concentrated on the livestock activities (28.6%), mainly because of the enteric gases’ emissions and the land usage change (Figure 9). Next, they come the emissions as a product of the energy demanded by industry and residential sector (that could be divided mainly into gas and electricity demand), and in the 4th place it positions the transport sector. Aside the livestock activities, the other three ones most intensive in terms of GHG emissions are related to the energy sector. In this sense, the main actions that were presented in the electricity sector were the ones from the Energy Scenarios 2030 from the Energy Ministry [18], framed in the first place by law 27.191 that was put into force in 2016, which establishes the integration of 20% renewable energies generation by 2025 suggesting an increase of 14 – 18 GW by 2030 (so far it has been contracted ca. 4.5 GW under the renewable auctioning scheme *Renovar*); second, by the hydroelectric projected capacity to grow 3 GW; followed by nuclear one, 2 GW; and at last by increasing efficiency of thermal generation, among other measures.

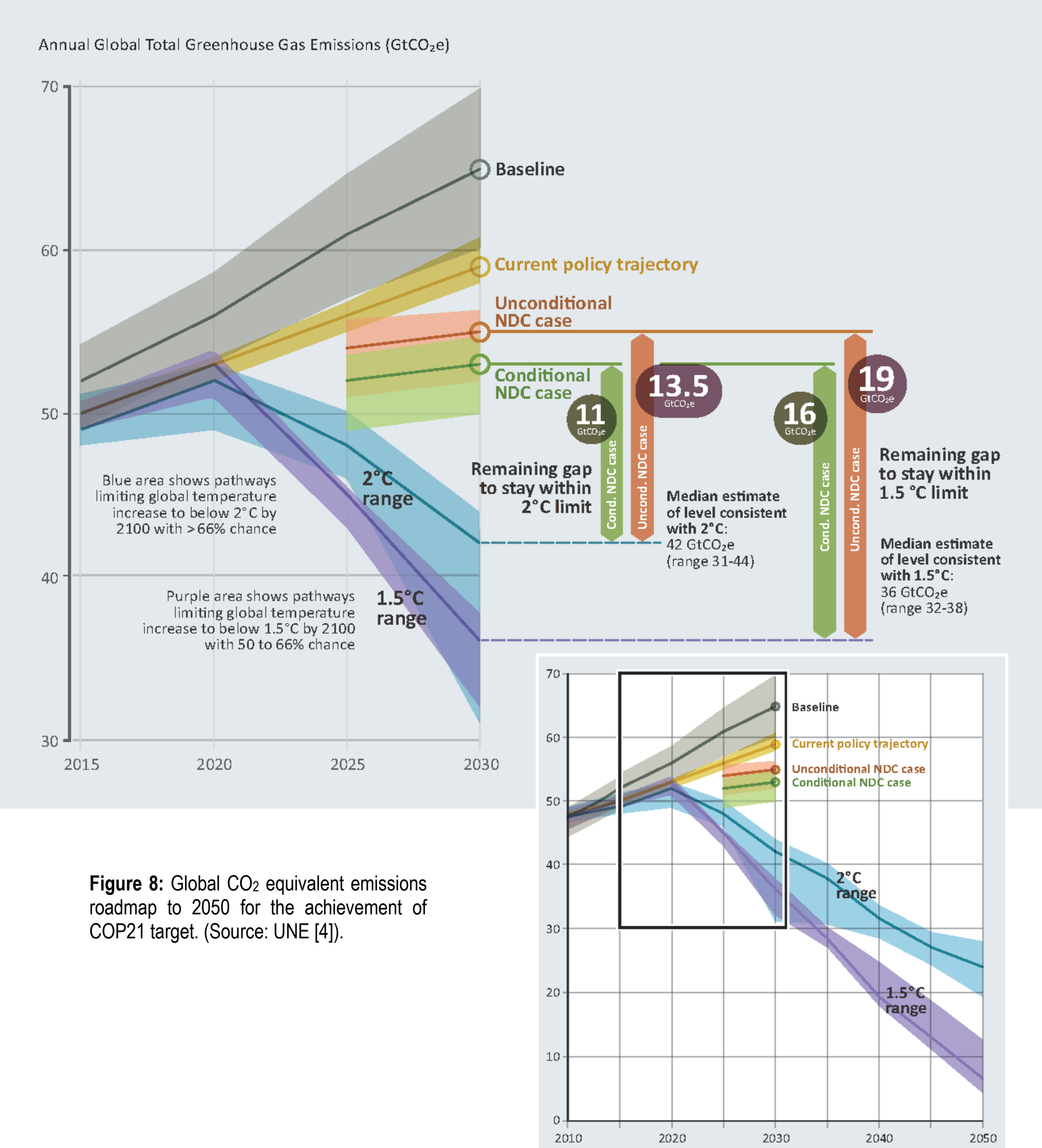

Figure 8: Global CO_2 equivalent emissions roadmap to 2050 for the achievement of COP21 target. (Source: UNE [4]).

In regards to the transport sector, its second largest CO_2 emitter, it is composed by 14 million of registered vehicles as of 2016 [19]: 76% of passenger vehicles, 19% commercial vehicles, and 5% of heavy duty and other vehicles [20]. This sector demands 20% of the total consumed primary energy [5]; that was 18 MTOE yr^{-1} in 2016 out of a total of 89 MTOE yr^{-1}, which emitted 49 Mt CO_2. It is expected between 3.5% and 4.5% yr^{-1} growth per capita [6] of the registered vehicles in this sector, which means ca. 6% yr^{-1} growth overall. Following a BAU projection up to 2030, annual emissions production would climb to 75 Mt CO_2 and then cross the barrier of 100 Mt CO_2 by 2050, even if fuel efficiency actions were implemented in the middle by new technologies deployment. This goes clearly against the path established by UNE, where CO_2 emissions should reduce approximately by 10% and 50% from current level, respectively.

Fostered by public policies, rapid decrease of battery prices, and the aid of new technologies development, this effect could be reduced by the implementation of battery electric vehicles (BEV), replacing partially current internal combustion engine vehicles (ICEV). So far, Argentina announced in 2017 a reduction on the import duties of hybrid, electric and hydrogen fuel cell vehicles for local automakers ranging from 0% to 5%, according to the 8 established categories [8]. Nonetheless, this measure alone had no visible impact so far (and will probably not have if not accompanied by other policies), as BEVs still don't have the necessary charging infrastructure and market acceptance nor have they surpassed the economic barriers for its landing.

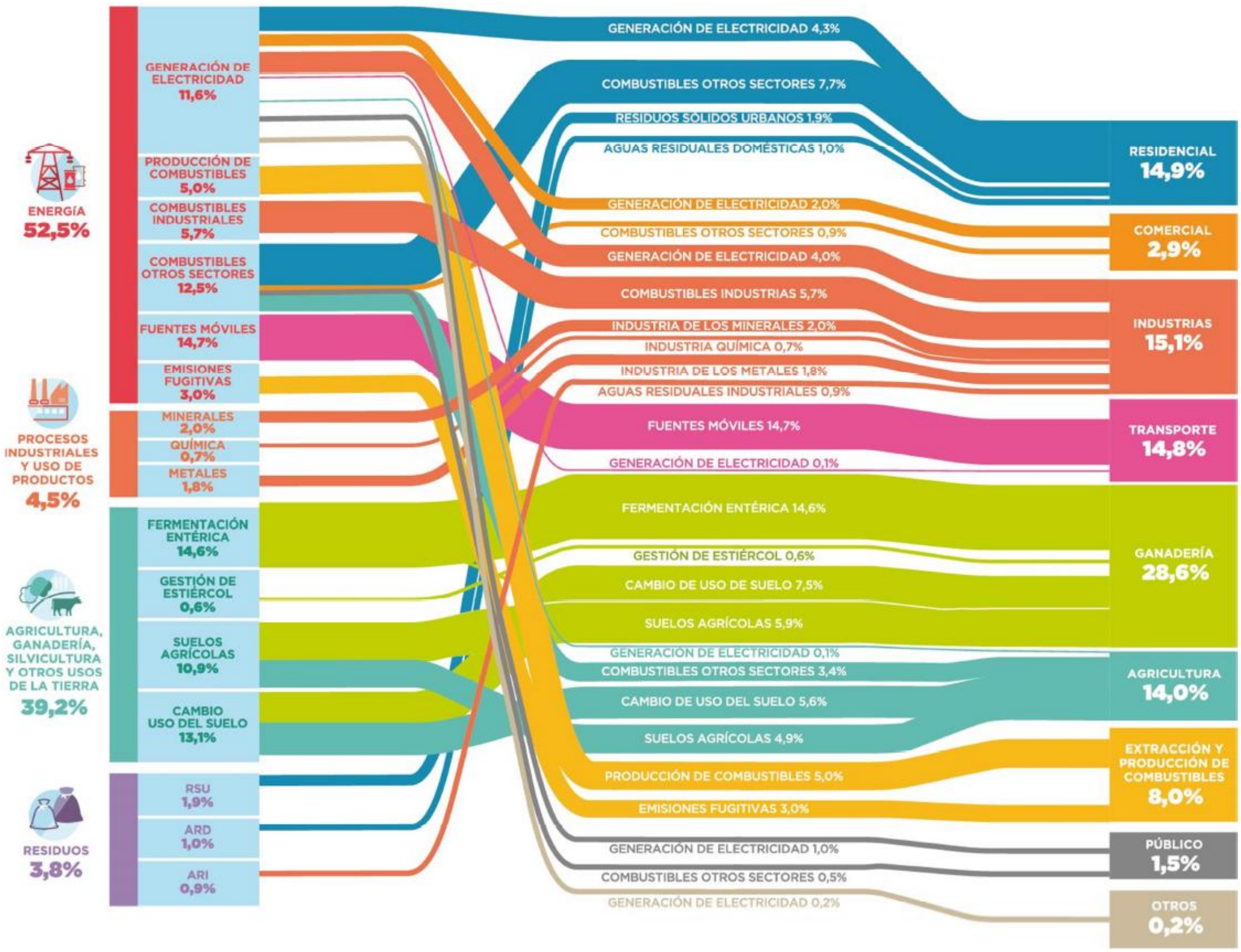

Figure 9: GHG Emissions breakdown in Argentina. (Source: Environmental Secretariat [17])

In either case, supposing this measure were effective and in order to assess its effectivity, a question poses in this regard: do BEVs actually reduce CO_2 emissions when compared to state-of-the-art ICEVs? Although BEVs are well known for being eco-friendly due to its zero emissions, this is only true from the tank to wheel (TTW) perspective, but not necessarily when assessing well to wheel (WTW), as there are specific amounts due to electricity generation, necessary for battery charging. For instance, taking into account the average emissions' value for electricity generation of the last 5 years in Argentina (330 gCO_2/kWh, almost constant [21]) and a typical energy consumption of a compact BEV (180 Wh/km) [22], then the average emissions if the battery is charged from the grid in a 100% efficient process would range 60 gCO_2/km. Considering a plan to introduce BEVs by 2030 where ICEVs are targeted to emit TTW less than 70 gCO_2/km (in Europe, still under discussion for 2025 target, most likely with the introduction of hybrid vehicles into the automaker's fleet), that would be around 85 gCO_2/km WTW, and supposing European technology would reach Latin American market quickly, then the effort of introducing a disruptive transport technology such as BEVs plus all its necessary infrastructure of EVSE wouldn't mean a sensitive improvement regarding the emissions amount. This first approximation indicates that it is necessary to understand how will the electricity grid evolve and what will the impact of renewable energies be, as these sectors will be strongly tied, and how will BEVs demand energy from the grid (uncontrolled or controlled charging).

The purpose of this work is to analyze CO_2 emissions impact for different scenarios of BEV introduction in Argentina, limiting the scope to LDT sector, in order to determine whether the introduction of this technology could be a step forward to the necessary countermeasures to implement in order to achieve COP21 objective. Briefly, it will be analyzed whether this hypothetical scenario could make sense in a couple of years from an economical perspective in the consumer's choice. It will not be calculated the impact that different policies and actions will have on the penetration of BEVs in the transport sector; instead these will be mentioned as case studies and assumed that BEVs will have a certain market share in the future helped by these. Within the universe of ICEVs, will also fall in the hybrid vehicles. It is out of the scope of this work to treat them separately, as these in the end have an internal combustion engine so as to consider them an evolution of current ICEV technology. Because the emissions limits set as from 2025 will be hard to achieve with conventional ICEVs, this will obligate the automotive industry to introduce hybrid vehicles technologies, at least partially in their manufacturing fleets.

The proposed methodology will be to estimate the energy demand in each sector based on the assumptions that will be established. For the electricity sector, these are the overall demand, demand profile, annual growth, and energy generation mix; and for the transport sector, the evolution of specific fuel consumption of the fleet, usage patterns, and grade of penetration of BEV. In this basis, there will be established a bridge between the electricity sector and the transport one, calculating the necessary energy supply in a time series monthly, dividing it into 3 slots according to the time of the day (*valley,* between 23 and 05 hs.; *peak*, between 18 and 23 hs.; and *rest* for the rest of the day). For that demand and according to the energy mix calculated by means of an algorithm that assigns the generation priority, it will be calculated the specific emissions of the system at each step of the series. Then, it will be built a relationship between the electricity generation specific emissions and how does that impact in the ones of a BEV in a time dependent basis, that is, weighing the emissions according to the specific ones of the grid at the time of the day BEVs are being charged. That made, it will be calculated total emissions in order to compare them to a baseline scenario of ICEVs' evolution.

2. Main aspects of the battery electric vehicles

2.1 Total cost of ownership of BEVs vs. ICEVs

In order to determine whether the introduction of BEV could make sense from an economical point of view comparing to the one of ICEV, it will be presented a quick assessment of the investment by comparing the total cost of ownership (TCO). The objective of it is to evaluate the purchase cost, cost of operation, and cost of disposal of an asset.

The purchase cost of a BEV is composed by its manufacturing cost, which is considerably higher to the one of an ICEV, mainly due to the high cost of batteries and the fact that it has not achieved a large-scale economy yet [23]. BEV differential manufacturing cost is impacted by the battery, electric motors, power electronics, R&D charging systems, which replace current technology: engine, transmission, and fuel peripherals. Figure 10 compares the manufacturing costs of main components of a compact BEV and an ICEV.

Batteries account for the largest portion of the price; is what mainly places BEVs at a higher market price than current technologies and delays its massive commercialization. Report from Arthur D. Little [24] explains the evolution that battery prices have had on the past 10 years, that nowadays positions between 190-250 U$S/kWh, and the future of it. Battery prices should be around 100 U$S/kWh for BEV to be an attractive alternative. It is expected to have a disruption on battery's industry, shifting to solid-state electrolyte batteries allowing to use other electrode materials. This will considerably increase the capacity, life-cycle (which nowadays for a BEV is in-between 1000-1500 cycles) and consequently drop specific costs down, with another positive effect of reducing flammability risk; hence, increasing safety as well. So far, state-of-the-art batteries attend existing demand and delay the arrival of new technologies because these cannot reduce scale manufacturing costs in order to cross the "valley of death". Under different assumptions, it is expected to shift to this new technology within the next 10 years.

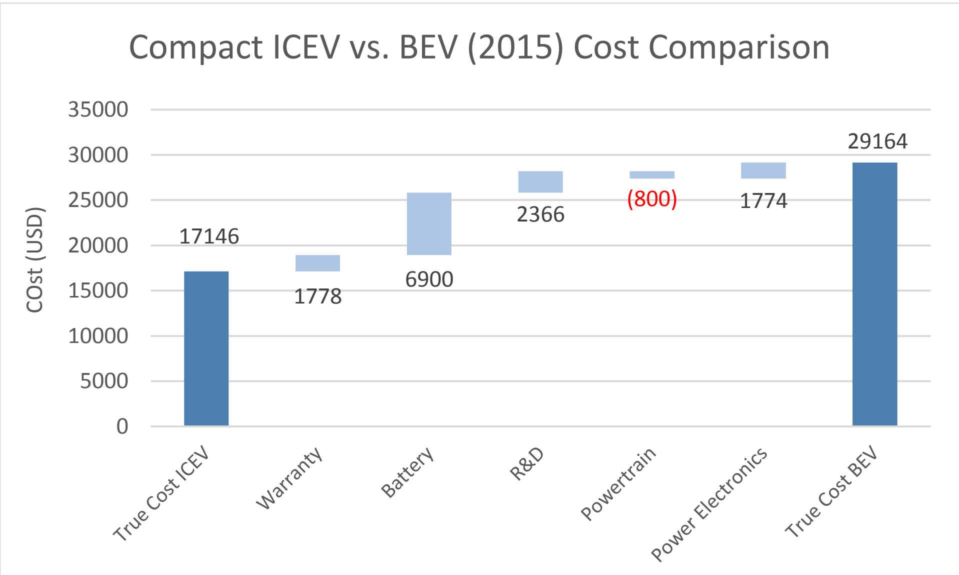

Figure 10: True cost comparison between a compact ICEV and BEV. (Source: ADL report [23])

When assessing the saving between the purchase of a compact ICEV or a BEV with the premise that it is travelling 22000 km/year, compared with the opportunity investment of local bonds which have an internal return rate of 10% [25], and having the upfront costs from Figure 10 (it will require 1 battery change after 10 years once it reaches approximately 1300 load cycles) then the net present value (NPV) of a BEV TCO in a 20-year period compared to an ICEV TCO, where its lifecycle is completed and its value is completely amortized, is 505 USD lower and the parity produces at the 14th year. This would not seem an attractive investment opportunity from the economic point of view. Moreover, if this is done by a private user, who does not purely base the choice of a vehicle purchase on the utility, that this is a technology that changes very fast, and that there is high risk to predict investments' returns in Argentina 20 years ahead. This could be a barrier for its take-off. Figure 11 shows the comparison with the capitalized costs over each annual period.

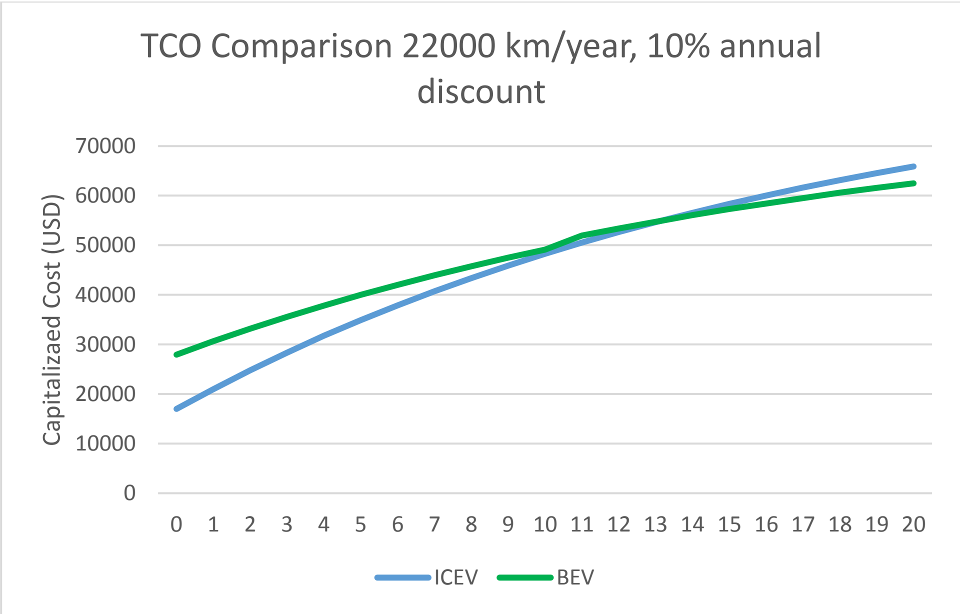

Figure 11: TCO Comparison, case 1.

Now if the vehicles were managed by a private company as a fleet, for example, and instead they would travel 44000 km/year (the double), then it would be necessary one battery change every 5 years, assuming it would have in half period the same amount of load cycles than the one of previous case. Although it would probably have to rely more on fast charging, consequently shortening its life, in a first analysis this will be disregarded. Making the TCO comparison with the same discount rate, the NPV of a BEV TCO in a 20-year period is USD 2330 lower than the one of an ICEV, and the TCO parity produces at the 5th year, as shown in Figure 12. This would seem a better investment opportunity for BEV implementation and the parity will be reached earlier. It is demonstrated here that mileage is a key factor on the TCO. In contrast to a private user, a company will more likely base its choice on maximizing utility, being in this case the BEV a better option. Moreover, considering that this is taken from 2015 costs. It is also expected to see BEV prices drop down when these achieve large-scale economies and new-generation batteries, while ICEVs will probably have limitations to meet Euro and CO_2 emissions requirements, obligating their price to rise due to higher R&D and inboard after-treatment systems costs. Therefore, this will make BEVs even a better investment opportunity in the future.

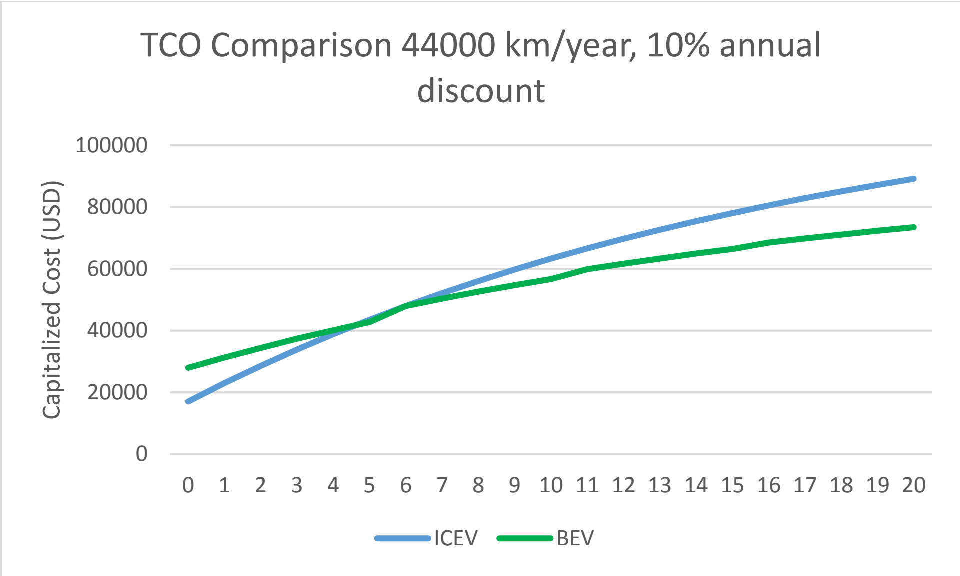

Figure 12: TCO Comparison, case 2.

2.2 BEV charging

BEV charging is assessed under the following three aspects: type, mode, and level. The type refers to charging standard that specifies the socket and connector, mode refers to the communication interface with the vehicle, and level refers to the charging power.

The early deployment of BEVs in this new era (BEVs are actually as old as ICEVs, but resurrected in the last 20 years accompanied with new technologies) was encouraged since 2001 by a supporting infrastructure of charging systems (EVSE), which started in the US with SAE J1772-2001 standard. In 2009, SAE updated its connector standard to the one developed by manufacturer Yazaki to SAE J1772-2009, also included in European norm IEC 62196-2 as AC type1 connector (aka Yazaki). This was adopted as US AC standard connector and Europe adopted it in its standard, but with European AC voltage (250V single phase) in contrast with SAE specification (120V). Europe manufacturers started working at the same time with manufacturer Mennekes to develop IEC 62196-2 AC type 2 chargers (aka Mennekes), for European market. Nowadays there is a type 3 connector under development by manufacturer Scame from Italy.

Under the necessity to fulfill customer's range anxiety in public spaces, in 2008 a new fast charger generation was deployed by the Japanese industry. This gave place to the creation of CHAdeMO in 2008 (from Japanese: O cha demo ikaga desuka, which means "how about a cup of tea?"; *aka* CHArge de MOve), and was early adopted by Tokyo Electric Company (TEPCO), Nissan, Mitsubishi, Fuji Heavy Industries and, at last, by Toyota. This connector had the capability to deliver up to 62.5 kW at 500V DC current (125A), the fastest charging level at the moment of deployment. It was originally conceived as an independent socket from the ones of AC outlets and used the CAN communication protocol. It is nowadays in use by the same brands, still communicates to the vehicle through CAN protocol, and comes as an independent socket from the one of AC slow charger.

Lately, in 2009, during the ZEV Symposium held in California, a conglomeration of European and US automakers called for a single protocol compatible with the one of smart grids, and started working in it within the society of automotive engineers (SAE) framework. This gave place at the 15th International VDI-Congress of the Association of German Engineers, held in Baden-Baden, to the Combined Charging System (CCS), which defined a single connector pattern on the vehicle side that offers enough space for a type 1 or type 2 (depending whether it is US or European market, respectively, as depicted in Figure 13) connector along with space for a 2-pin DC connector allowing up to 200 A. Seven automakers (Audi, BMW, Daimler, Ford, General Motors, Porsche and Volkswagen) have agreed to introduce the Combined Charging System in mid-2012, and also to use HomePlug GreenPHY as the communication protocol.

Figure 13: CCS Connectors for US and Europe.

At the same time, Tesla has developed its own fast-charging connector, known as Tesla Supercharging, together with a fast charging USA-wide network and there also exists in the market the China fast charging system. The result of all latest developments is that there is no fast-charging unique standard, but at least 4 different with no clear trend of having a single winner in the near future. As fast-charging stations are only compatible with specific vehicle's communication protocol and socket standard, this increases the complexity and tends to slow down the take-off of BEVs, as it naturally increases the infrastructure cost of EVSE.

Regarding the charging modes, there are 4 categories, being mode 1 the most basic charging interface with no connectivity, mode 2 being able to detect when the cable is connected to the vehicle, and mode 3 the one capable to communicate the vehicle with a smart grid. Mode 1 to 3 are compatible with SAE J1772-2009 and IEC 62196-2 standards. However, mode 1 is prohibited in some countries like US due to safety issues (it allows, for example, the vehicle to run while charging). Mode 4 is reserved for DC fast charger, compatible with CHAdeMO and CCS chargers. Table 3 presents a summary of the charging types and their features [22].

		Conventional Plugs	Slow chargers		Fast chargers		
Level		Level 1	Level 2		Level 3		
Current		AC	AC		AC, triphasic	DC	
Power		3.7 kW	3.7 kW < P < 22kW	< 22 kW	22 kW < P < 43.5 kW	< 200 kW	
Type	China	Type I	GB/T 20234 AC			GB/T 20234 DC	
	Japan	Type B	SAE J1772 Type 1	Tesla		CCS Combo 2 (IEC 62196-3)	Tesla and CHAdeMO (IEC 62196-3 Type 4)
	Europe	Type C/F/G	IEC 62196-2 Type 2		IEC 62196-2 Type 2	CCS Combo 1 (SAE J1772 & IEC 62196-3)	
	North America	Type B; SAE J1772 Type 1	SAE J1772 Type 1	Tesla	SAE J3068 (Under development)	CCS Combo 1 (SAE J1772 & IEC 62196-3)	
	Australia	Type 1	IEC 62196-2 Type 2			CCS Combo 1 (IEC 62196-3)	
	Korea	Type A/C	IEC 62196-2 Type 2			CCS Combo 1 (IEC 62196-3)	
	India	Type C/D/M	IEC 60309 industrial socket (draft) and IEC 62196-2 Type 2		IEC 62196-2 Type 2 (Draft)	GB/T 20234	CHAdeMO (Draft

Table 3: Summary of connector types and levels grouped by the main regions.

2.3 BEV energy demand and WTW efficiency

The concept of efficiency in mobility is always considered in relative terms of the energy demanded to make a certain amount of work. It is not possible to define the efficiency to transport one passenger from point A to B in absolute terms. In that case what would the efficiency of an ICEV be compared to the one of a train, a bus or a BEV? If the train were electric, then it would have a high efficiency to transform electric to mechanical energy, while the thermal to mechanical tranformation of an ICEV would probably be around 25%. However, if the train is carrying only one passenger, it would probably demand more energy to move him from A to B than the one demanded by a private ICEV as the carried weight has a larger inertia, rolling resistance, drag, and therefore it requires a greater work for that task (which in the best case can only be recovered partially by regenerative brakes). And if the passenger would travel that distance by bicycle or just walked, there will be no external energy demanded instead. What this tells us is that thermal or mechanical efficiency of a process is not always a good indicator in mobility. In absolute terms, the most efficient process is the one that demands less (or no external) energy.

Said this, BEV are supposed to be introduced in order to replace ICEV. Hence, the efficiency could be compared directly on how much energy would consume to make a certain amount of work in one case and another. A BEV produces mechanical energy out of an electric source. This transformation is highly efficient. In contrast, an ICEV uses a thermal conversion to produce this mechanical energy which has a much lower technological limit. This comparison is the so-called tank-to-wheel (TTW) and assesses the efficiency of the isolated system of the vehicle, regardless how was the vehicle fed with potential energy (battery charging, hydrogen or combustion fuel). TTW efficiency of BEV is around 88% and of ICEV is around 25%, almost 4 times lower. According to the Worldwide Harmonized Light Duty Test Cycle (WLTC), a compact BEV (e.g. Nissan Leaf) with a reference mass of 1350 kg consumes in average 206 Wh/km TTW [26], so it demands 180 Wh/km effective energy. In the same case, an ICEV with 25% TTW efficiency would consume 720 Wh/km. If the fuel has a heating value of 34,6 MJ/liter, this corresponds to a consumption of 7,5 liter/100 km, the fuel consumption of an efficient ICEV vehicle.

In order to assess the real efficiency, the whole process should be considered, and this comparison should be done considering the process of producing the potential energy from which the vehicle is fed. As primary energy normally comes from oil, gas, hydroelectric, nuclear, and renewable sources, the well-to-wheel (WTW) efficiency must be assessed by considering how much of these primary energy sources will reach the wheels.

Well-to-tank (WTT) efficiency of ICEV depends directly from the upstream and downstream of fuel production which is around 78% overall [27]. This leads to a WTW efficiency of ICEV of 19,5%. WTW efficiency of BEV, instead, depends on the electricity generation process, where at least 2 possible alternatives present in this aspect. On the one hand, electricity is produced in a centralized electricity grid from thermal sources like oil and gas, and then transported up to the point where the BEV is charged. This case would be the one of thermal electricity generation process and will have 28% overall WTW efficiency on a BEV, slightly higher than the one of an ICEV but with one big advantage: in high traffic density cities, air pollution from ICEV will be generated at urbanized area, while in the case of BEV, pollution will be away of the city in the electricity generation plants. The other scenarios are the ones where clean generation sources (nuclear, hydroelectric, renewables) play a key role. These are either a special case of the aforementioned one, produced in a centralized system, so there will still exist transport loses and the WTW efficiency climbs up to 79%, and in the other one they are produced in a distributed generation scheme, so there are no transport loses. In this case, WTW efficiency would be almost equal to the one of TTW: 88%. Actually, WTW efficiency will actually be a combination of all these processes, illustrated in Figure 14. The fraction of energy that relies on thermal sources will have a WTT efficiency similar to the one of ICEVs. The goal will be to increase the clean generation sources so that the efficiency increases and there is also a really decarbonisation on the system.

Considering the average emissions' value for electricity generation of the last 5 years in Argentina (330 gCO_2/kWh, almost constant [21]) and the effective demand of a BEV (180 Wh/km), then the average emissions if the battery is charged from the grid in an 88% efficient process would range 87 gCO_2/km WTW. In contrast, CO_2 emissions from a liter of gasoline equal 2376 gCO_2 [29]; but in Argentina, there is a mix among light and commercial vehicles that use natural gas, gasoline and gas-oil fuels. Combined by the total energy delivered by each type of fuel according to MINEM [5] and the specific emissions [28], average emissions are 2466 gCO_2 per liter equivalent of fuel. Hence, in the case of an ICEV (720 Wh/km TTW and 78% efficiency WTT), real TTW emissions would be 185 gCO_2/km; and WTW emissions, 237 gCO_2/km, almost 3 times bigger than the ones of a BEV.

Energy reports generally account the TTW demand when calculating the one of the transport sector. The loses from well to tank are considered as industrial demand. In order to compare total energy demand, the best way to compare between BEVs and ICEVs is considering WTW basis.

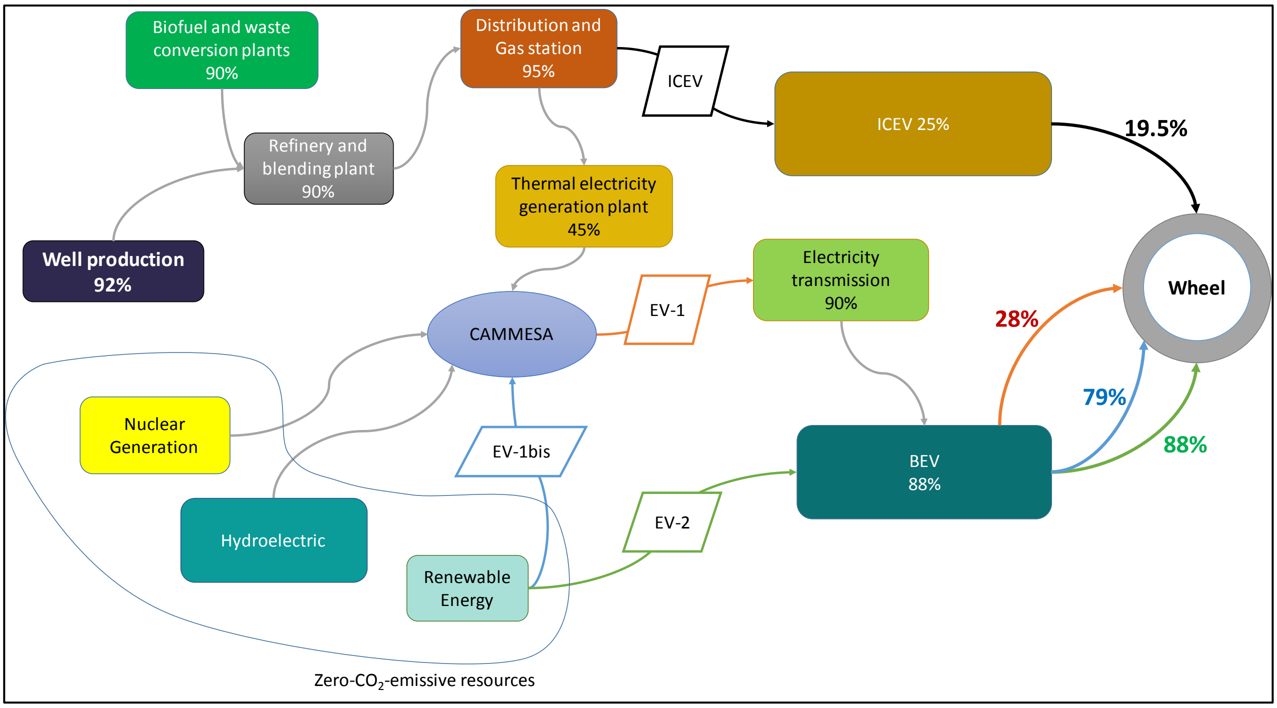

Figure 14: WTW efficiency of an ICEV compared to a BEV.
(Source: Strategic Energy Management Course [27].

2.4 Business cases replicable in the region

From the tariff categories of a metropolitan area utility, it can be induced that the residential demand of Argentina is, in average, between 700 and 1400 kWh per month. That is, roughly around 1.5 kW of mean power. As stated in 2.4, a slow charger consumes between 3.7 – 22 kW, in-between 2 to 20 times the average residential consumption (see Figure 15). Introducing massively this technology to the grid without an assessment of its impact could collapse the system operation. The grid capacity should be prepared for this demand, and considering its magnitude, should be also prepared to deliver in such a way that the peak values are as closest to the average ones as possible. Moreover, considering that the intermittent generation of renewable sources will require a higher installed capacity to compensate this. Otherwise, an energy storage method should be used (hydrogen storage, power-to-gas, batteries, pumped reservoirs, etc.), incurring in higher infrastructural costs, or the grid should be over dimensioned in order to compensate this effect and be able to respond at the moment of peak loads or at the one of low energy production from renewable sources.

It is demonstrated that electricity demand is inelastic against electricity price (between 10-30%) [36]. That means that the response in the demand cannot be forced directly by changing the electricity price. In order to counteract this effect, different strategies incentivize users to adapt their demand to supply variations. Demand Side Management (DSM) is defined as actions taken on the customer's side of the meter to change the amount or timing of energy consumption. Utility DSM programs offer a variety of measures that can reduce energy consumption and consumer energy expenses. In order to do this, tariff differentiation among *peak, rest,* and *valley* time slots should exist in residential tariffs (as it already exists in industrial ones), and households should be connected by the internet of things (IoT) to smart grids, which should regulate the price in order to adjust demand and distribute it as evenly as possible. Electricity DSM strategies have the goal of maximizing end-use efficiency to avoid or postpone the construction of new generating plants, for example, accommodating their demand to the periods of valleys. This could be a good starting point to incentivize users to use electricity in a more effective way according to supply.

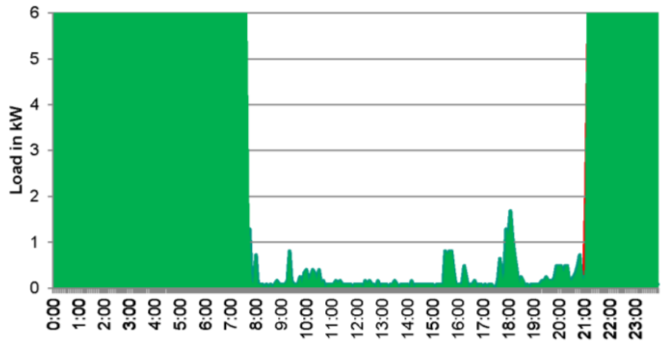

Figure 15: Simulation of BEV demand superposed to a residential one. (Source: KIT EESEM Lecture Notes [36])

This idea applied to BEV also suggests that the need to minimize deployment costs of charging infrastructure should be tailored to the evolution of the electric car stock growth in order to optimize effort and resources. In Argentina there are limitations regarding private space to install own chargers, and successful EVSE deployment strategies also need to match consumer preferences. BEV charging could also have a sizeable impact on the capacity required by the grid at certain times and locations, with consequences for the adequacy and quality of the power supply, risks of cost increases for consumers and negative feedback on transport electrification prospects [22]. Two good examples of these are taken from policies adopted in Amsterdam and Paris. In Amsterdam, it has been adopted a strategy which involves zoning actions via a demand-based approach for deploying its EVSE network. This approach comprises the deployment of public charging infrastructure only upon the identification of user-based demand (citizens can sign up with the municipality to have a charger installed near their home when purchasing an EV), and only if there are no private or off-street alternative solutions. This innovative initiative allows the deployment of public charging infrastructure in an optimized way by installing new, publicly accessible charging outlets only when coupled with new BEVs circulating in the area. In Paris, on the other hand, recent legislation mandated that any new or renovated residential building must be pre-installed with conduits that allow the easy installation of EVSE ranging between 7 kW and 22 kW. Similar legislation applies to commercial building, leaving enough space for parking bays of at least 22 kW.

Having this addressed, financial and regulation incentives could benefit the efficient deployment of BEVs, like the ones that already exist, for example, in Barcelona. These are differentiated tariffs in tolls, free parking in metropolitan areas with charging spots, exclusive lanes shared with public transport, among others. Other successful case studies are the ones of car sharing and carpooling platforms. These are not covered in this work, but just to mention, Car2go, Zipcars, and Moovel are examples of successful car sharing platforms, operating in Europe and US, that give users the possibility to rent temporarily a car in order to move from one point of the city to another where a parking spot from these rental platforms exist, without worrying on where to park and reducing the amount of vehicles commuting daily to metropolitan areas. As stated in 2.3, higher mileage help BEV to reach TCO parity earlier, so a fleet management could be an ideal scenario.

3. Roadmap of the transport and electricity sector in Argentina by 2050

3.1 Current energy balance breakdown in Argentina

3.1.1 Sankey Diagram

According to IEA [1], in 2015 (latest annual available data) there was a total primary energy production and imports of 91830 kTOE, 2% above MINEM estimation for the same year [5]. From that, 61930 kTOE was consumed by end-users: 11150 kTOE as electricity, 22080 kTOE as natural gas, and 25770 kTOE as oil. The total amount was complemented with coal and biofuels. The difference between production and consumption were due to export and stock variations (3820 kTOE), exploitation losses (1030 kTOE), thermal energy to electric work transformation (17200 kTOE), energy production inherent processes consumption (7960 kTOE), accounting in total 30010 kTOE.

From those values, the final consumption of the transport sector in Argentina was 17530 kTOE, 24% of the total consumed energy (leaving aside transformation loses), positioning it in the 2nd place among the other sectors: residential and commercial, industry, and non-energy. Figure 16 shows the break-down of the energy consumption of the transport sector: 73% of the energy demand of the sector came from oil products, which are aero kerosene, fuel-oil, diesel-oil, gas-oil and gasoline fuels; it was followed by natural gas (20%), biofuels and waste (7%), and others (<1%). In the Annex A.1 is the energy balance of this sector, taken from Sankey diagram of Argentina in 2015 [1].

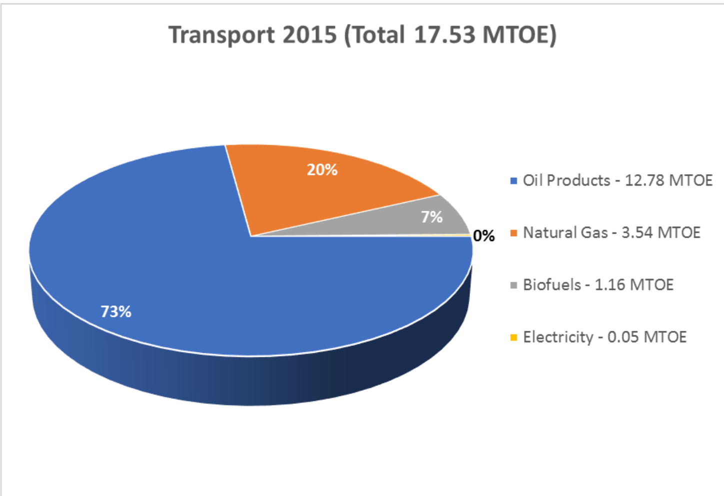

Figure 16: Total transport energy demand in Argentina, 2015 (Source: IEA [1]).

The breakdown of energy consumption by primary energy of the main consumers worldwide is shown in Figure 17. Total amounts slightly differ from the ones presented, as information is taken from another source. Nevertheless, it illustrates clearly the breakdown of these resources. There, they are listed the main energy users worldwide with an exception of Norway, which is not shown because of the total energy it uses, but because of the mix of it: it is the only country that relies mostly on non-emissive CO_2 resources, without having nuclear energy at all (that is, hydroelectric and renewables). In the case of Argentina, it can be seen that it relies mostly on clean energies and is one of the countries, together with Norway, that uses the least amount of coal (5%), the most CO_2 intensive fuel, among the listed ones.

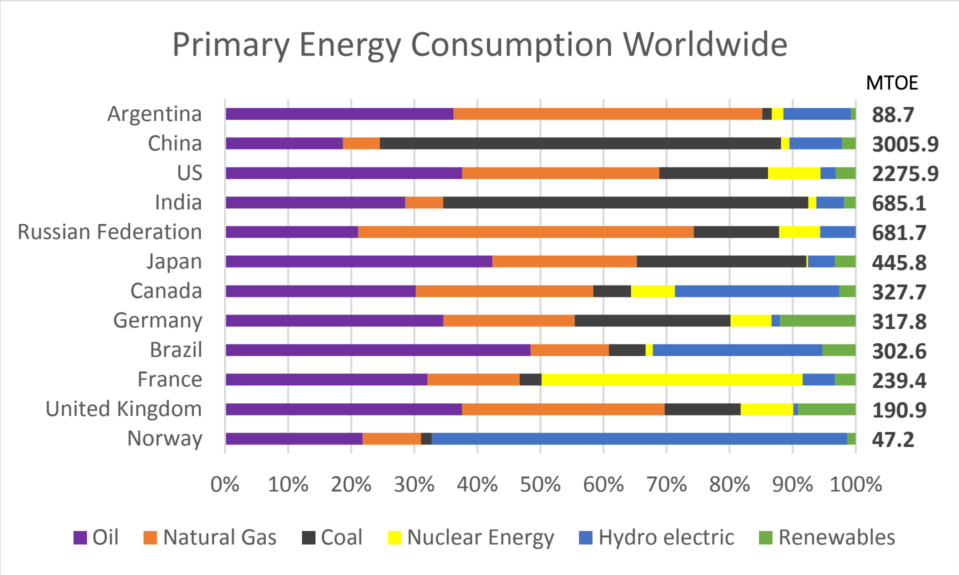

Figure 17: Breakdown of Primary Energy Consumption (Source: own elaboration from BP report [30]).

3.1.2 Electricity generation breakdown

In Argentina there was an annual electricity demand of 132 TWh in 2017, and an average growth of 1.7% during the past 5 years (Figure 18). There is a plan to grow to ca. 180 TWh by 2025. According to the value presented in section 3.1.1 of 11150 kTOE (129,7 TWh) from IEA, there was annual growth of 1% between 2015 and 2017, consistent with the information from the Company of The Wholesale Electricity Market (CAMMESA) [31].

The market is entirely administrated by CAMMESA. Renewable energy did not take off yet, representing nowadays 2% of the energy generation mix, although latest public tender, *Renovar*, has been very successful in both of its editions, and there is an ambitious target of reaching 20% mix by 2025 in order to comply with law 27.191 requirement [7]. As from 2015 and according to CAMMESA [31], there have operated in total 224 thermal plants (combined cycle, gas turbine, vapor turbine, and diesel engine), 60 hydroelectric plants (renewable and conventional), 3 nuclear plants, 11 wind parks, 5 solar photovoltaic parks, and 11 plants of other renewable energy sources, which supplied energy under different contract models. The most common is the wholesale electricity market (MEM) under which CAMMESA contracts thermal energy and power, but there are special contracts like the ones of *MATER*, special contracts for nuclear energy, and some others not intended to be covered in detail for this work.

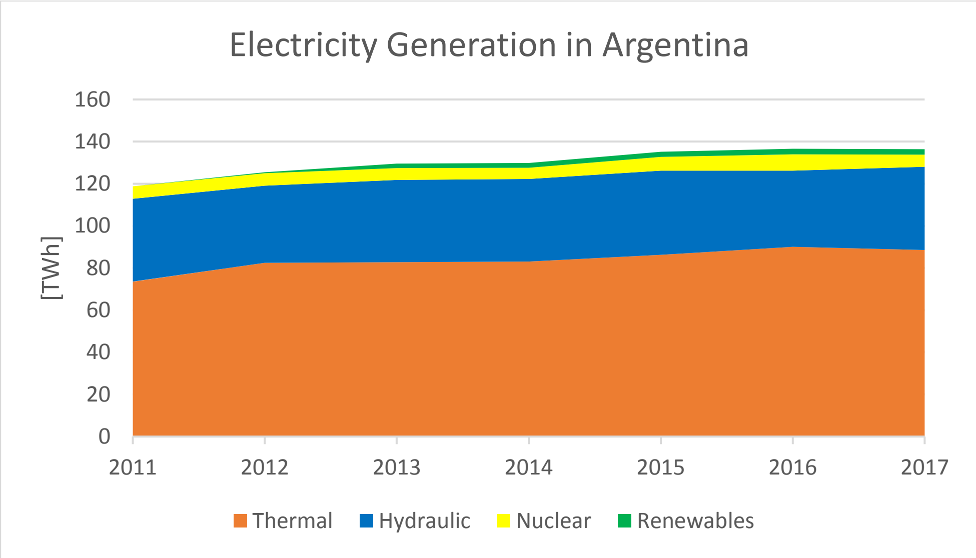

Figure 18: Annual Electricity Generation in Argentina:
2011: 118.8 TWh
2012: 125.4 TWh
2013: 129.5 TWh
2014: 129.8 TWh
2015: 135.2 TWh
2016: 136.6 TWh
2017: 136.5 TWh
(Source: CAMMESA)

According to CAMMESA, there is an installed capacity of 37 GW, distributed as shown in Table 4. Latest evolution of installed capacity was given mostly by expanding the thermal capacity, reaching in 2018 to the following distribution: 64% thermal energy, 29% hydroelectric energy, 5% nuclear energy, and 2% renewables. Current projections show a plan to expand the grid capacity between 53 and 58 GW by 2025.

	YEAR						
TYPE	2012	2013	2014	2015	2016	2017	2018
Hydraulic	10,794	10,795	10,797	10,739	10,752	10,746	10,768
Combined Cycle	9,191	9,191	9,191	9,227	9,227	10,436	10,844
Gas Turbine	4,036	4,061	4,035	4,595	5,251	6,006	6,931
Vapor Turbine	4,451	4,451	4,451	4,451	4,451	4,451	4,451
Nuclear	1,005	1,010	1,010	1,755	1,755	1,755	1,755
Diesel Engine	1,347	1,388	1,415	1,415	1,834	2,003	1,879
Eolic	109	162	187	187	187	227	227
Biogas	0	0	0	0	17	22	22
Solar	6	8	8	8	8	8	8
Small hydraulic	381	381	381	439	488	496	497
INSTALLED CAPACITY [MW]	31,320	31,447	31,475	32,816	33,970	36,150	37,383

Table 4: Installed capacity evolution of different generation sources. (Source: CAMMESA)

MINEM publishes average CO_2 emissions for the whole electricity sector in a generalized way and the last available value is 345 $kgCO_2/MWh$ in 2015. In order to project emissions for different scenarios, it is necessary to understand how this calculus is made [32]. From CAMMESA publications, it is available the amount of electricity generated by each machine and the amount of fuel dispatched to it. Nevertheless, this value by itself could lead to ill conclusions, as it will not correspond exactly the amount of fuel dispatched to each machine in every period with the amount of generated electricity for 2 main reasons: The electricity plant could end up using the fuel dispatched to one machine into another, and could also use its stock on the next month (and vice versa). Hence, the thermal efficiency must be grouped and calculated for each plant from the net generated electricity of each machine from the corresponding plant, and averaging the results of 37 periods, from January, 2015 up to January, 2018 so as to compensate these variations. Considering generated energy over heat released from the burned fuel according to caloric values from [28], the results can be estimated.

From CAMMESA information is estimated for 2015, 2016, and 2017 on Table 5, showing high correlation on year 2015 (2% relative error).

Year	η_{therm}	$kgCO_2/MWh$
2015	66%	339
2016	65%	341
2017	69%	311

Table 5: Average CO_2 emissions of the electricty system on the last 3 years, calculated from fuel dispatch and total generated energy.

Figure 19 shows the efficiency of the main generating plants that operated between the same period, responsible of generating 80% of the total electrical energy, being 100% efficiency in the cases where they have either operated with renewable, hydroelectric or nuclear fuels, and a lower value when operating in thermal cycles (Diesel engine, Rankine cycle, Brayton cycle, combined cycle, etc.). These plants produced energy between 2015 and 2017 as shown in the trend chart of Figure 20.

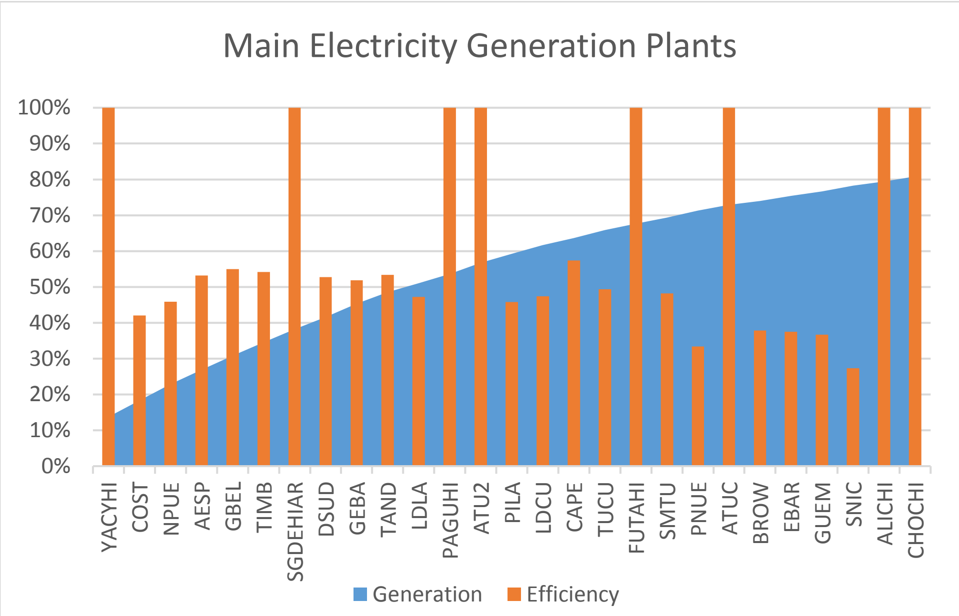

Figure 19: Annual Electricity Generation Plants between 2015 and 2017.
Yacyretá is the main contributor and supplies 14% of the total electricity to the grid.
(Source: CAMMESA)

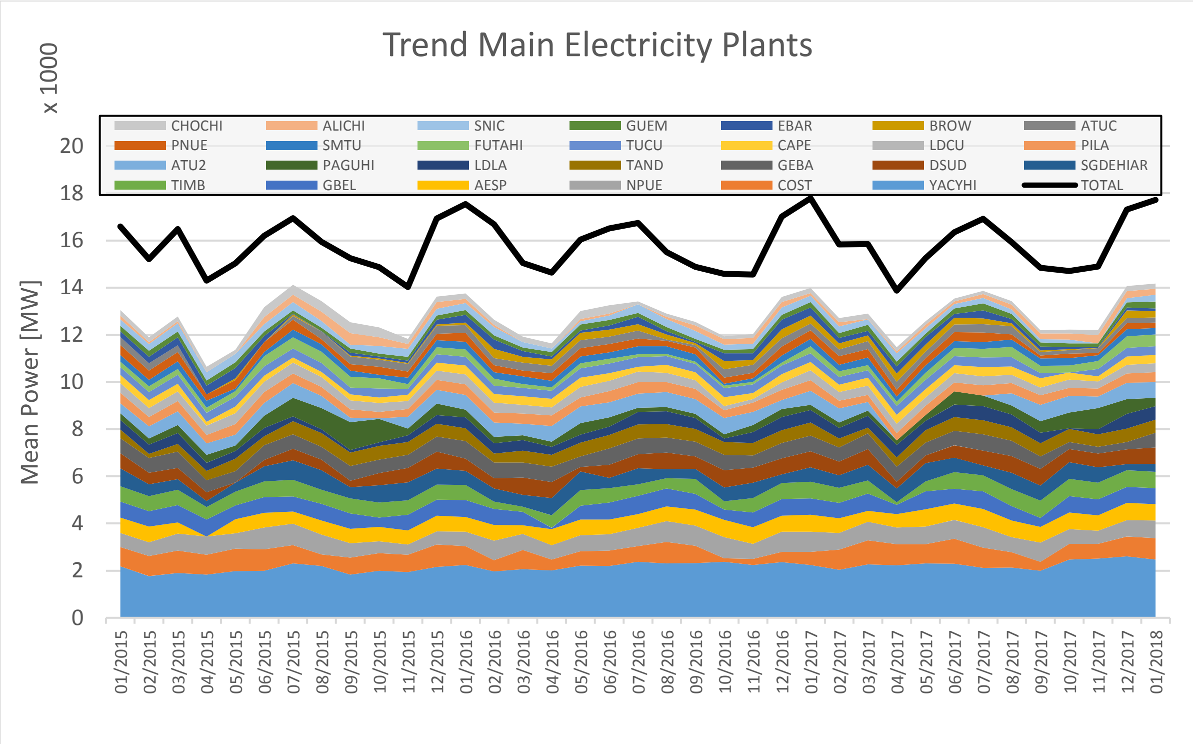

Figure 20: Trend of Main Electricity Generation Plants between 2015 and 2017.
(Source: CAMMESA)

Figure 21 shows an average fuel usage distribution, divided in energy units, during an averaged year, where it can be seen that during the months between May and August less natural gas is used because of less availability to produce electric energy in order to supply it for residential heating. Gas oil is used almost exclusively to replace natural gas, also surrogated in a smaller proportion by fuel oil which has a bulk level of 10%, while coal usage remains almost constant along the year in a total proportion of around 4%. Biogas and biodiesel usage for electricity generation are at the moment of making this analysis negligible, as it is almost entirely used for production of fuels. Nevertheless, it is expected some growth within the awarded *Renovar* projects (268 MW awarded capacity for biomass and biogas generation, 250 GWh projected annual generation).

Cycle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CC - Natural Gas	50%	49%	53%	51%	44%	34%	33%	52%	57%	55%	62%	54%
CC - Gas Oil	0%	1%	1%	1%	8%	20%	22%	8%	3%	3%	0%	0%
Joule - Natural Gas	24%	22%	20%	23%	20%	13%	14%	15%	14%	18%	17%	21%
Joule - Gas Oil	0%	1%	0%	1%	3%	7%	6%	1%	1%	1%	0%	0%
Diesel - Natural Gas	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Diesel - Gas Oil	3%	3%	2%	2%	2%	2%	2%	1%	1%	1%	2%	2%
Diesel - Fuel Oil	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Rankine - Natural Gas	8%	6%	7%	6%	6%	3%	3%	5%	3%	7%	7%	9%
Rankine - Fuel Oil	13%	15%	14%	13%	14%	18%	17%	14%	15%	11%	8%	10%
Rankine - Coal	2%	3%	2%	3%	2%	2%	3%	3%	3%	3%	3%	3%

Table 6: Fuel usage distribution in energy units ratio by type of thermal generation. (Source: own elaboration from CAMMESA information)

The breakdown of this fuel usage by type of thermal cycle is given in Table 6 (a minor difference is expected as the data series for the table is 2 years shorter than the one for the figure).

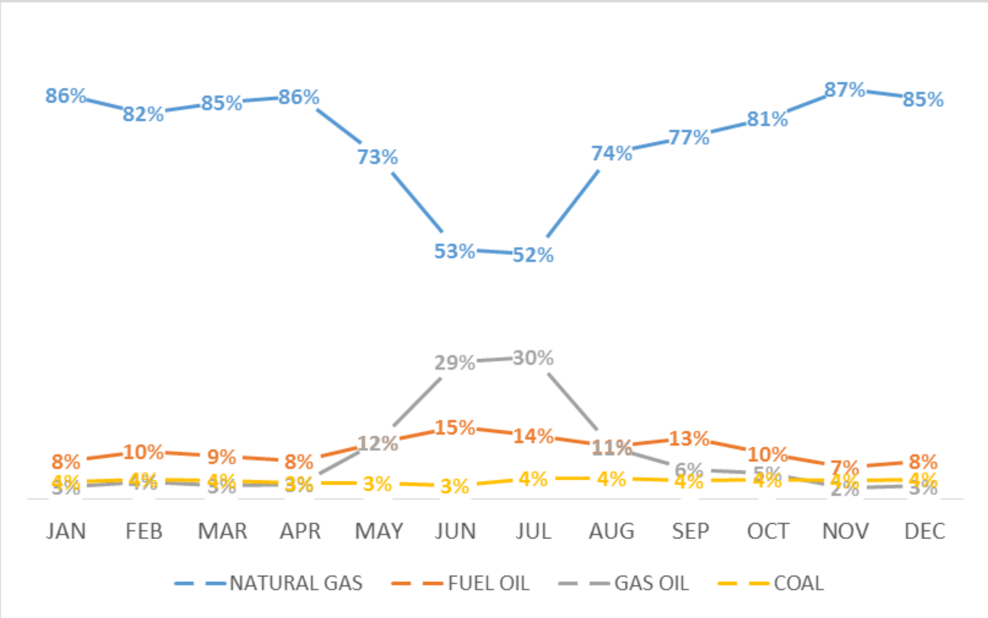

Figure 21: Seasonal variation of energy usage by fuel type. (Source: own elaboration from CAMMESA information)

Figure 22 illustrates a typical pattern of MEM demand along a whole winter and summer day, where the maximum average demand is 18500 MW for both cases, but interesting to notice is the difference between summer and winter peak. On 8th February, 2018 at 15:00 hs, it was registered the highest historical demand, mainly due to high temperatures, which increased the climate systems' demand, totalizing a power of 26320 MW. This left the system with an apparent total reserve of 25%, but considering the fact that the system operates with 30% intermittent sources (hydraulic mostly), and at that moment was only delivering 80% of its installed capacity, that around 20% of the thermal infrastructure is obsolete and in fact more than 10% of it was down for maintenance, the system was left with a rotating reserve of 1895 MW, plus a cold reserve of 803 MW, totalizing an effective 9% reserve, a stringent limit of the total capacity, urging a plan for rapid increase by closing cycles of gas and vapor turbines, and installing new thermal generators as an immediate measure. The maximum during a hot summer day is typically seen in this timeframe. On the other hand, winter peaks are generally registered at 21:00 hs with a maximum value around 21500 MW, much lower to the one of summer. At this timeframe, it is almost the same value registered for summer than for winter because climate system usage reduces its intensity due to temperature decrease, but there is more at home using typical household appliances: TV, light, oven, electric heating, and other devices.

CAMMESA programs a semester ahead the mean power needed at each time of the day [33], which is then adjusted by the real values. This demand is differentiated into 3 time slots along the day. The first one is "*valley*" (23:00 – 05:00), the next one is "*rest*" (05:00 – 18:00), and the last one is "*peak*" (18:00 – 23:00). A differentiation in the tariff exists for big demands such as industry, but it is fixed for the residential one.

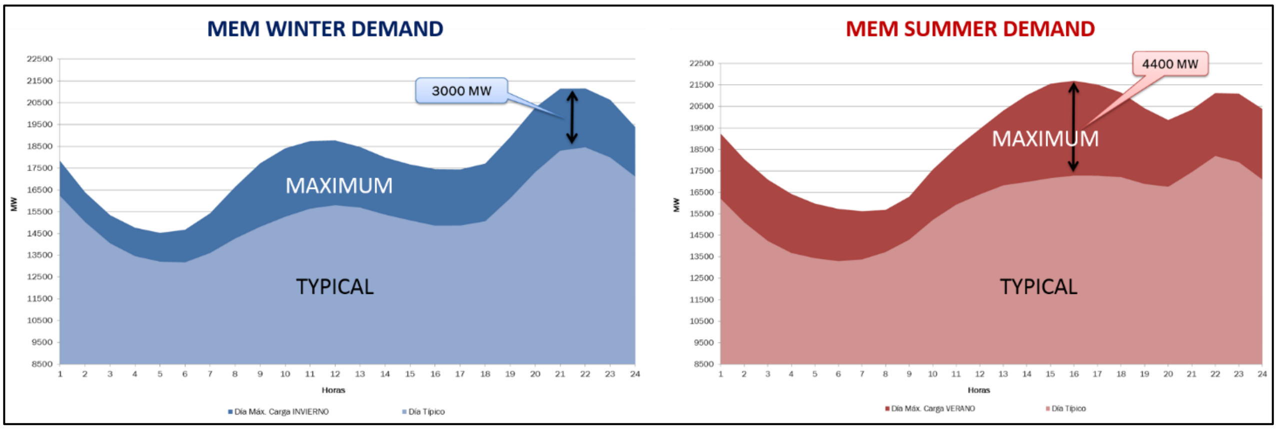

Figure 22: Typical demand profile during winter and summer seasons.
(Source: CAMMESA)

3.1.3 Renewable energies integration to the electricity grid

2017 was declared the year of the renewable energies, not because of its generation level, which represented a modest 2% of the total, but because among *Renovar* auctioning rounds, which started at the end of 2016 and went all along till the end of 2017, there was awarded almost 4500 MW, plus 500 MW of former programs (*GENREN*), which had been awarded in 2011, had not been executed and were then re-awarded under Resolution 202/2016 of the Energy Secretariat. It is expected to have a 3rd round of this program and some impact of private contracts under the new term market regulation, *MATER*, which implements subsidies to those wholesale market users that replace grid electricity by hiring or generating their own renewable energy at a minimum established percentage. Figure 23 shows the evolution of *Renovar* plus *Resolution 202* projects, supposing all of them will be executed on the planned dates. So far, the main awarded projects should be running by mid-2020, and the program will be completed with other smaller ones until 2022. The gradual implementation of it, allows the electricity transport infrastructure to grow and increase its capacity. Otherwise, it would be inviable to generate efficient energy in order to supply metropolitan demand. Nevertheless, this will not be enough to reach the 20% target, so depending the impact of the MATER program on the grid expansion, a 3rd and probably a 4th round of *Renovar* should be executed by 2025. To this, it should be added a continuous growth of renewable energies in order to attend the continuous demand growth.

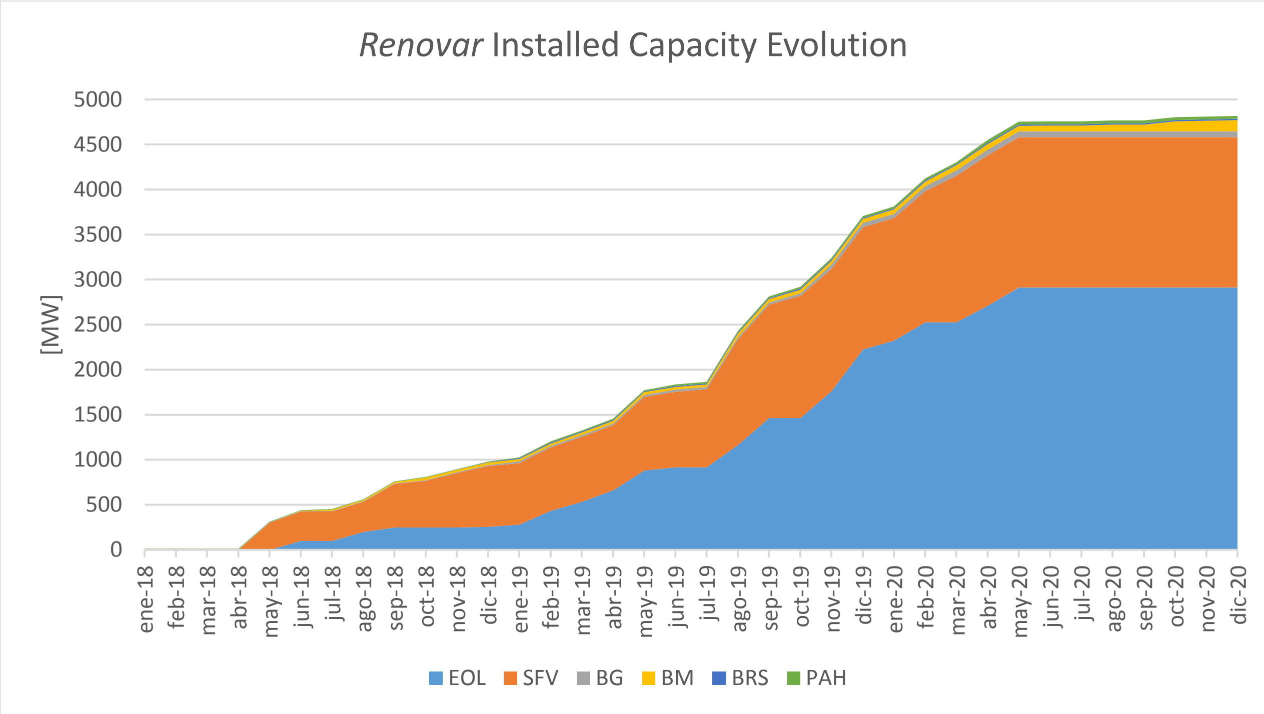

Figure 23: Expected evolution of *Renovar* renewable energy projects in Argentina.
(Source: own elaboration from *Renovar* auction results)

3.1.4 Transport demand breakdown

According to the National Directorate of Motor Vehicle Registration (DNRPA) statistics, there are over 14 million of registered vehicles as of 2017 [19]. Nevertheless, this number differs from the one of vehicles exposed to risk from the Superintendence of National Insurances (SSN), which shows 10 million of insured vehicles exposed to risk (VER) on the same year [34]. This difference is due to 2 main reasons: the first one is that abandoned vehicles are most likely left in DNRPA as if they were registered, despite the fact that they are not in service. Hence, unless someone intentionally proceeds to unregister these vehicles, they will still be registered. The other reason is that there is a proportion of registered and uninsured vehicles in service. As this number is probably low but hard to estimate, it will be dismissed on this projection and assumed to be 0.

According to latest data [34], the distribution is as follows: 6.8 million of cars, 2.5 million of light duty and commercial vehicles, 683 thousand of heavy duty, and 1.3 million of motorbikes. From this population, it will be excluded heavy duty vehicles and motorbikes. The remainder proportion, the one of vehicles exposed to risk according to SSN stats, is the object under study. The annual growth of this population is less than the annual value of new registered vehicles, and this is expectable because at the same time that there are new vehicles registered, there is a smaller portion that have ended their time in service, together with vehicles that suffered a sinister, and are left off circulation.

In order to predict this evolution of the transport system in Argentina, it is interesting to analyze the historical evolution of it, by proposing a model capable to represent it. If the model is able to estimate current proportion of vehicles exposed to risk distributed by model year, then by applying a usage factor (new vehicles are most likely to have a more intensive usage than old ones) and knowing the average consumption of each vehicle type by model year, it is possible to predict the annual emissions of the transport sector and project future values based on projected sales under different scenarios.

In the proposed model, the disposed number of vehicles is modelled with a Weibull distribution based on the time in service [x = 0 for 0 years in service (YIS)].

The probability density function (PDF) of the Weibull distribution is given by the following expression:

$$f(x;\lambda,\kappa) = \begin{cases} \frac{\kappa}{\lambda} \cdot \left(\frac{x}{\lambda}\right)^{\kappa-1} \cdot e^{-\left(x/\lambda\right)^{\kappa}}, & x \geq 0 \\ 0, & x < 0 \end{cases}$$

And the cumulative distribution function (CDF) is given by:

$$F(x;\lambda,\kappa) = \begin{cases} 1 - e^{-\left(x/\lambda\right)^{\kappa}}, & x \geq 0 \\ 0, & x < 0 \end{cases}$$

Where lambda (λ) is known as the scale parameter and kappa (κ), as the shape parameter. The value of λ establishes at which value of *x* it will be accumulated 63.21% ($F[x = \lambda] = 1 - e^{-1} = 63.21\%$) of the probability distribution, while the value of κ shows how this distribution will be given over time (variable *x*). Being *x* the variable “time to disposal”, then a value of $\kappa < \lambda$ means that the disposal rate decreases over time; a value of $\kappa = \lambda$ means that the disposal rate is constant over time; and a value of $\kappa > \lambda$ indicates that the disposal rate increases over time.

The model should, in the first place, be able to predict from a baseline number of vehicles how many of these will be exposed to risk nowadays according to latest SSN records, making a progression of new vehicles' annual registrations. This baseline number of vehicles is given by the earliest available value from SSN, the one from 2003. New vehicles are less likely to be disposed than old ones, at the same time that new vehicles are more likely to be used more intensively than old ones. The usage factor, combined with the population distribution, would indicate the probability to find a vehicle in service from a certain model year (MY) in circulation on a random observation, and this probability distribution will give the mileage accumulation for each MY according to an average usage. If the factors are correctly set and the model is suitable for this study, then the numbers of vehicles exposed to risk, starting from 2003, should match with the ones of 2016, at the same time that the observed MY distribution in service should match with the prediction of the model. The values chosen for this model for time to disposal are $\kappa = 4$ and $\lambda = 19$, and for usage factor, $\kappa = 1.09$ and $\lambda = 14$. These are plotted on Annex A.2. The evolution of the number of registered vehicles [19] out from this model compared to the data taken from SSN [34] is shown in Figure 24.

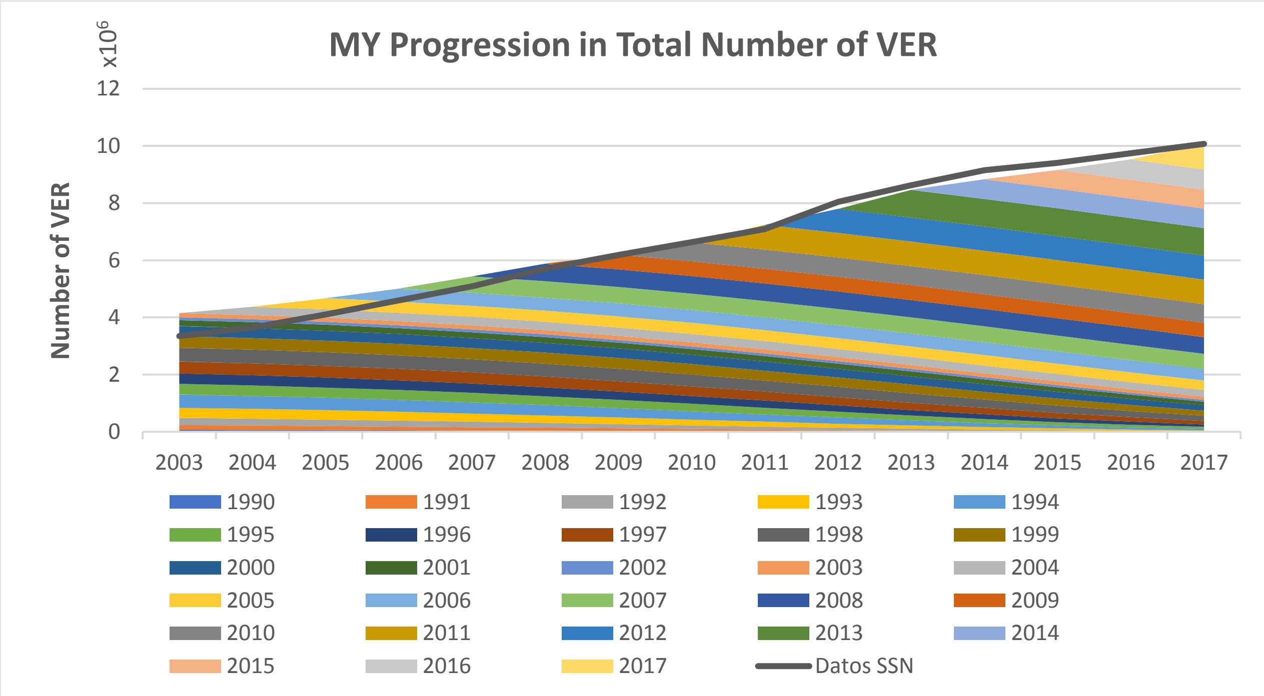

Figure 24: Comparison between evolution of registered vehicles from the proposed Weibull distribution for each model year ($\kappa = 4$ and $\lambda = 19$) and actual data taken from SSN.

Goodness of Fit

As seen in Figure 24, this model follows quite well the progression of total volume of LDT. But in order to check whether the model is a good fit to actual values distribution per model year, an observation has been carried out between 18 hs. and 19 hs., in *Gral. Paz* Avenue, a concurred avenue that divides the metropolitan and suburban area of Buenos Aires, in a commuting timeframe, on 3 different days with a sample size greater than 90 vehicles on each observation, taking note of the plate numbers of the vehicles. The plate numbers were then correlated with the registration year according to the evolution of them, which is in Annex A.3. Vehicles prior to 1995 were disregarded from this observation as it is not possible to determine the registration year out from the plate number.

In order to assess the goodness of fit for the proposed model, a Chi-Square test is performed for both measurements on Minitab®. This test weighs the deviation of a discrete variable from its expected frequency for a given distribution according to the following formula:

$$chi - square = \sum_{i=1}^{n} \frac{(e_i - o_i)^2}{e_i}$$

Where e_i is the expected frequency to find in the same sample size from the one of the observation, o_i is the observed value and n is the number of degrees of freedom. In this case, there are 24 independent years, hence, 23 degrees of freedom. The p-value is a tabulated value according to the amount of degrees of freedom and the calculated value. In this case, it is calculated by Minitab®. When the p-value is greater than 0.05, it means that it fails to reject the null hypothesis that the proposed distribution is equal to the observation, so it is accepted as equal. When the p-value is less than 0.05, the null hypothesis is rejected, accepting the alternative one that these are not equal [35]. In this case, the p-value of the total observation is 0.309, ranging the one from independent observations between 0.337 and 0.763. Thus, it fails to reject the null hypothesis and the model is accepted as representative. The results are presented in Table 7 and the MY distribution, in Figure 25.

Year	Observation 1		Observation 2		Observation 3		Total		Expected frequency
	frequency	chi-square	frequency	chi-square	frequency	chi-square	frequency	chi-square	
1995	2	6.454	0	0.402	0	0.517	2	0.354	0.44%
1996	2	3.934	1	0.375	0	0.703	3	0.815	0.60%
1997	1	0.030	0	0.851	1	0.008	2	0.222	0.94%
1998	0	1.258	0	1.272	1	0.247	1	2.405	1.40%
1999	1	0.080	0	1.341	2	0.044	3	0.440	1.47%
2000	0	1.397	0	1.413	1	0.367	1	2.843	1.55%
2001	0	0.965	0	0.976	1	0.052	1	1.508	1.07%
2002	0	0.542	1	0.372	0	0.705	1	0.352	0.60%
2003	1	0.017	0	0.888	0	1.141	1	1.251	0.98%
2004	1	0.449	1	0.464	3	0.096	5	0.303	2.15%
2005	2	0.215	1	1.159	3	0.101	6	1.099	3.08%
2006	3	0.052	3	0.061	4	0.045	10	0.156	3.80%
2007	4	0.064	4	0.076	3	1.425	11	1.079	5.04%
2008	7	0.752	3	0.869	8	0.313	18	0.097	5.61%
2009	4	0.029	6	0.578	6	0.020	16	0.172	4.84%
2010	7	0.288	3	1.338	5	0.796	15	0.816	6.35%
2011	5	0.828	7	0.044	12	0.525	24	0.026	8.32%
2012	6	0.272	3	2.703	10	0.013	19	1.264	8.25%
2013	9	0.029	15	4.773	6	2.309	30	0.122	9.45%
2014	6	0.001	8	0.551	6	0.465	20	0.001	6.77%
2015	8	0.815	8	0.759	7	0.043	23	0.719	6.47%
2016	6	0.015	10	2.058	14	4.103	30	3.979	7.01%
2017	7	0.125	12	1.889	15	2.032	34	2.125	8.89%
2018	8	2.872	5	0.060	9	1.820	22	3.656	4.92%
Total	**90**	**21.484**	**91**	**25.269**	**117**	**17.889**	**298**	**25.807**	**100%**
p-value	**0.548**		**0.337**		**0.763**		**0.309**		

Table 7: Correlation of the proposed model with actual distribution from observations.

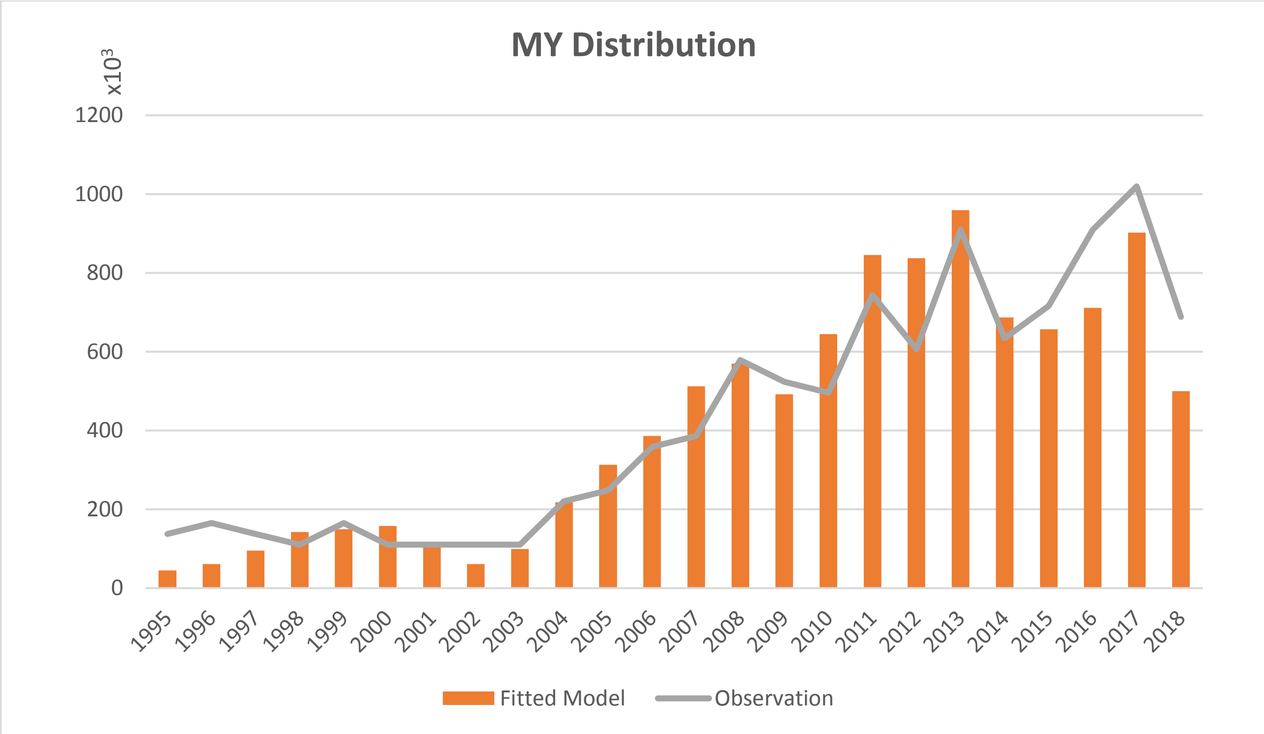

Figure 25: Correlation between proposed distribution of vehicles per model year and actual data from observations.

Energy Consumption

Considering this roadmap and CO_2 emissions per model year as exposed in Section 1.2, it is time to roadmap historical CO_2 emissions in Argentina from 2003 up to 2016 for the LDT.

According to Figure 7, a vehicle emitted in 1995 186 gCO_2/km in the NEDC, and with the correlation between emissions and fuel consumption presented in 2.3, that means that a vehicle from 1995 following NEDC would consume 8.2 L/100km. As NEDC is biased from actual data in the vicinity of 40% (see section 1.2), Argentina generally is a step behind in emissions technology, and normally metropolitan areas have a higher traffic density where fuel consumption tends to increase, the baseline for 1995 will be set 50% above this value, in 12.3 L/100km. The evolution of fuel consumption will be according to the MY given by this same figure, which shows a decreasing slope of 1.7% until 2006, an almost flat slope until 2008, and a 4% decreasing slope until 2016. Projecting those values, 2016 fuel consumption is 7.5 L/100km, same value as the one presented in 2.3 for an ICEV with 25% efficiency.

For each year, the following expression for the light duty transport energy balance should then hold:

$$E\_bal_{light,year} = \left[\sum_{i=1990}^{year} \left(vol_{car,i} \cdot FC_{car,i} + vol_{comm,i} \cdot FC_{comm,i} \cdot ratio \right) \cdot factor_i \right] \cdot km_{year}$$

Where $E\_bal_{light,year}$ is the energy usage of the light fleet taken from the energy balance [5], $vol_{(car/comm),i}$ is the fleet volume, $FC_{(car/comm),i}$ is the fuel consumption per 100 km (for cars and commercial vehicles), $ratio$ is the mileage ratio between commercial vehicles and cars, and $factor_i$ is the usage factor, same as the one presented for the goodness of fit in this study, of vehicles from the i^{th} model year circulating on $year_i$, which in average travel a total amount of km_{year}.

The goal is then to define in the first place the ratio of energy usage from the light fleet over the total, and the amount of km per year for each, cars and commercial vehicles. There is no precise way of breaking down the energy usage by type of vehicle, so it will be proposed as a rough approximation, considering their volumes, a possible fuel consumption and mileage ratio that these may have, that light duty transport uses 85% of the total energy from this sector. As a way of verifying this (at least partially), from cars and commercial vehicles warranty databases (confidential information), it can be inferred that a car travels in average 21400 km per year and a commercial vehicle, 42000 km. The ratio of mileage per year between those is rounded to 2. The calculated value for km_{year}, consistent with the total energy consumption from the LDT sector, is the one shown in Figure 26 for each year.

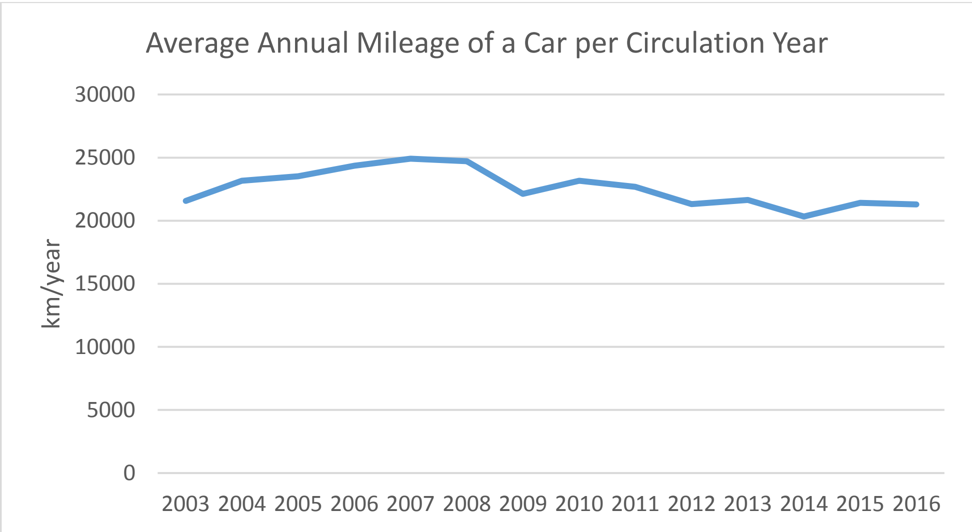

Figure 26: Correlation between energy usage of the transport sector and annual mileage of a car.

With these values set, the whole roadmap for model year distribution, fuel consumption, travelled kilometers, and CO_2 emissions is now defined and the prediction of EV impact can be done with this starting point. The correlation of the stacked values per model year according to this estimation with the actual ones is shown in Figure 27.

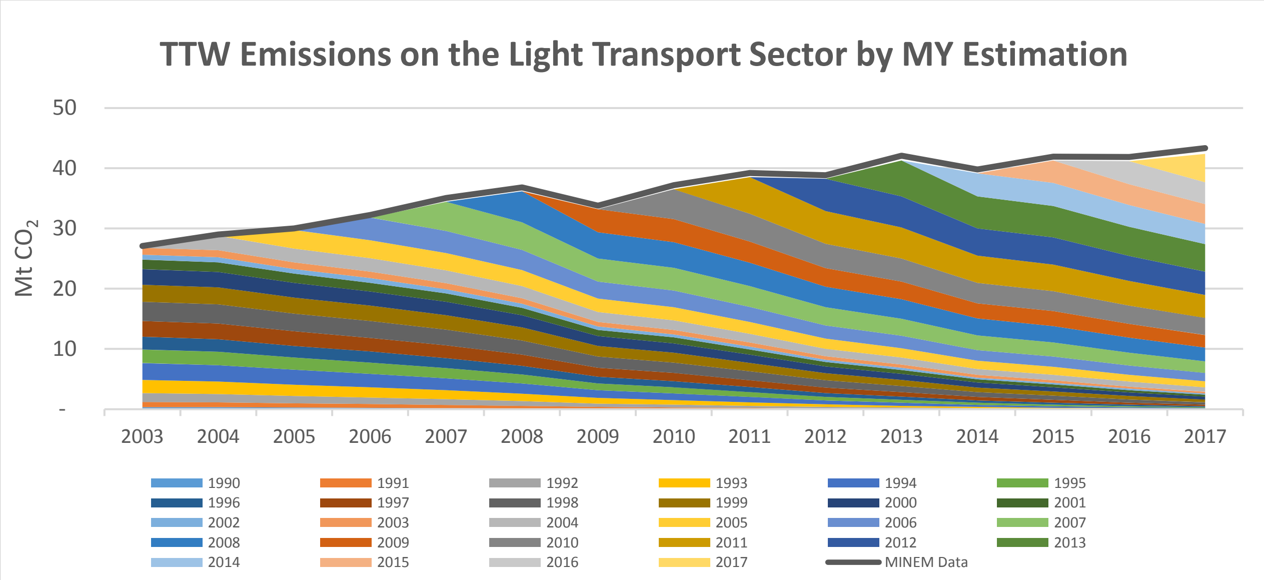

Figure 27: Modeled and actual emissions evolution in the transport sector from a TTW perspective.

3.2 Assumptions of the model

Introduction of a disruptive technology at an early stage, such as it is the case of BEVs in Argentina, where so far they have not penetrated into the transport sector at all, is a case in which it is hard to predict the behavior. Different studies sustain that the market forecast is associated with many uncertainties without a unique solution when there is less than 2% of market share [37]. In order to estimate CO_2 emissions of the transport sector, different scenarios will be analyzed, about potential cases of BEVs penetration and electricity market deployment. In these scenarios, some assumptions will hold. In Section 3.1.2 there is an analysis of current electricity market of Argentina, in 3.1.3 it is explained the current status of renewable sources, and in 3.1.4, from historical data, there is a proposed breakdown of the transport sector by MY, passenger/commercial vehicle mileage, fleet size and consumption ratio. This will be the baseline to calculate the evolution of the light duty transport (LDT).

From this baseline, in the first place, energy demand ratio of the LDT over the total transport sector will be 85%, assumed in Section 3.1.4, and will not change in the whole period of study. It will also be assumed constant the specific energy consumption ratio between commercial and passenger vehicles per sales model year and the annual mileage of passenger and commercial vehicles, regardless the fact whether it is electric or fuel propelled. ICEVs fuel demand will continue their path towards fuel-efficiency, but at a slower pace. Taking BEVs as the benchmark of potential energy to work conversion, this will set the technological limit for ICEVs. Within these will also fall hybrid vehicles, as they produce available work out of thermal energy. Plug-in hybrids are a special case that fall between ICEV and BEV and will be disregarded from this study (same as considering half of the population at each side). Considering that a thermal cycle in the best case could yield to 40% efficiency and that current ICEV technology has an efficiency around 22%, the assumption will be that ICEV population will tend asymptotically to one of 31% (the middle) up to year 2050, as Figure 28 shows. That corresponds to a fuel consumption of 6.25 L/100 km.

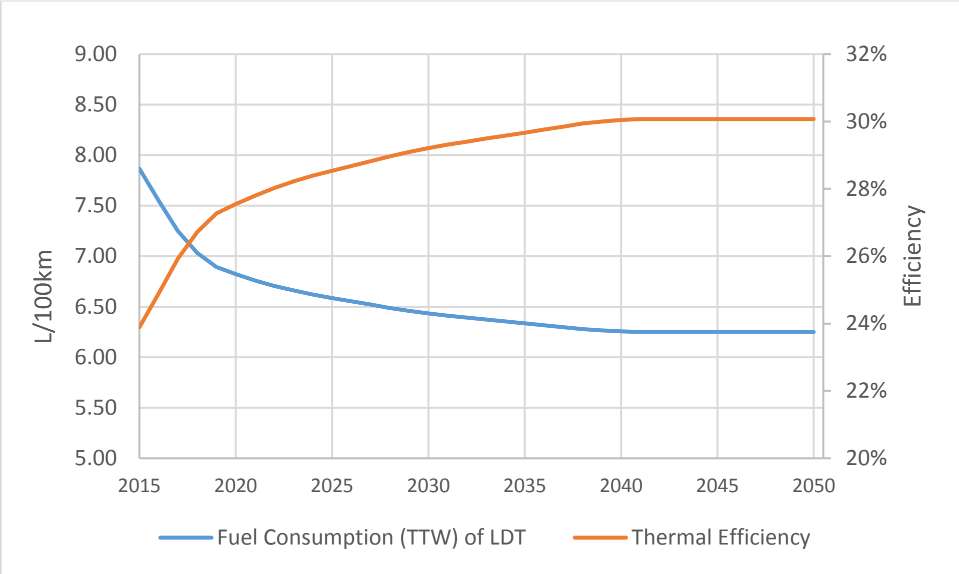

Figure 28: Assumed evolution of fuel efficiency on ICEV.

Total sales will follow the trend stated in [6] up to 2025 and then assumed to grow at a slower pace. In a 30-year period it is hard to predict when an economic recession would hit the market. Despite the fact that these would probably exist, it is assumed that no economic crisis will slow down the electricity and transport market growth. Because this is a long-term estimation, the system will be able to recover and come along to reach the proposed demand values in the end.

Correlation from warranty databases from different automakers (confidential information) show that an acceptable average value for annual mileage on passenger cars is around 21400 km, while on commercial vehicles it is 42000 km. These total values will be assumed to be constant over the whole period. This means that there can be fluctuations in the average travelled kilometers and fleet size due to changes in customer behaviors, but these changes will lead to the same total value of kilometers travelled by the fleet, hence, consuming the same amount of total energy. It is out of the scope of this analysis to assess the impact that the measures presented in section 2.4 will have in the take-off of BEVs in Argentina. Despite admitting that these will be necessary policies to adopt for the deployment of this new technology, it is simply assumed that the conditions are given for having the baseline scenario from a MINEM report [18] and, from this baseline, it is then analyzed an aggressive case in which BEVs would take-off, with the objective to see how the grid will respond under the hypothetical case of an unexpected take-off.

Nevertheless, one remark is made regarding customer's behavior. It is demonstrated by an empirical correlation that the introduction of a more efficient technology or process induces a change in consumer's behavior, generating an offset between the potential save that would be achieved in the case that no behavioral change would exist and in the actual case. This is called the rebound effect [39] and the behavioral change can be estimated with a quasi-experimental *before and after* approach or, more exactly, with an econometric approach, measuring in this case the elasticity of demand for energy services with respect to the price of energy. The rebound effect can be attributed as the value of this elasticity. According to correlations made from experimental data in the transport sector, when an efficient measure is put in place rebound effect lies between 10% and 30%. For this model, out from the values used for the estimation on section 2.1, this effect will be added by assigning a mileage 20% higher to BEV than the one estimated in 3.1.4 for LDT fleet.

The fleet size per model year is calculated from the information of registered vehicles with a proposed Weibull distribution (Annex A.2), as explained in section 3.1.4. The shape and scale factors determined in this section for the correlation are assumed to hold constant for this simulation on both scenarios, no matter whether it is a BEV or an ICEV. Energy demand and charging efficiency of BEV is also assumed constant along the whole period.

As stated in section 1.2, the effect of pollutants will tend to diminish over time, converging direct CO_2 emissions with equivalent ones. For this projection, the effect of pollutants in the greenhouse effect (CO_2 equivalent emissions) will not be considered, as well as the effect of fugitive gases from the exploitation of gas and petroleum reservoirs, and projection will be done over the basis of direct CO_2 emissions.

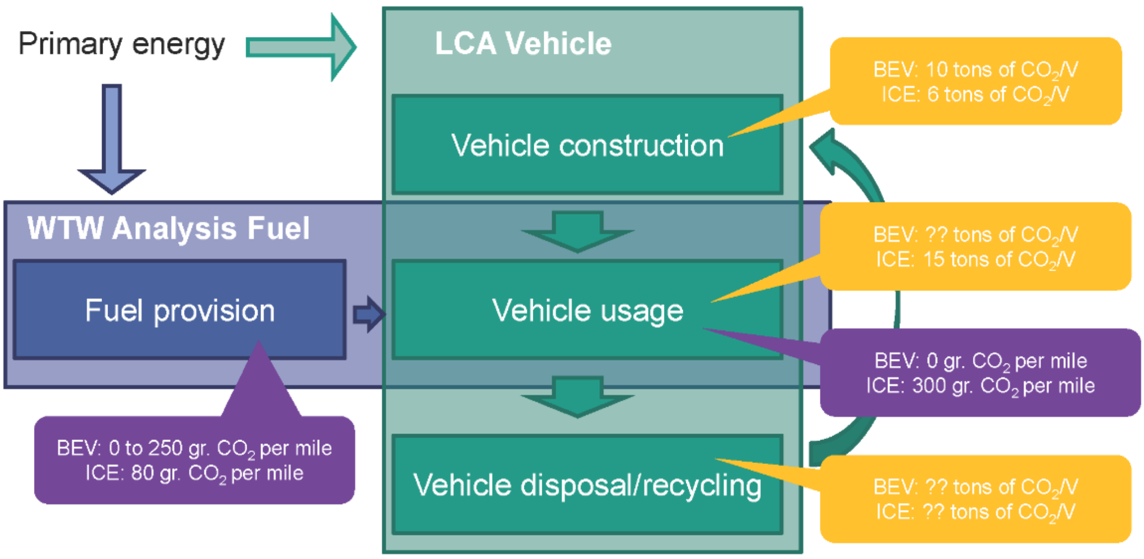

Figure 29: Models of emissions' assessment. (Source: KIT EESEM Lecture Notes [36])

Last, but not least, Figure 29 shows 2 approaches of how to assess of BEV emissions: A vertical one, considering the emissions from the beginning of the vehicle life cycle assessment (LCA) up to its disposal, and a horizontal one, considering the emissions of the vehicle usage from the primary energy source mining, going on through the generation process and the end usage. The scope of this simulation is focused on the WTW vehicle usage emissions. The vertical assessment is not considered mainly because of 2 reasons. On the one hand, BEVs deployment is very early so as to assess the disposal CO_2 equivalent emissions in comparison to the ones of ICEV. On the second hand, the manufacturing technology of batteries nowadays is concentrated in China and Japan [40]. There are plans to deploy batteries' manufacturing sites in Argentina in the future, taking advantage of the lithium reserves, but this is not considered as an input for the simulation. BEV's manufacturing emissions differential compared to ICEV's one account to a total value between 4 and 5 tCO_2 equivalent (considering the GWP from Table 1) per vehicle because of the battery pack [23], [36], plus an equivalent value considering a replacement in the middle of the vehicle's lifecycle (20% lower due to large scale optimization).

3.3 BEV market: proposed take-off scenarios in Argentina for 2050

In order to model the take-off of this technology in Argentina, it will be assumed that it will follow an S-shape, as most studies predict so [37], [38]. This shape will be modelled with a Weibull CDF responding to 2 scenarios, as shown in Figure 30. The necessary measures to shift from a moderate to an aggressive penetration are briefly explained in section 2.4. And in line with these measures, the local deployment of this technology in the automotive industry will bring investments from automakers, generate employment, and help towards the upfront costs reduction, making BEVs more competitive with current state-of-the-art technologies.

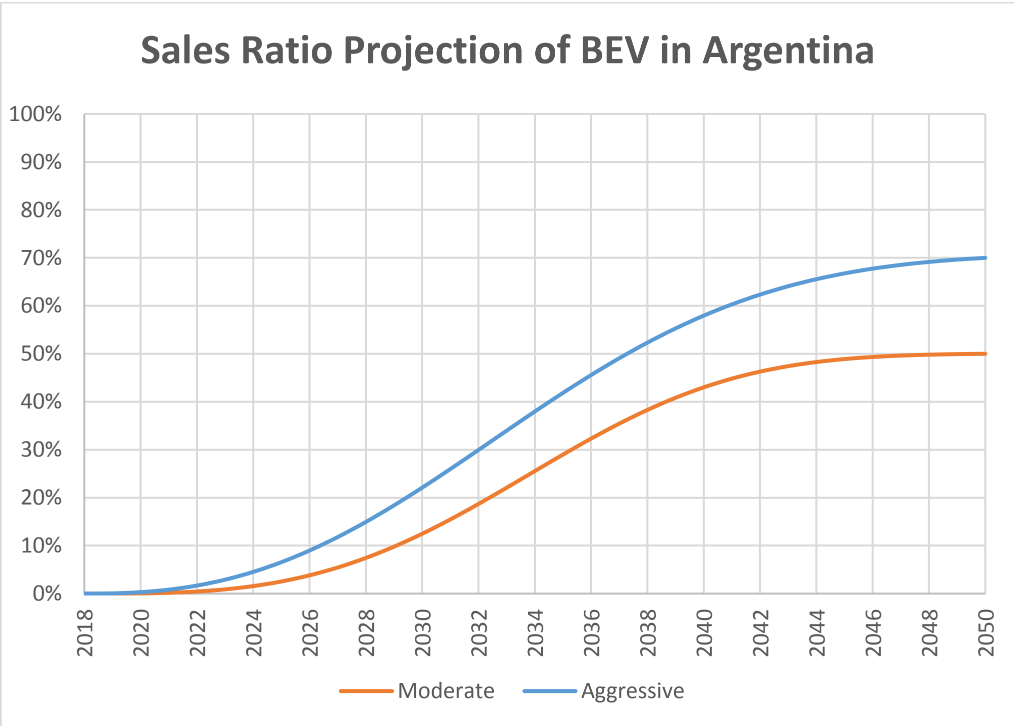

Figure 30: Proppossed BEV's market penetration in Argentina up to year 2050.

The first one is a moderate introduction, where by 2050 50% of the BEV sales share BEV will be reached [18]. In this case, also by 2030, 12% of the sales will be of BEV and will correspond to 3% of the fleet. By 2040, sales will cross the barrier of 40% sales and BEVs mix will reach 21%. After that, market share will reach a stagnation point in which 50% of the sales will be BEVs and they will stabilize in a mix close to 40% of the total fleet. This detail is represented in Figure 31-a.

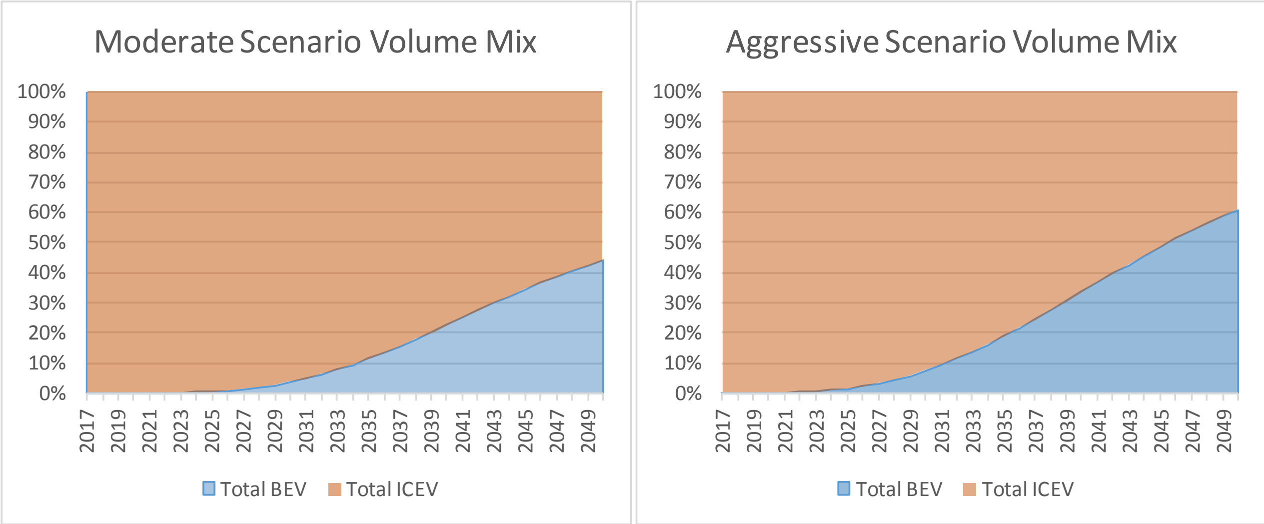

Figure 31: Market share of BEVs in Argentina for the proposed scenarios up to year 2050.
a (Left) – Moderate introduction scenatio; b (Right) – Aggressive introduction scenario.

The second one is an aggressive scenario in which 70% of the sales share will be reached by 2050 and at this point they will still have a growing trend. In this case, 21% of the sales will correspond to BEVs by 2030 and this will represent 7% of the volume fleet. Sales will continue a steeper growth and by 2038 they will already cross the 50% sales share barrier, representing 25% of the total fleet. By 2050, share of BEVs will reach 70% and the mix will climb to 57% of the total, also having a growing trend, as represented in Figure 31-b.

As explained in 3.1, these BEVs will be added to a fleet that will evolve according to a time to disposal Weibull function, explained in 3.1.4 and shown in Annex A.2. The growth of the total fleet up to 2025 will be the ones projected in Scenario A of Science and Technology Ministry report [6]. Then it will be projected a constant growth of new registered vehicles up to 2030, where, close to a saturation point, the annual growth rate will slow down and will hold constant up to 2050 in the vicinity of 2%. Projected volume of the total LDT (ICEV + BEV) fleet is plotted in Figure 32.

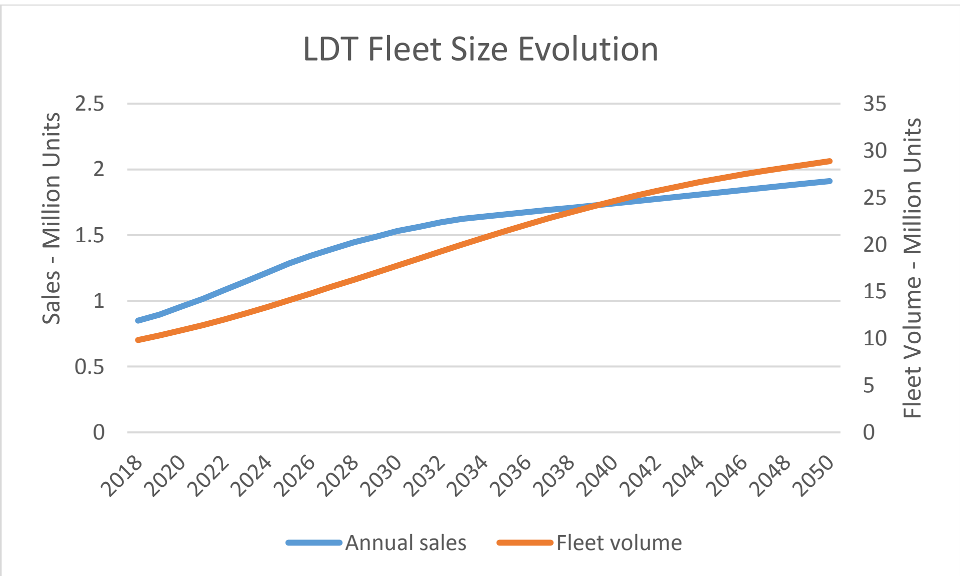

Figure 32: Projected total sales and fleet volume of the LDT sector in Argentina up to year 2050.

Using the same estimation of this report and the estimated transport market growth to 2025 [38], extrapolating data up to 2030 and then assuming that there will be a slower growth in a more saturated market up to 2050 the market penetration according to Figure 31 will be the one of Figure 32.

3.4 Electricity generation: proposed scenarios for 2050

From the baseline stated in 3.1.2, and according to MINEM report [18], the plan for 2030 is to expand the grid following 2 different scenarios under certain assumptions: the first one is a BAU scenario where it is projected an annual growth in demand of 3.4% up to 2030. This average value is reached considering the whole demand and without disaggregating each demand sector. The other one is an efficient scenario where it is projected a 16.8% saving compared to BAU. This means a 2% annual growth, also considering the aggregated demand.

Resolution/Plant	Type	Power [MW]	Year in Service
Res. 21	Thermal	1915	2018
CC Roca	Thermal	160	2018
CC Vuelta de Obligado	Thermal	280	2018
Res. 287	Thermal	1810	2019
CT Río Turbio	Thermal	240	2020
CC Brigadier Lopez	Thermal	140	2022
CC Ensenada de Barragán	Thermal	280	2022
El Tambolar	Hydroelectric	70	2022
Aña Cuá	Hydroelectric	270	2022
Ampliación Yacyreta	Hydroelectric	465	2023
Cóndor Cliff	Hydroelectric	950	2024
La Barrancosa	Hydroelectric	360	2025
Chihuido I	Hydroelectric	637	2026
Portezuelo del Viento	Hydroelectric	216	2028
Repotenciación Embalse	Nuclear	32	2018
CAREM 25	Nuclear	27	2023
IV Central Nuclear	Nuclear	750	2025
V Central Nuclear	Nuclear	1150	2027

Table 8: Planned power from non-renewable sources to be put in service up to 2028. (Source: CAMMESA [18])

In order to reach this demand and according to an already agreed plan currently in execution process, it is projected a growth in the generation sector, consistent with each scenario, according to the entries of A.4.1

and A.4.2 for BAU scenario, and A.4.1 and A.4.3 for efficient scenario. Considering that the system is running through a normalization process [18], where obsolete machines will be put off service and new thermal plants should be finished before 2022 as shown in Table 8, after this point there shouldn't be such a rapid growth, instead one consistent with the demand increase and having in mind the target set in law 27191 (20% renewables generation by 2025). These generation values are projected in this same report and the data is then extrapolated up to 2050, assuming that as from 2030 there is a 30% efficiency in demand growth for both scenarios (that means, 2.4% and 1.4% growth, respectively).

Specific emissions are calculated from the electricity generation sector so as to be able to calculate the WTW efficiency of BEVs. The projection of fuel usage comes together with electricity generation based on reference values from 2015-2017 monthly performance from CAMMESA's database. There, it is listed the available power, fuel usage by each machine and generation of it as well. Machines are then grouped into plants and from that it is arranged the simulation data, as it figures in annexes A.4.1, A.4.2 and A.4.3.

The simulation is performed with a time series that contains averaged monthly values. Each month is divided into 3 slots according to the categories used by the electricity system in Argentina. Recalling from 3.1.2, these are "*valley*" (23:00 – 05:00), "*rest*" (05:00 – 18:00), and "*peak*" (18:00 – 23:00). Priority is based on an algorithm which assigns the power to each slot by turning on power plants in stages up to the point where the demand is covered, following this logic:

- Renewable sources will deliver all its power times the capacity factor in the first stage at first priority, as *Renovar* program states. Photovoltaic will only deliver power during the daytime, that is, from the "*rest*" timeslot.
- Next, hydroelectric plants will turn on in the first stage 30% its capacity, in the second stage 45% its capacity, in the third stage, 65% its capacity, and at last 85% its capacity. In average, they will never be able to deliver 100% their capacity because that would mean that every river will be flowing during the whole month with its maximum tide height.
- Nuclear plants, on the other hand, will turn on in the first stage 40% its capacity, in the second stage 70% its capacity, in the third stage 85% its capacity, and in the fourth stage, if needed, 100% its capacity.
- At last priority in each stage, thermal plants will turn on, following these criterias:
    - In the first stage they will turn on 40% its capacity, decreasing progressively their participation over time up to 2030 to 20% remaining constant after that point (as a means of modelling a partial phase out of thermal energy which is replaced mainly by renewables) only if the efficiency is above 40%.
    - In the second stage, they will turn on 80% its capacity (decreasing in the same fashion to 40% by 2030) the ones that turned on in first stage, plus the ones above 30% efficiency, that will turn on with the aforementioned strategy in this stage.
    - In the third stage, the ones that turned on in first stage will deliver up to 100% capacity (decreasing in same fashion to 70% by 2030), the ones that turned on in the second stage will follow same thing that did the first ones in second stage, and it will be added, if needed, the rest of the plants, turning on as they did the ones in the first stage delivering 40% their capacity decreasing to 20% by 2030.
    - In the fourth stage, if needed, they will jump forward one stage all the plants who did not reach 100% power delivery at this point.

This is summarized in Table 9. Same strategy is applied on the efficient scenario, but with different ratios summarized in Table 10.

Priority	Type	Technology	Stage 1	Stage 2	Stage 3	Stage 4
1	Renewables	All	Up to CF	-	-	-
2	Hydroelectric	All	30%	40%	65%	85%
3	Nuclear	All	40%	70%	85%	100%
4	Thermal	$\eta > 40\%$	40% → 20%*	80% → 40%*	100% → 70%*	-
5		$\eta > 30\%$	-	40% → 20%*	80% → 40%*	100% → 70%*
6		Rest	-	-	40% → 20%*	80% → 40%*

* Decreasing gradually up to 2030, and remaining constant at the final value after that.
Table 9: Power priority assignation of the electricity generation in MEM for the BAU scenario.

Priority	Type	Technology	Stage 1	Stage 2	Stage 3	Stage 4
1	Renewables	All	Up to CF	-	-	-
2	Hydroelectric	All	30%	45%	70%	85%
3	Nuclear	All	40%	75%	85%	100%
4	Thermal	$\eta > 40\%$	40% → 20%*	80% → 40%*	100% → 70%*	-
5		$\eta > 30\%$	-	40% → 20%*	80% → 40%*	100% → 70%*
6		Rest	-	-	40% → 20%*	80% → 40%*

* Decreasing gradually up to 2030, and remaining constant at the final value after that.
Table 10: Power priority assignation of the electricity generation in MEM for the efficient scenario.

The operating technology and the efficiency of the nuclear, hydroelectric, and renewables have assigned an efficiency of 100%. It will be disregarded the fact that it is lower (nuclear energy will not transform 100% into electric; the same will happen with the power from a river flow, or with the wind power, for example) because the efficiency will be used to calculate the specific fuel consumption and from that value, the emissions. A flow chart of this simulation model is shown in Figure 33-a for the main skeleton, Figure 33-b for plant selection strategy.

In BAU and efficient scenario it is assumed the same fuel distribution usage by type of thermal machine as the one used in Table 6. The fuel used by each thermal plant is the average mix from previous years according to the month period of the year and type of machine, and their specific emissions are the ones from [28].

On a BAU scenario, capacity evolution from A.4.1 and A.4.2 is as shown in Figure 34. The assumption is that by 2025 and 2030, 20% and 25% respectively of generation will come from renewable sources. Then, it will continue growing but at a slower pace in order to satisfy demand. The goal will be to have 35% renewable generation by 2050.

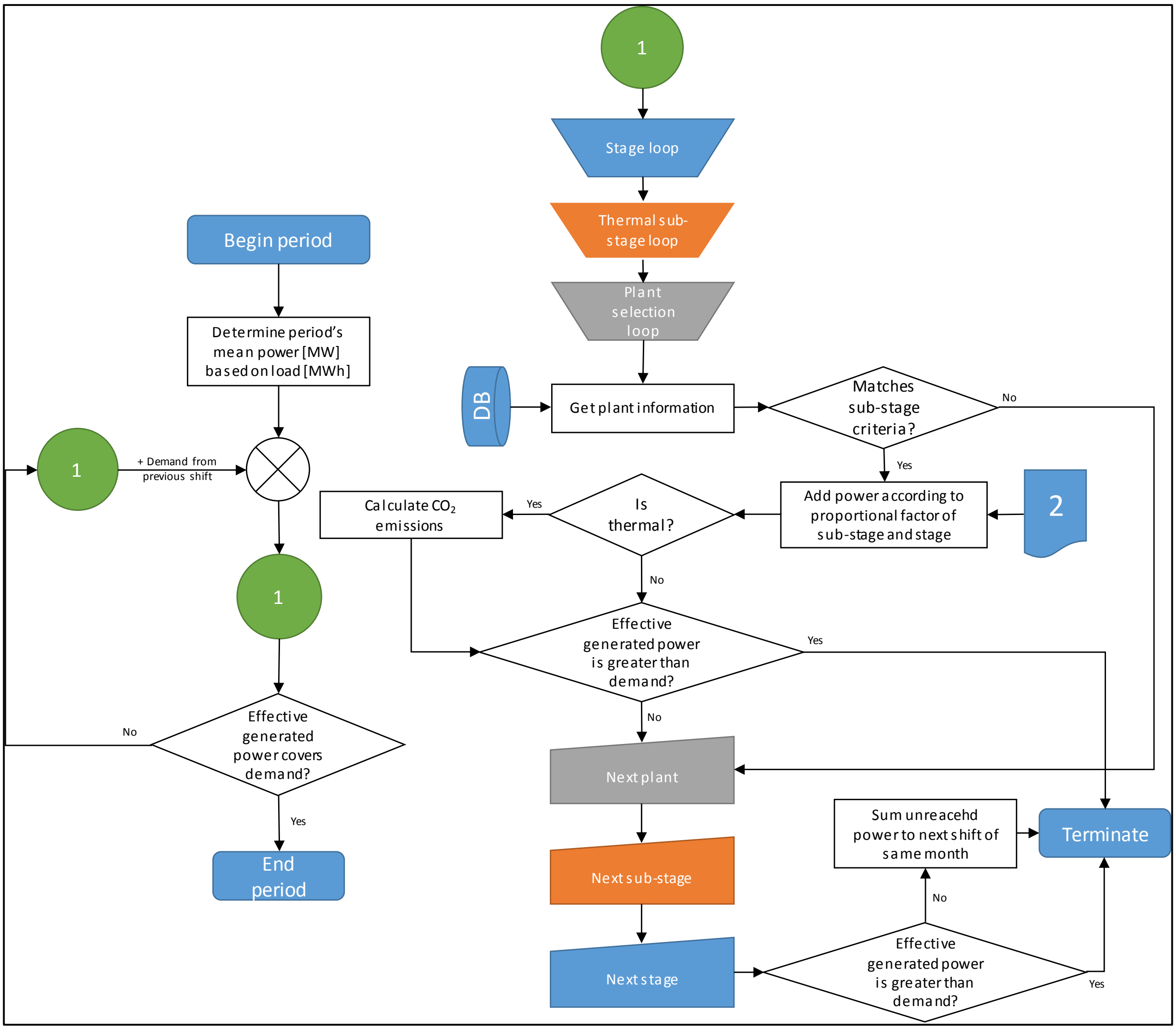

Figure 33-a (Left): Main skeleton of the simulation strategy. **-b (Right):** Power plant selection strategy.

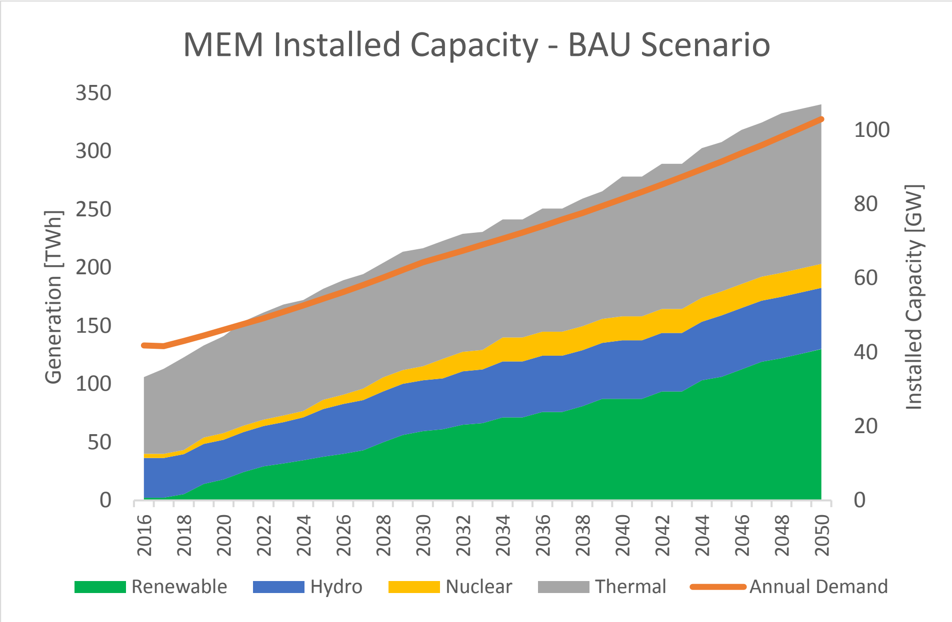

Figure 34: MEM installed capacity and generation of the electricity sector (excluding BEVs) in a BAU scenario up to year 2050.

Instead, in the efficient scenario it is assumed that the same target of renewables up to 2030 will exist, but the difference is that a more efficient demand will require lower installed capacity to cover it in the first stage up to this year. In the second phase, up to 2050, it is assumed that renewables will take off at a steeper pace than in BAU scenario, replacing in a big amount the usage of thermal generation. The results of this, from the listed plants on A.4.1 and A.4.3, are on Figure 35.

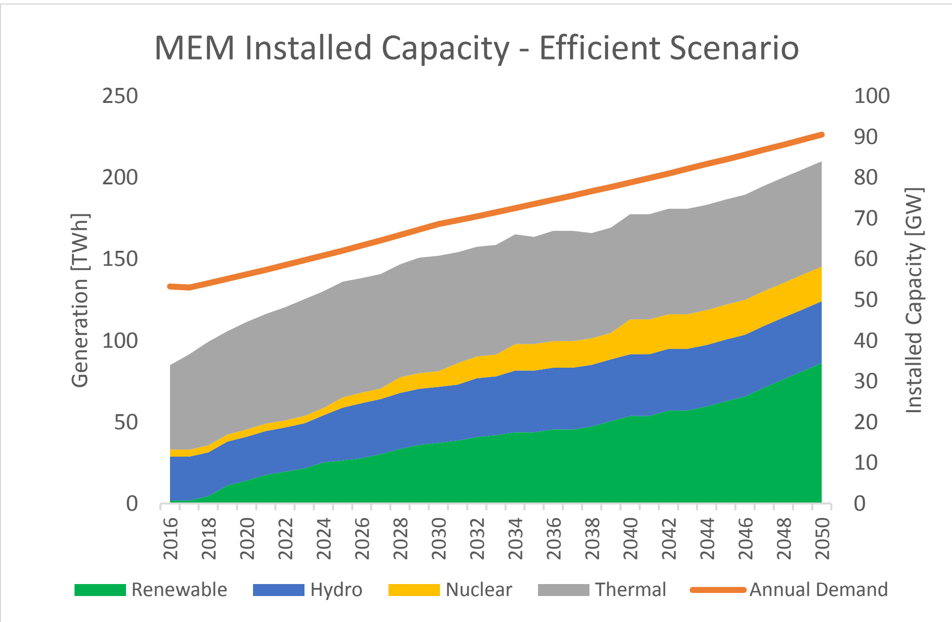

Figure 35: MEM installed capacity and generation of the electricity sector (excluding BEVs) in an efficient scenario up to year 2050.

Sources of error

The model is a simplified projection of how the electricity sector really operates. These simplifications may induce error in the following points:

- Every thermal plant operates with the type of fuel that CAMMESA currently assigns in average, based on the time of the year and the type of machine and cycle listed in Table 6. The real-world planning strategy might vary from the proposed model.
- Generating plants operate according to an average demand, based on a seasonal factor and on the time slot. So, the total demand of a year is divided into 36 pieces: 12 months and each month into *valley*, *rest*, and *peak*. As shown in Figure 22, in winter it is expected higher values at peak while in summer, at rest. Localized peaks (like the maximum MEM demand on February, 2018, for example) are not able to be represented in such model. Even more, climate factors and average temperature increase is not considered as a variable to represent the demand. Instead, annual average growth considers this effect as a whole.
- The effect of pollutant emissions on thermal generation plants (NOx, CO, PM, SOx, etc.) will be dismissed for the calculation of CO_2 equivalent emissions. It will only be considered direct CO_2 emissions.
- Plants are turned on to cover demand following an established strategy with the following guidelines:
    - This sequence sums up discretized values in order to cover the demand. Nevertheless, the generation will not match exactly with the demand due to this discretization. Generation will always be slightly above.
    - In practice, geographical distribution allows lower efficiency plants to operate, in order to alleviate the transmission lines. In this model, this will be disregarded.
    - Biofuels are considered a renewable source that does not emit CO_2, although CAMMESA calculates net emissions considering the ones of biofuels.

Sensitivity analysis

From the modeled data, it is possible to take 2016 and 2017 specific emissions based on the demand and compare simulation results with real values. Results are shown in Figure 36 for 2017 simulation and compared with actual values from 2016 and 2017. It is also analyzed the variation in emissions if the system operates 20% over- and undercharged for these years.

This is an expectable result, as the thermal plants operate at an average of 540 $kgCO_2/MWh$, so increasing the load will necessary implicate to turn on the least priority thermal plants, increasing consequently the net emissions. On the other hand, decreasing the load will have an inverse effect. Simulated curve from 2017 shows the result of disaggregating the thermal plants with the proposed simulation model, reaching to a specific emissions value in between the one of 2016 and 2017. Recalling Figure 18, the energy generation in these years was practically the same, being slightly cleaner the one from year 2017.

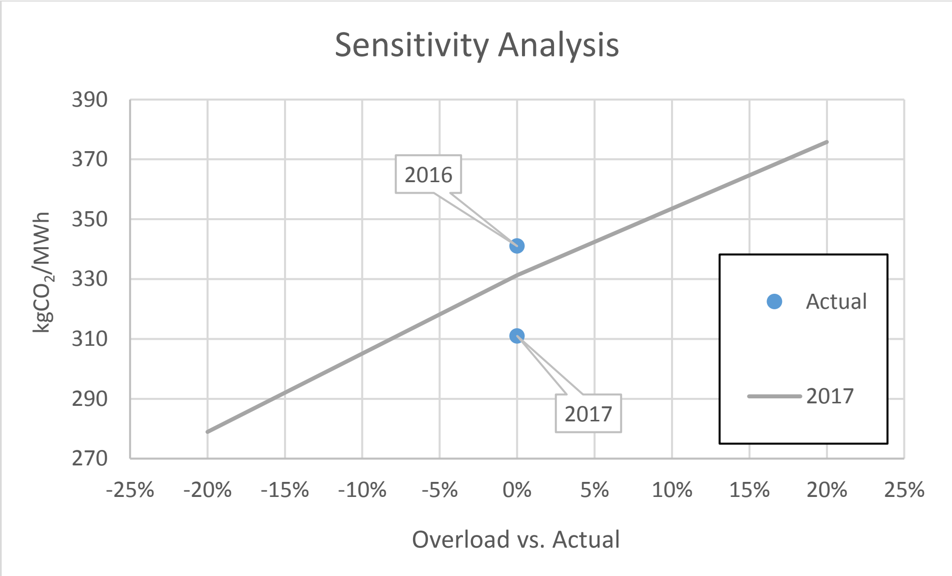

Figure 36: Sensitivy analysis taking as a baseline the generation data from 2016 and 2017 and comparing to simulation of 2017.

4. Simulation of projected CO_2 emissions

4.1 Emissions calculation methodology

The goal at the end of this simulation is to calculate the WTW emissions of BEV and compare it to the one of ICEV. There exist diverse ways for BEV's emissions calculation, depending on the available data.

On the one hand, the most straightforward model is the one where it is taken an annual average of emissions in the electricity sector and that is divided by BEV's specific demand per kilometer. This averaged model does not consider the time of the day when the vehicle is charged and whether the user takes any advantage of DSM strategies, where the electricity comes from zero-emissions sources. There can even exist the case where, due to the generation intermittence, vehicles are used as reservoirs in periods of generation excess, with the V2G strategy. So, there is a second case, where emissions are weighed by the time of the day when the vehicle is charged. This is the time-dependent emissions calculation [41]. In this case, there will tend to be high when the charging is uncontrolled and there are periods where the grid operation is highly inefficient, but reduced considerably if the user absorbs the intermittency of the grid with DSM, coming mostly from zero-emissions sources, and most of the time it is covered by base energy, which has much lower specific emissions.

In both cases it is treated as a "one-to-one" analysis and the model will answer the question of which vehicle has lower WTW specific emissions. Nevertheless, this wouldn't answer which case emits less comparing total fleet WTW emissions. If the case were the one that a BEV intends to replace an ICEV, then the "one-to-one" analysis multiplied by the total fleet will probably answer quite well the question. But, as stated in 2.1, the TCO of a BEV reduces considerably when the annual mileage is increased. So, there is a third scenario that is useful when sharing platforms are implemented, so that the fleet would be somehow reduced in order to accumulate higher mileage, hence higher energy consumption. Were this the case, it will be interesting to calculate a baseline scenario and compare it to this one.

Step-by-step calculation of time-dependent BEV specific emissions

According to the projected volume and the projected average kilometers per year, it is calculated the total kilometers of vehicles from a specific MY on a certain year. Considering that sales start in 2018, this will be:

$$km_{EV,year} = \sum_{MY=2018}^{year} vol\_EV_{MY} \cdot km_{year}$$

The necessary demand to travel those kilometers is given by:

$$Energy_{EV,year} = km_{EV,year} \cdot \frac{cons_{EV}[Wh/km]}{\eta_{TTW} \cdot \eta_{chraging}}$$

Where $cons_{EV}$ is the specific consumption of an EV per kilometer, estimated constant over the whole calculation period and equal to 180 Wh/km [26], and $\eta_{chraging}$ is the efficiency to manage that demand. This annual demand has energy units [Wh] and is then converted to mean power [mean-MW] in order to have an easier management with the rest of the calculations of demanded power. To do so it is divided by 10^6 (mega) and by the total hours of a year period: 8760 hr.

$$Power_{EV,year}\ [mean-MW] = Energy_{EV,year}\ [Wh] \cdot \frac{1M}{10^6} \cdot \frac{1}{8760\ hr}$$

This annual demand is divided by a monthly usage factor and then by the fraction of charge that is made in a specified slot (*valley, rest, peak*). The sum of the monthly usage factor equals 1 and so does the sum of the period fraction. But, as the goal is to calculate mean-MW and not all the periods have the same length, this period usage factor should be affected by the length of it (it is not the same to use half of the daily demand in a 6-hour period than in a 12-hour period, the mean power in the first case will double the one of the second case). *Valley* has 6 hours length; *rest,* 13 hours; and *peak,* 5 hours. The same logic has to be applied with the monthly fraction, but in this case considering every month has the same length (disregarding 28, 29, 30, or 31 days' months).

$$Power_{EV,period}\ [mean-MW] = Power_{EV,year}\ [mean-MW] \cdot (f_{month} \cdot 12) \cdot \left(\frac{f_{period} \cdot 24}{length_{period}}\right)$$

This is the surplus power that BEVs will need to demand from the grid. A similar treatment is made with the demand from the grid, from which the annual demand is estimated based on [18], and the sum of both values is the power that the grid needs to supply at a certain monthly period. The power of the grid is turned on according to the algorithm described in 3.3. The energy of the grid can be calculated as follows:

$$Energy_{EV,period}[MWh] = Power_{EV,period}\ [mean-MW] \cdot length_{period}[h]$$

Specific emissions from a generator are calculated based on the fuel dispatched to a certain type of generator (combined cycle, Rankine cycle, Joule cycle, Diesel cycle) at a certain time of the year (Table 6), and taking the specific emissions for each fuel [28]:

$$CO_{2,gen-i}[Mt\ CO_2] = Power_{gen-i,period}\ [mean-MW] \cdot 720h \cdot \frac{length_{period}}{24} \cdot \frac{3.6GJ}{MWh} \cdot CO_2\left[\frac{kg\ CO_2}{GJ}\right] \cdot \frac{10^{-9}Mt}{kg}$$

Once this power is reached with a certain configuration of electricity generators, the specific emissions of a certain month are calculated using the fraction of total emissions corresponding to EV charging in each period, with a weighted average as follows:

$$CO_{2,EV-month}\left[\frac{kg}{MWh}\right] = \frac{\sum_{gen}\sum_{i=1}^{3} CO_{2,gen-i}[Mt\ CO_2] \cdot {}^{Power_{EV,i}[mean-MW]}\big/_{Power_{grid,i}[mean-MW]}}{\sum_{i=1}^{3} Energy_{EV,i}[MWh]} \cdot \frac{10^9\ kg}{Mt}$$

This value will represent the specific emissions from the generator to wheel (GTW). In order to calculate WTW emissions, total emissions must be divided by the factors from Figure 14.

$$CO_{2,WTW}\left[\frac{kg}{MWh}\right] = \frac{CO_{2,EV-month}\left[\frac{kg}{MWh}\right]}{\eta_{WTT}},\ \ where\ \eta_{WTT} = 91\% \cdot 90\% \cdot 95\% = 78\%$$

Using again the conversion of energy per travelled distance, the specific emissions of a BEV will be given by:

$$CO_{2,WTW}\left[\frac{g}{km}\right] = CO_{2,WTW}\left[\frac{kg}{MWh}\right] \cdot \frac{cons_{EV}[Wh/km]}{\eta_{TTW} \cdot \eta_{chraging}} \cdot \frac{1000\ g}{1\ kg} \cdot \frac{1\ MWh}{10^6\ Wh}$$

Scenarios

In total there will be modelled 3 scenarios, plus a sub-scenario in the 1st case. Table 11 summarizes the input for each of them.

	Scenario1		Scenario 2	Scenario 3
	1a	1b		
BEV Market Share	Moderate	Aggressive	Aggressive	Aggressive
Controlled Charging	No	No	Yes	Yes
Electricity Demand Profile	BAU	BAU	BAU	Efficient

Table 11: Summary of scenarios modelled for the simulation.

4.2 Data modelling for the electricity and transport sector

It will be modelled electricity generation under the assumptions of MINEM-30 [18], so that there will be a BAU and an efficient electricity scenario, with the difference that the values presented in this report will be used as a reference for making an algorithm that chooses among the list of electricity generators listed in annex A.4.1 and A.4.2 for BAU case, and A.4.1 and A.4.3 for the efficient one. The result of the simulation compared with the objective values are on Figure 37 for BAU and efficient scenario, and the evolution of the annual generation, in Figure 38.

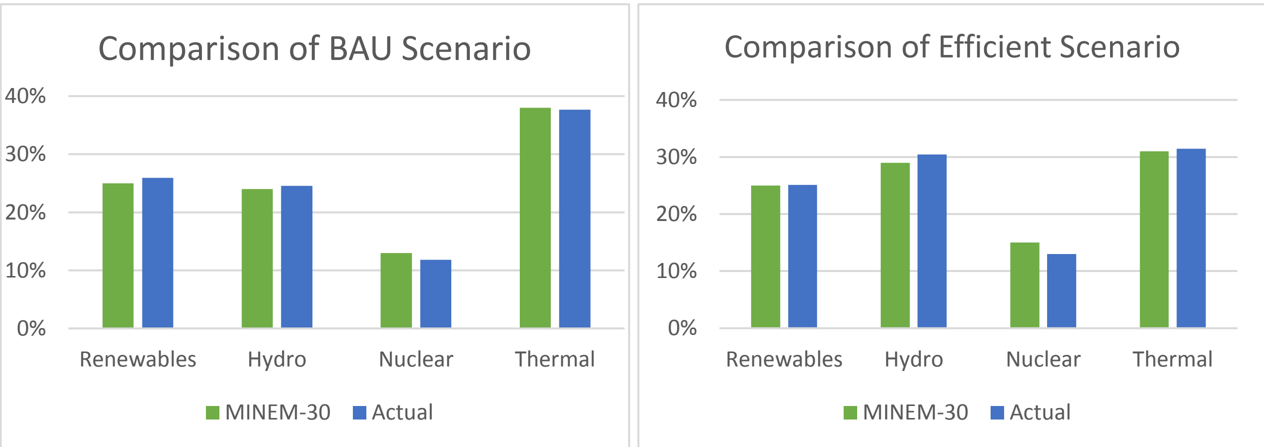

Figure 37: Comparison of simulation values with the ones presented in MINEM report [18].

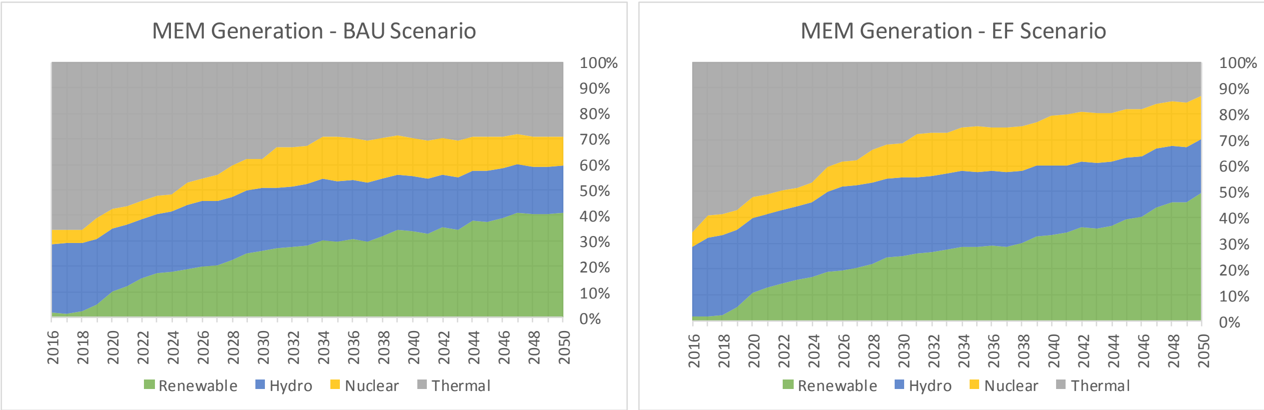

Figure 38: Comparison of simulation values with the ones presented in MINEM report [18].

In both cases, the normalization period will end by 2022 and the installed capacity of the electricity system will grow consistently with the demand in order to adapt the grid to it. The difference between BAU and efficient scenario will mainly be seen by a steeper take-off of renewables after MINEM prognosis period [18], that will happen as from 2036. Figure 37 illustrates the annual energy mix from each source, where it can be seen this difference.

As stated in 3.1.2, CAMMESA published in 2015 the emissions of the electricity system following two calculation methodologies [32], where total average specific emissions were around 310 $kgCO_2/MWh$. The calculated average specific emissions in both cases, only considering the electricity demand and with the same algorithm explained in 3.4, is plotted in Figure 39, starting in 2016 with 321 $kgCO_2/MWh$, consistent with Table 5 values. On the same Figure, in another scale, there are the total emissions coming from the electricity sector.

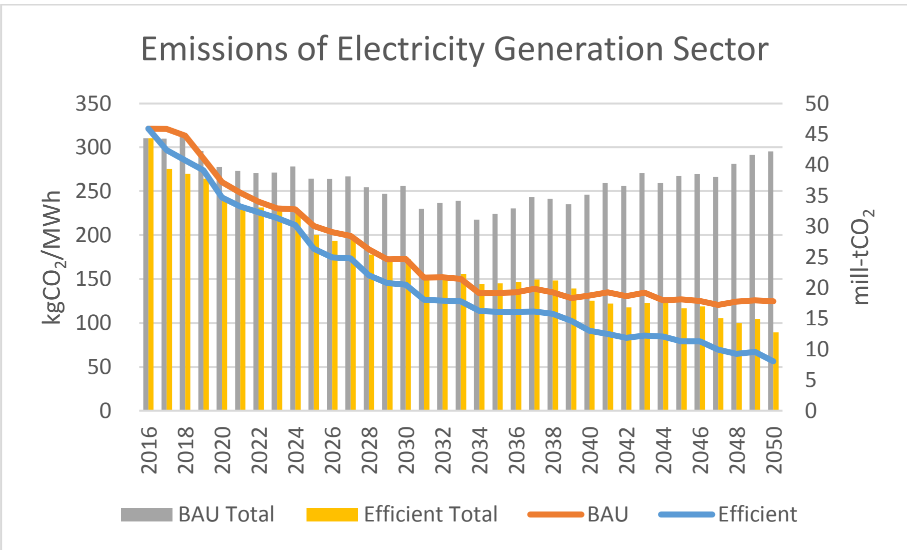

Figure 39: Total and specific emissions projection of the electricity sector (excluding BEVs) in BAU and efficient scenario up to year 2050.

4.3 Scenario 1: Introduction of BEVs in a BAU electricity generation scenario

4.3.1 1a: Moderate introduction of BEVs with uncontrolled charging

In this scenario, the load on the grid will not be significant in comparison to the projected electricity demand. Comparison of emissions of ICEV and BEV in a time-dependent average basis is presented in Figure 40 (light-blue).

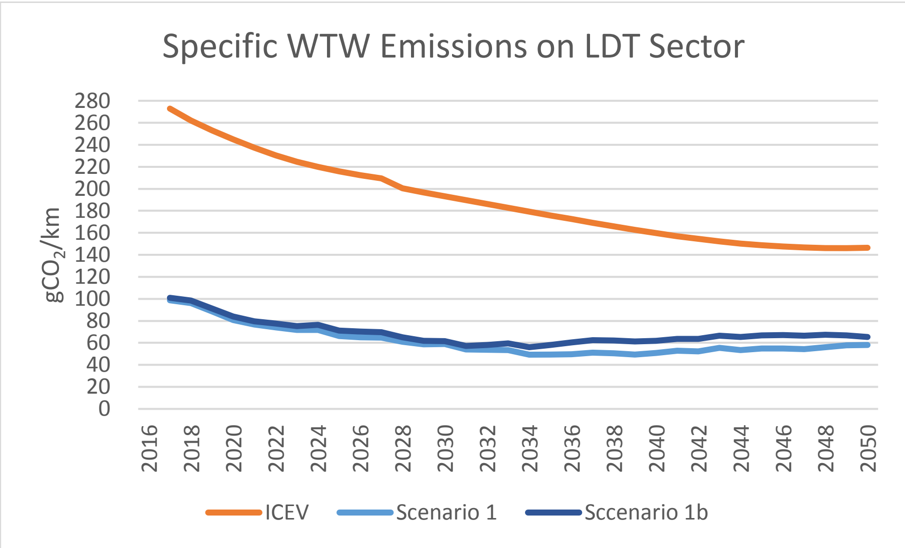

Figure 40: Specific WTW emissions projection of BEVs and ICEVs comparison in BAU electricity generation scenario up to year 2050 with uncontrolled charging.

The impact to the grid will be the highest in the last analyzed period for each scenario, where deployment of BEV will reach its maximum in terms of volume. In this case, Figure 41 shows the impact on the grid that BEV will have in 2050.

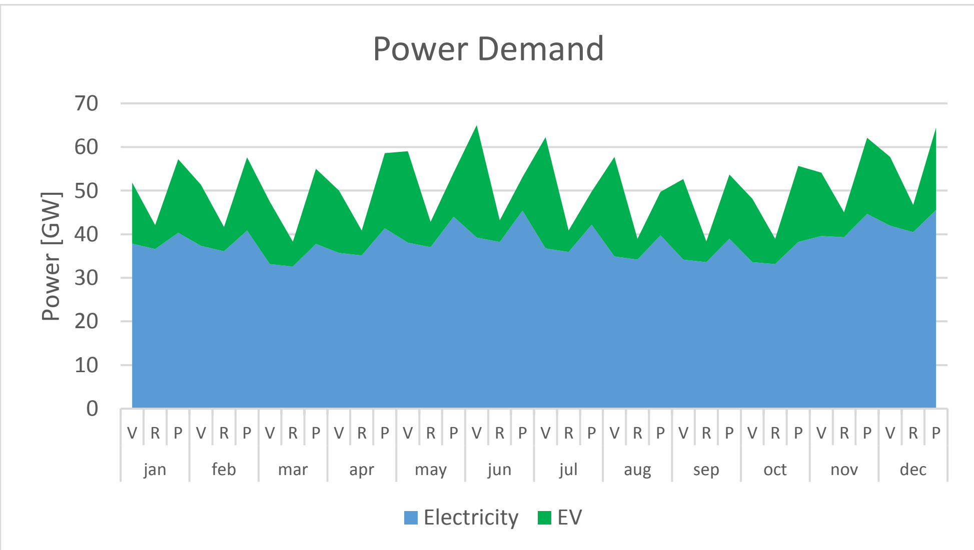

Figure 41: Projected total electricity power demand (BAU scenario) in year 2050 for each time slot, with a moderate introduction of BEVs and uncontrolled charging.

4.3.2 1b: Aggressive introduction of BEVs with uncontrolled charging

This is the case where BEVs have a high acceptance in the market but the infrastructure is not prepared to respond to such demand or the policies to incentivize a more efficient usage of the grid by means of controlled charging do not make the necessary effect. This could happen when the electricity market is still unprepared to have differentiated tariffs and a floating market with real-time trading and variation of the spot price in which customer awareness would tend to use the resources more efficiently. Were this the case in which electric vehicles are introduced, then the system would show an improvement in emissions at the beginning, but once BEVs penetration are close to reach the saturation point, the emissions performance will worsen considerably. Specific emissions can be seen in Figure 40 (dark blue). This model will also show in a limited way (because monthly values are being averaged) that there are periods in which there will be shortages and the demand of electric vehicles will have to be shifted to the next time slot. Comparison of emissions of ICEV and BEV in a time dependent average basis is presented in Figure 42.

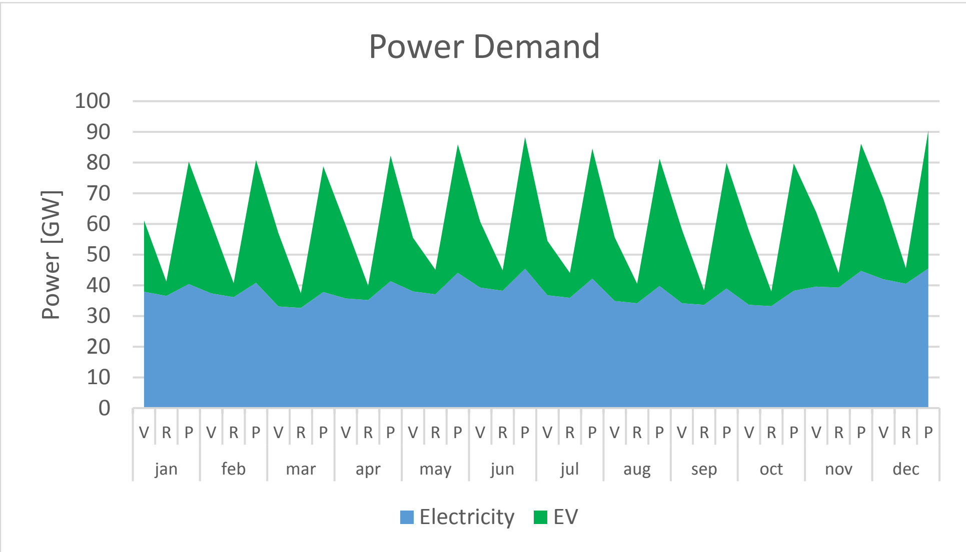

Figure 42: Projected total electricity power demand (BAU scenario) in year 2050 for each time slot, with an aggressive introduction of BEVs and uncontrolled charging.

4.4 Scenario 2: Aggressive and smart introduction of BEVs in a BAU electricity scenario

An aggressive and smart introduction of BEVs will either mean that sales reach a high volume and a critical mass of customers have the awareness to use the grid in the most efficient way to charge vehicles or that a smaller fleet is introduced by means of carpooling or car sharing platforms, and that is made with enough control to use the free capacity of the grid or even auto-generating electricity in order to reduce charging costs. In either case, what matter is the total kilometers that vehicles would travel monthly, either with a large fleet accumulating 21400 km annually or with a smaller one accumulating more mileage, so that the total sum in both cases is the same. Taking advantage of the free capacity of the grid, mainly in the valley time frame (23:00 to 05:00) will allow it to operate more efficiently, so the specific WTW emissions will stabilize at a value of 40 gCO_2/km, as shown in Figure 43 (light blue), and a sensitive improvement will be obtained in the grid balance when compared to Scenario 1 (Figure 44).

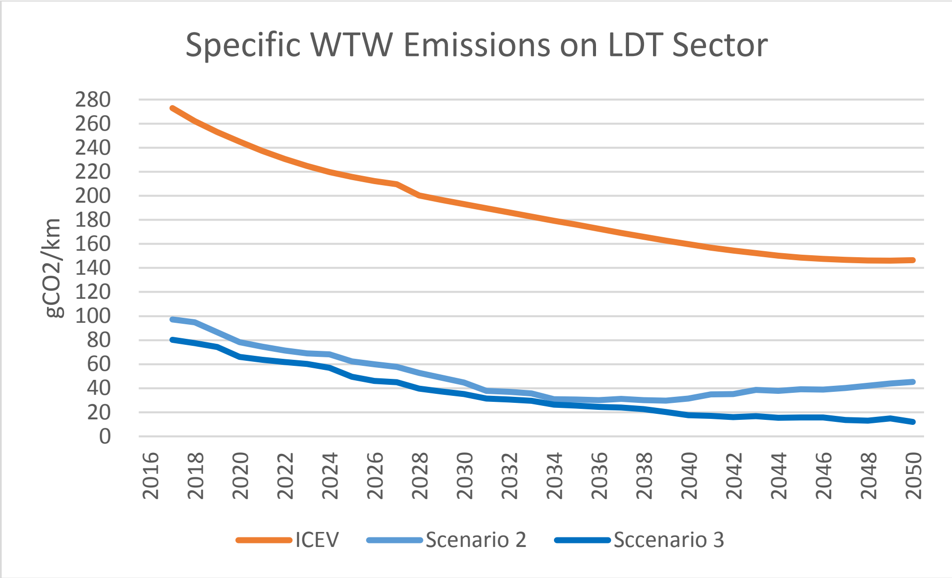

Figure 43: Specific WTW emissions projection of BEVs and ICEVs comparison in BAUand effficient electricity generation scenario up to year 2050 with controlled charging.

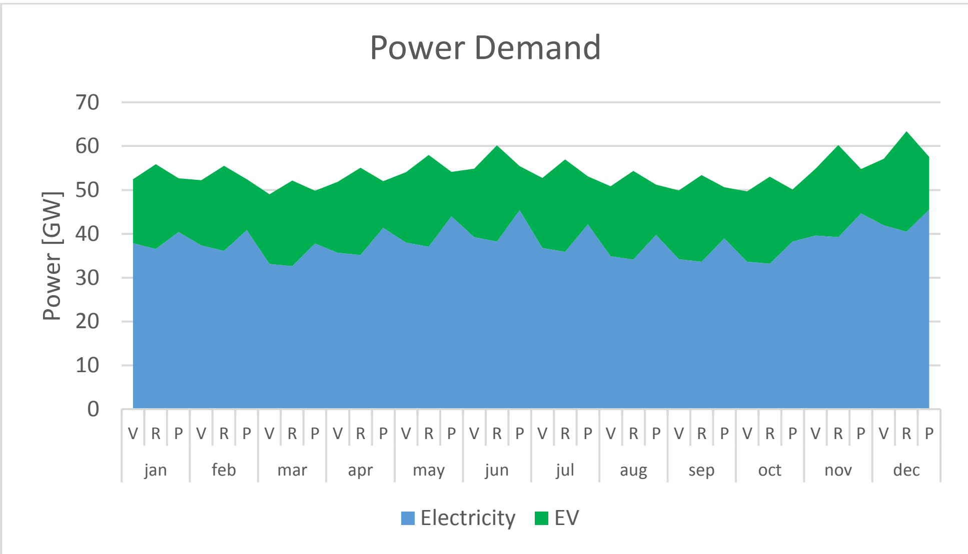

Figure 44: Projected total electricity power demand (BAU scenario) in year 2050 for each time slot, with an aggressive introduction of BEVs and controlled charging.

4.5 Scenario 3: Aggressive and smart introduction of BEVs in an electricity efficient scenario

This last scenario is similar to the one stated in 4.4, in the hypothetical case that efficiency measures from both sides, demand and supply, have been put in place. In this case, renewable energies finally take off at a higher pace as from 2030, yielding to a higher ratio of installed capacity of 48% by 2050, representing a total installed capacity of 48 GW and 42% of total generation. Thermal energy generation, on the other hand, is gradually phased out, reducing its priority to half of the initial value (2017). This action is equivalent to phase off inefficient plants and leave at a higher capacity factor the ones that operate more efficient and the measure as a whole reduces the generation share from 301 in 2030 to 18% in 2050. The vehicles' fleet is the same in both. Specific emissions are also plotted in Figure 43 (dark blue), and the grid power demand in year 2050 is plotted in Figure 45.

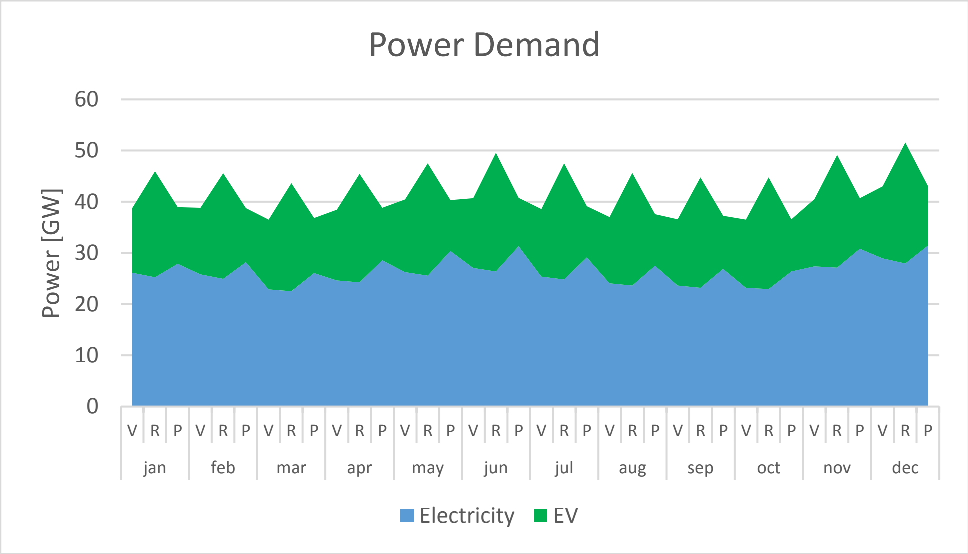

Figure 45: Projected total electricity power demand (efficient scenario) in year 2050 for each time slot, with an aggressive introduction of BEVs and controlled charging.

5. Discussion of results

This analysis assesses the emissions of the present fleet at the year it is being evaluated, trailing all the vehicles registered in the past years and still circulating at the time of assessment. According to the Weibull distribution function presented in annex A.2, in the year in which emissions are being calculated there will be high influence of vehicles up to 10 years older, hence leading to higher specific emissions than if they were considered only the ones of the same model year than the one evaluated. On the other hand, BEVs are assumed to have a constant energy demand over time, as this one relies mostly on total weight and electric components which are close to a technological limit, and their emissions would depend directly on the ones from the electricity grid at that year in service. Said this, efficiencies in the electricity grid will be captured more quickly in the BEV fleet than efficiencies on fuel consumption in ICEV fleet, as this one will be trailing the inefficient fleet. Introduction of BEVs show, as expected, a high correlation between the electricity generation sector and the transport one. The results of the proposed scenarios are summarized in Table 12.

	Baseline ICEV		Scenario 1a	Scenario 1b	Scenario 2	Scenario 3
Assessed Year	**2017**	**2050**	**2050**	**2050**	**2050**	**2050**
BEV Specific Emissions (g/km)	97	37	58	65	45	12
ICEV Specific Emissions (g/km)	287	170	157	146		
Electricity Generation Specific Emissions (kg/MWh)	426	160	292	379	261	161
BEV Total Energy Demand (TWh)	-	-	91	152		
Number of Shortages (time slots)	0	0	0	56	0	0
BEV Volume (millions)	-	-	13		18	
ICEV Volume (millions)	10	29	16		11	
Total BEV CO_2 Emissions (Mt)	-	-	23	46	30	8
Total ICEV CO_2 Emissions (Mt)	57	105	54	35	35	35
Net CO_2 Reduction vs. Baseline	-	-	27%	23%	38%	59%

Table 12: Summary of results from each scenario.

Argentina has no control over the demand by tariff regulation. Moreover, as stated in section 2.4, electricity demand is highly inelastic against electricity price, so tariff regulation alone would not force the electricity system to operate more effectively by means of DSM. This should be complemented with smart grid connected to IoT, for example. Otherwise, it will be difficult to balance the electricity load of BEVs into the grid, with the possibility of collapsing at peak demand hours. Results in Figure 46 show that a massive impact of BEVs in the transport sector in Argentina's BAU electricity grid with uncontrolled charging (Scenario 1b) will also push the system to produce inefficient electricity, scaling exogenous emissions exponentially and capturing lower save than in scenario 1a (23% vs. 27% total CO_2 savings). Therefore, a higher penetration of BEVs in the LDT will have a counter-productive effect in total emissions against baseline case of ICEV if there is no control over the demand. Moreover, considering that this is a WTW analysis (as stated in 3.1) and that the vertical LCA is not considered, if the disposal emissions were considered this would scale to higher values, in the vicinity of 20% [23], even up to the point of not having a reduction in total CO_2 emissions.

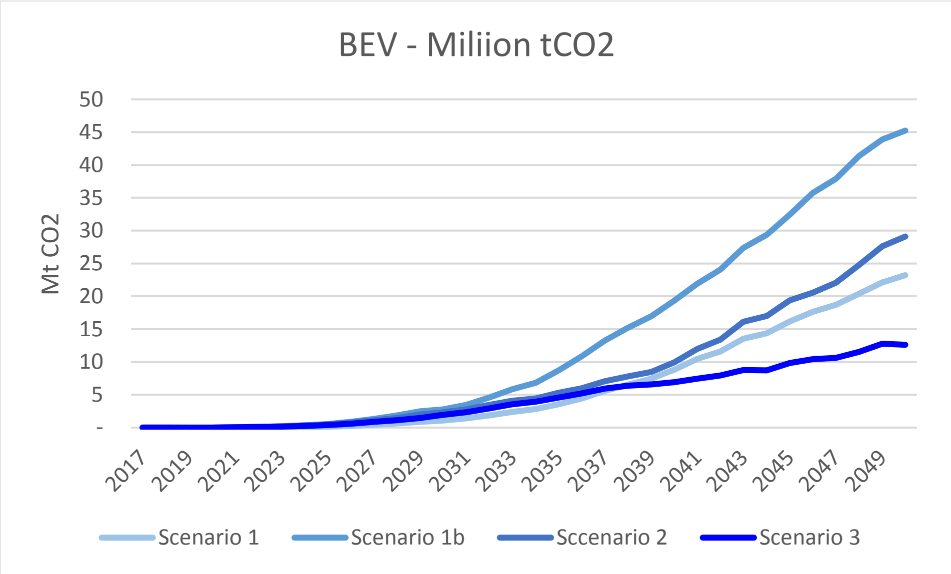

Figure 46: BEV WTW specific emissions on the LDT sector evolution up to year 2050 on each scenario.

On the other hand, if controlled charging were implemented, then the savings in terms of net CO_2 emissions will be almost 40%. The direct correlation to the grid efficiency is seen in the result of scenario 3 simulation, where this same case will lead to a total saving of 59%. The evolution along the whole simulated period is seen in Figure 47. There is a breakthrough point in carbon footprint as from year 2030 in all scenarios, where a higher fleet of BEV start to show clear differences with the ones of ICEV baseline scenario.

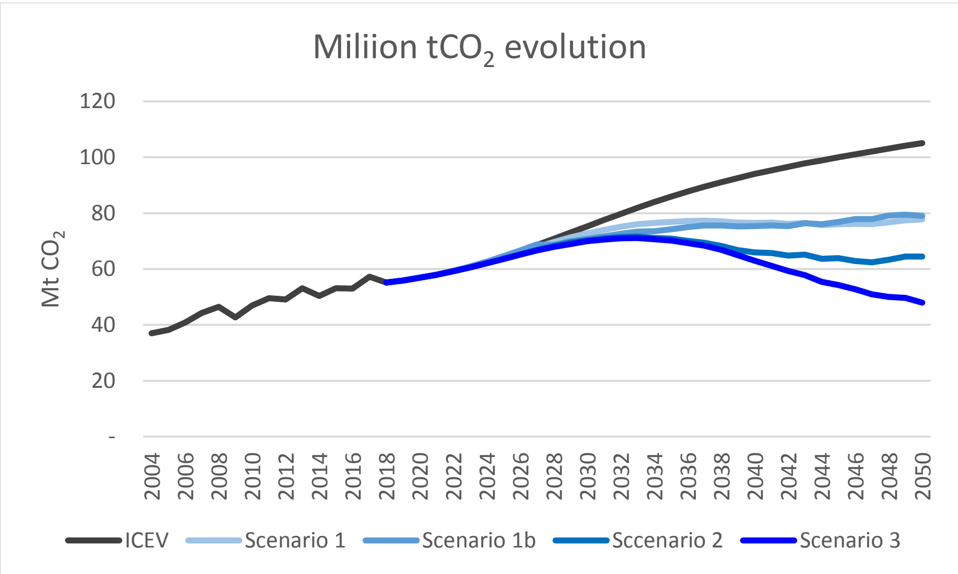

Figure 47: Total WTW emissions of the LDT sector evolution up to year 2050 on each scenario.

The simulation model used to deliver these results is poor to predict the impact of localized spikes into the electricity grid. In order to do this, higher refination would be needed on the time step, but in order to make sense, it would also be needed detailed information for the input about demand patterns of electricity in the different sectors (residential, commercial, industrial, BEVs), how will the electricity grid evolve, and what will the strategy of CAMMESA be in the future to generate electricity. However, if the model detects one of these shortages, it means that in average the grid is not able to respond to the total demand at a certain time slot, so there will probably exist these shortages if no actions are taken (DSM, grid expansion, demand efficiency, among others), obligating the system to import energy from neighbor countries or to expand the grid quickly, for example, relying on diesel engines and gas turbines, with higher specific emissions than the average producer. Scenario 1b shows for this installed capacity a high risk of shortage due to BEVs load, where 56 time slots along the whole period are detected to have shortages. Figure 48 shows the beginning of this effect, in December 2043, which keeps accentuating over time, as BEV demand grows faster than grid's installed capacity. It should be added the effect of spikes to this: for example, warm days from summer, specific high demand of particular (BEV + ICEV) transport (strikes, rainy days, extreme cold days, etc.) at a certain period, electricity plants' shutdowns, and week/weekend day's and holidays difference in demand, among others.

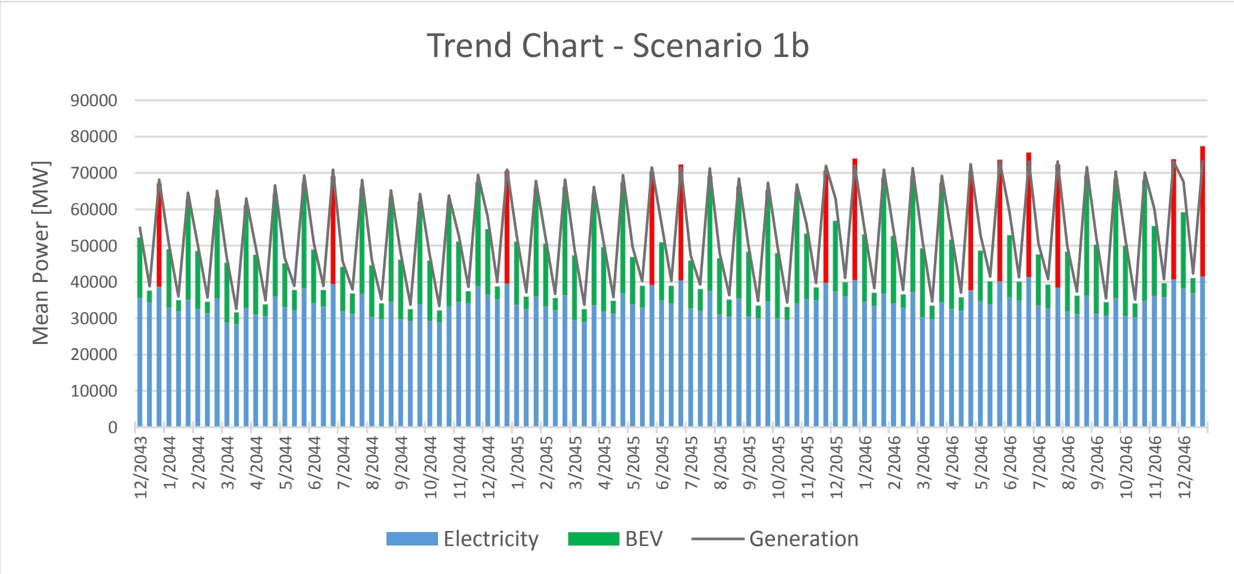

Figure 48: Evolution of the demand between 12/2043 and 12/2046 on scenario 1b, where higher penetration of BEV with uncontrolled charging leads to an increase of shortage periods along time (red bars). The response of the grid gets worse over time with the increasing demand due to transport sector electrification.

6. Conclusions and recommendations

This work answers the introductory question, whether the BEV as a replacement of ICEV is a sensible measure towards the objective of carbon footprint reduction in Argentina, set in COP21 Paris Agreement. In order to do this, it was projected real emissions that BEV would have in usage by building the relationship between the electricity sector of Argentina and the energy demand of the transport sector, mapping all the electricity plants, operative or planned to operate, plus a proposed evolution made under certain assumptions. Results show that BEV are a very positive alternative in the transport sector of Argentina, and local policies should encourage the participation of it mainly because of 3 reasons.

In the first place, electricity production in Argentina is already very clean in terms of emissions when comparing to other countries (Figure 17). Argentina's electricity grid relies mostly on thermal (65%) and hydroelectric (28%) energy and the grid emits in average around 330 gCO_2/kWh. The first mentioned source uses mostly natural gas reserves, the cleanest hydrocarbon fuel in terms of CO_2 emissions for a thermal cycle, while the second one produces no CO_2 emissions. There is also a clear intention to progress towards a cleaner electricity grid. Latest measures impacting in thermal sources included the expansion of these by closing current Rankine (vapor turbine) and Joule (gas turbine) cycles into combined ones, taking advantage of the exhaust heat and elevating this way even more the total efficiency of the system. Applied to the transport sector, that would mean that nowadays a BEVs would have 97 gCO_2/km (WTW) emissions, more than 50% less than current WTW emissions level of an ICEV.

Secondly, according to law 27191, which came into force in 2016, there is a commitment to produce 20% of the electricity generation from renewable sources by 2025. Up to 2017, total participation of renewable energies was barely 2% and, so far, there has been a tender of 4466 MW of renewable energies by *Renovar* program, that could produce 15 TWh, around 11% of current demand. The expansion of this program in the future is still uncertain, considering the volatile economy in Argentina and the fact that infrastructural investment in transport electricity should also come associated with it in order to exploit these resources. However, if Argentina is able to achieve at least partially the objective of renewables integration, specific emissions could decrease below 250 gCO_2/kWh, leading to 70 gCO_2/km (WTW) in BEV emissions.

As a positive side effect, it appears the fact that BEVs emit no exhaust gases and therefore have significantly lower emissions than conventional diesel ICEVs. Thanks to regenerative braking, BEVs can also reduce non-exhaust emissions from road traffic. The lower emissions of local air pollutants together with the noise reduction by the fact of eliminating the internal combustion engine could be one of the key drivers of interest in electric mobility in big cities where there are rising concerns about air quality and noise contamination, as it is the case in Buenos Aires. Paradoxically, BEV has had so far, its biggest deployment in China, and it appears as an alternative to reduce operative costs on the transport sector, even when 63% of its primary energy relies on coal reserves [30], which emits roughly 1000 gCO_2 per kWh of electricity produced, 3 times more than specific emissions of the electricity sector in Argentina. As a consequence, there is a parity between ICEV and BEV specific emissions in terms of CO_2 (with the only consideration that 2-wheelers ultra-light vehicles are less energy intensive and have the biggest share, as a solution to mobility in the big Chinese cities). In this case, the advantage of improving air quality and reducing noise makes BEV in China an attractive market to compete against internal combustion technologies.

Along with the benefits, there will also come the externalities of this measure and the challenges to address them. This huge demand could produce an imbalance in the electricity grid, obligating the system to either import expensive electricity, produce it with high specific emissions, or, even worse, have periodical shortages on the grid. The latter was a situation experienced in Argentina during last years, mainly in summer periods, which symbolized the total failure or absence of national energetic policies. In order to avoid stumbling twice with the same stone, these situations should be previewed and avoided by any means. It is important to deploy this sector with the priority set on a controlled charging in order to maximize its benefit. One good alternative is to encourage the implementation of controlled fleets on the private sector, managed by smart platforms of car sharing. This would allow vehicles to reach a higher mileage per year, hence reducing significantly the TCO, reaching the parity with current technologies earlier. Besides, it will be easier to control a higher demand over one huge client, which could also offset its demand by auto generating its own energy in order to reduce costs and maximize utilities, than spreading millions of vehicles to particular users with no control nor stimulation of using DSM strategy.

Last but not least, in light of UNE estimations about global CO_2 reductions needed to close the emissions gap in order to reach COP21 objective [4], results of the simulation show that only on one of the scenarios considered (scenario 3), emissions by 2050 are reduced by 25% with respect to 2017 baseline (ilo 2016, used in UNE report), still far from the objective set of cutting CO_2 equivalent emissions to half the ones of the starting point. This scenario, as defined by UNE, should be the one of a conditionally INDC that Argentina should pursue to contribute to the global objective. The INDC should be in-between the scenario 1a and scenario 2, where a moderate to aggressive penetration of BEVs should result in an emissions reduction without generating a big imbalance in the electricity grid. The scope of this work is limited to LDT extent, so it should be taken as complementary to other analyses made for the region for this sector, which inspired the one written here. The first one is a recommendation of e-mobility solutions to implement in the Metropolitan Area of Buenos Aires [42], showing the impact it would have mainly in taxis and buses fleets, and the other one is the impact of different solutions to implement in the City of Buenos Aires [43], like the one of e-mobility, emissions standards update, biofuels, and fostering public transport and shared mobility platforms usage.

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Annexes

A.1 Sankey diagram of Argentina's energy balance

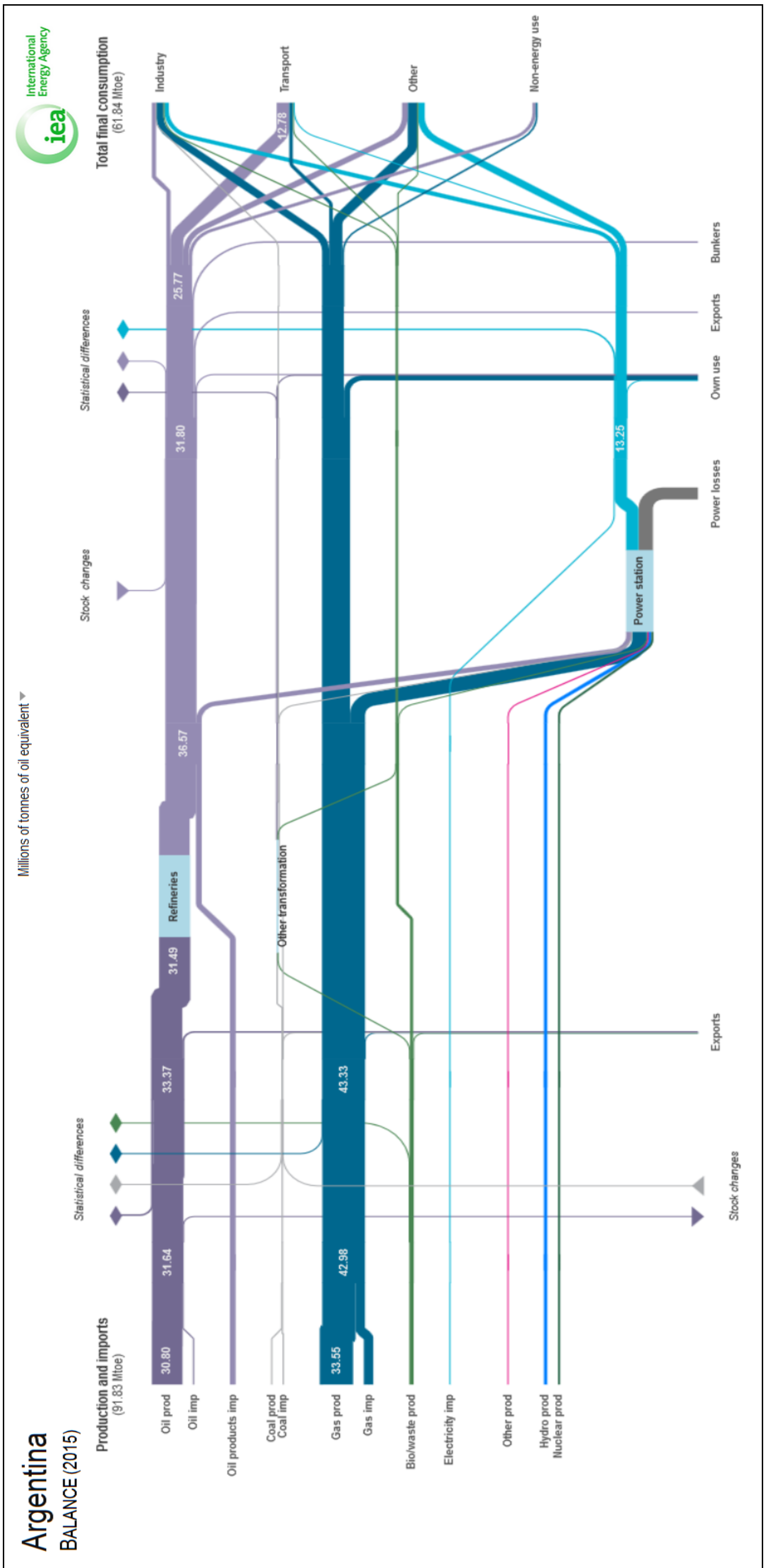

Figure A1: Argentina's Energy Sankey Diagram (Source: IEA [1])

A.2 Weibull distribution functions for light duty vehicles in Argentina

A.2.1 Time to disposal distribution function

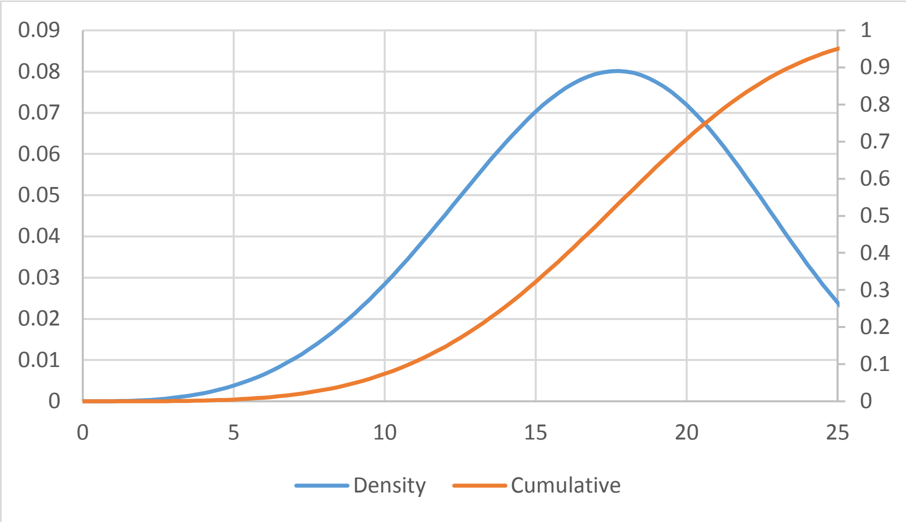

Figure A2: Time to disposal Weibull function for the LDT. Parameters: $\lambda = 19;\ \kappa = 4.$

A.2.2 Usage factor distribution function

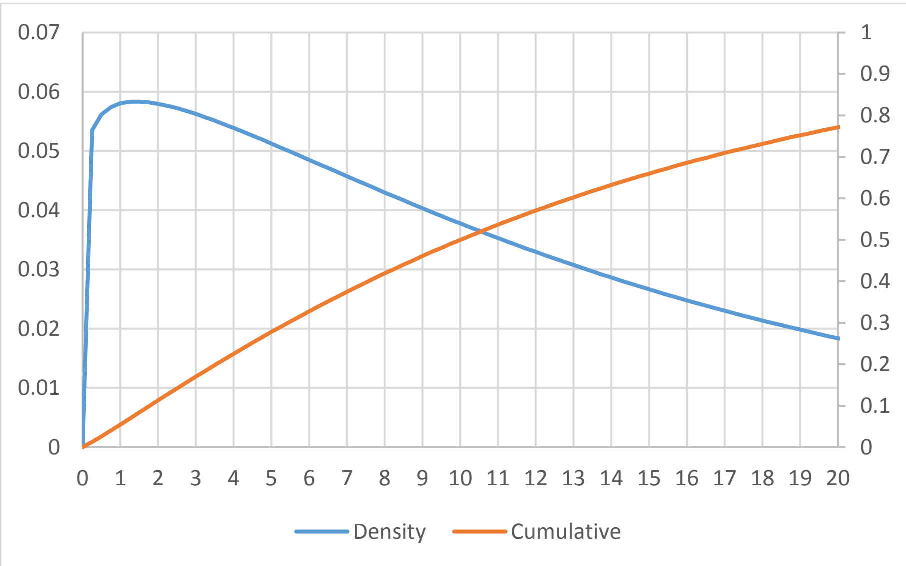

Figure A3: Usage factor Weibull function for the LDT. Parameters: $\lambda = 14;\ \kappa = 1.09.$

A.3 Plate number correlation with total vehicle sales

Registration Year	Sales Volume	Plate Number Starting With…
1995	384207	AAA000
1996	368335	AOU207
1997	422237	BCY542
1998	484400	BTE779
1999	406636	CLV179
2000	352769	DBL815
2001	206628	DPA584
2002	101143	DWZ212
2003	146047	EAW355
2004	292479	EGM402
2005	389234	ERS881
2006	452582	FGS115
2007	572841	FYC697
2008	615256	GUD538
2009	516799	HRU794
2010	665552	ILR593
2011	860820	JLH145
2012	845562	KSJ965
2013	963598	LYX527
2014	688480	NJZ125
2015	657161	OKL605
2016-1	170000	PJS766 - PQG766
2016-2	541631	AA000AA
2017	902733	AA801FZ
2018	-	AC136QM

Table A1: Plate number correlation with the registration year

A.4 Input of Electricity Generators for Simulation:

A.4.1 Electricity Generators Baseline Defined by CAMMESA

CENTRAL	Description	Source	Technology	Eff.	Max Power	Capacity Factor	Date in	Date out
YACYHI	E.B. YACYRETA	HI	Hydroelectric	100%	2745	79%	Operative	
COST	ENDESA COSTANERA SA	TH	TV	42.1%	1982	37%	Operative	
NPUE	CENTRAL PUERTO SA	TH	TV	45.9%	1188	33%	Operative	2038
AESP	C.T. AES PARANA	TH	CC	53.2%	845	76%	Operative	
GBEL	TERMOELECTRICA M.BELGRANO S.A.	TH	CC	55.0%	868	73%	Operative	
TIMB	TERMOELE. JOSE SAN MARTIN S.A	TH	CC	54.2%	865	68%	Operative	
SGDEHIAR	CTM SALTO GRANDE	HI	Hydroelectric	100%	945	61%	Operative	
DSUD	CENTRAL DOCK SUD	TH	CC	52.8%	870	62%	Operative	
GEBA	GENELBA - PETROBRAS	TH	TG	51.9%	838	70%	Operative	
TAND	C.T. SALTA (TERMOANDES)	TH	TV	53.4%	416	100%	Operative	
LDLA	C.T. LOMA DE LA LATA S.A.	TH	TG	47.2%	645	61%	Operative	2017
PAGUHI	HIDR. PIEDRA DEL AGUILA S.A.	HI	Hydroelectric	100%	1440	35%	Operative	
ATU2	NUCLEOELECTRICA ARG. SA	NU	Nuclear	100%	745	73%	Operative	
PILA	CT PILAR - EPEC	TH	TV	45.8%	666	60%	Operative	2035
LDCU	C. TERMICAS MENDOZA SA	TH	CC	49.6%	540	70%	Operative	
CAPE	CAPEX S.A. AUTOGENERADOR	TH	CC	57.4%	477	67%	Operative	
TUCU	YPF ENERGÍA ELECTR.ex PLUSPETG	TH	CC	49.3%	447	79%	Operative	
FUTAHI	HIDROELECTRICA FUTALEUFU SA	HI	Hydroelectric	100%	494	56%	Operative	
SMTU	YPF ENERGÍA ELECTR.ex PLUSPETG	TH	CC	48.2%	382	71%	Operative	
PNUE	CENTRAL PUERTO SA	TH	TV	40.3%	589	100%	Operative	
ATUC	NUCLEOELECTRICA ARG. SA	NU	Nuclear	100%	362	78%	Operative	
BROW	TERMOELECTRICA GUILLERMO BROWN	TH	TG	37.8%	583	33%	Operative	
EBAR	CT BARRAGAN - ENARSA	TH	TG	37.5%	567	38%	Operative	2031
GUEM	C.TERMICA GUEMES S.A.	TH	TG	36.7%	361	55%	Operative	
SNIC	C.TERMICA SAN NICOLAS	TH	TV	27.3%	675	39%	Operative	2020
ALICHI	AES ALICURA.	HI	Hydroelectric	100%	1050	35%	Operative	
CHOCHI	HIDROELECTRICA EL CHOCON SA	HI	Hydroelectric	100%	1290	35%	Operative	
BBLA	CENTRAL PIEDRABUENA S.A.	TH	TV	37.8%	620	40%	Operative	2031
BSAS	ENDESA COSTANERA SA	TH	CC	45.8%	322	41%	Operative	
ARGE	SIDERCA SA(EX ARGENER-GEN.PAR)	TH	TG	45.7%	163	82%	Operative	
ACAJ	C.T. AGUA DEL CAJON	TH	CC	26.2%	184	70%	Operative	2021
ENSE	LA PLATA COGENERACION SA	TH	TG	43.7%	128	76%	Operative	

CENTRAL	Description	Source	Technology	Eff.	Max Power	Capacity Factor	Date in	Date out
PPLEHI	PICHI PICUN LEUFU	HI	Hydroelectric	100%	285	35%	Operative	
VOBL	CT VUELTA DE OBLIGADO	TH	TV	35.0%	567	23%	Operative	2021
MMAR	GENERACION MEDITERRANEA	TH	TG	35.7%	248	36%	Operative	
BLOP	CT BRIGADIER LOPEZ - ENARSA	TH	TG	37.2%	280	31%	Operative	2032
PATA	ENERGIA DEL SUR S.A.	TH	CC	40.8%	125	76%	Operative	
NECO	C.COSTA ATLANTICA	TH	TV	27.9%	204	36%	Operative	
CCOLHI	C.H.LOS CARACOLES - EPSE	HI	Hydroelectric	100%	121	46%	Operative	
CACHHI	CONSORCIO POTRERILLOS	HI	Hydroelectric	100%	120	47%	Operative	
PBANHI	HIDR. CERROS COLORADOS S.A.	HI	Hydroelectric	100%	472	35%	Operative	
VGES	C.COSTA ATLANTICA	TH	TG	30.4%	125	42%	Operative	2028
RGDEHB	EPEC GENERACION	HI	Hydroelectric	100%	750	35%	Operative	
ARROHI	HIDROELECTRICA EL CHOCON SA	HI	Hydroelectric	100%	128	45%	Operative	
AVAL	C.TERMICA ALTO VALLE	TH	CC	36.9%	96	46%	Operative	
CAIM	CT CAIMANCITO -SULLAIR	TH	DI	45.4%	91	63%	15/06/2017	
NIH1HI	HIDROELECTRICA LOS NIHUILES SA	HI	Hydroelectric	100%	72	46%	Operative	
NIH2HI	HIDROELECTRICA LOS NIHUILES SA	HI	Hydroelectric	100%	110	35%	Operative	
MDPA	C.COSTA ATLANTICA	TH	TV	23.8%	177	28%	Operative	2021
PNEGHI	C.H.PUNTA NEGRA - EPSE	HI	Hydroelectric	100%	63	50%	Operative	
MDP2	CT 9 de JULIO C Cost ATLANTICA	TH	TG	35.9%	95	42%	20/06/2017	
ULLUHI	HIDROTERMICA SAN JUAN	REN	PAH	100%	42	51%	Operative	
FRIA	GENERACION FRIAS S.A.	TH	TG	38.8%	60	43%	Operative	
YPFA	YPF LOS PERALES AUTOG	REN	BG	100%	28	100%	01/04/2018	2018
ADTOHI	H. DIAMANTE SA	HI	Hydroelectric	100%	150	35%	Operative	
CONDHI	CONSORCIO POTRERILLOS	HI	Hydroelectric	100%	54	46%	Operative	
SORR	C.TERMICA SORRENTO	TH	TV	36.1%	217	33%	Operative	
AMEGHI	HIDROELECTRICA AMEGHINO SA	REN	PAH	100%	47	42%	Operative	
BRA3	CT BRAGADO 3 - GENNEIA	TH	TG	34.6%	61	50%	01/01/2018	
INDE	GENERACION INDEPENDENCIA S.A.	TH	TG	35.3%	120	28%	Operative	
LOM4EO	C.EOLICA LOMA BLANCA IV-ENARSA	REN	EOL	100%	50	41%	Operative	
RAW1EO	P.EOLICO RAWSON I - ENARSA	REN	EOL	100%	53	38%	Operative	
LREYHB	H. DIAMANTE SA	HI	Hydroelectric	100%	224	35%	Operative	
ROJO	CT GENERAL ROJO - RIO ENERGY	TH	TG	39.3%	151	21%	15/06/2017	
PPNO	GENERADORA ELEC.TUCUMAN SA	TH	TG	32.0%	232	19%	Operative	2029
BRA2	CT BRAGADO 2 - GENNEIA	TH	TG	34.8%	59	36%	20/06/2017	
PIQI	CENTRAL TERMICA PIQUIRENDA	TH	DI	40.7%	30	59%	Operative	
LEVA	EPEC GENERACION	TH	TG	23.1%	64	24%	Operative	2021

CENTRAL	Description	Source	Technology	Eff.	Max Power	Capacity Factor	Date in	Date out
QULLHI	QUEBRADA ULLUM - EPSE	REN	PAH	100%	45	27%	Operative	
RHONHI	HIDROELECTRICA RIO HONDO SA	REN	PAH	100%	16	100%	Operative	
PILB	CT PILAR BS AS- PAMPA ENERGÍA	TH	DI	48.2%	100	34%	01/10/2017	
CPIEHI	CENTRAL CASA DE PIEDRA	HI	Hydroelectric	100%	60	35%	Operative	
RSAU	C.MEDANITOS-RINCON SAUCES	TH	DI	36.5%	32	68%	Operative	
CCORHI	AES JURAMENTO	HI	Hydroelectric	100%	101	35%	Operative	
ROCA	CT ROCA SA	TH	TG	32.3%	130	21%	Operative	2023
NIH3HI	HIDROELECTRICA LOS NIHUILES SA	HI	Hydroelectric	100%	42	35%	Operative	
COSM	MOTOGENERADORES COSTANERA	TH	DI	50.5%	36	41%	Operative	
RAW2EO	P.EOLICO RAWSON II - ENARSA	REN	EOL	100%	31	40%	Operative	
JUNI	CT JUNIN - SOENERGY	TH	DI	39.3%	22	55%	Operative	
PERZ	CT PEREZ - SECCO	TH	DI	45.6%	81	36%	12/08/2017	
ARMA	CT LAS ARMAS - EMGASUD	TH	TG	34.3%	34	47%	Operative	2029
CERI	ECOENERGÍA - PETROBRAS	TH	TV	30.0%	13	89%	Operative	2027
CGOM	CT CAÑADA DE GOMEZ - SECCO	TH	DI	44.1%	67	30%	12/08/2017	
LMO1HI	EPEC GENERACION	HI	Hydroelectric	100%	52	37%	Operative	
BRAG	CT BRAGADO - EMGASUD	TH	TG	34.5%	50	43%	Operative	2029
GBMO	UGEM 12 - GBA - ENARSA	TH	DI	41.0%	359	4%	Operative	2017
SLTO	CT SALTO - SOENERGY	TH	DI	38.8%	23	42%	Operative	
NIH4HI	HIDR NIHUIL IV (EMSE SE)	REN	PAH	100%	18	51%	Operative	
SERT	CT RIO TERCERO II - SoENERGY	TH	TG	39.7%	60	28%	20/05/2017	
LMADHI	HIDROCUYO S.A.	REN	PAH	100%	31	32%	Operative	
CARRHI	CONSORCIO POTRERILLOS	REN	PAH	100%	17	52%	Operative	
ESCAHI	HIDROELECTRICA TUCUMAN SA	REN	PAH	100%	24	49%	Operative	
LOBO	CT LOBOS BS.AS - SULLAIR	TH	DI	39.0%	20	35%	Operative	
LCA2	CT LOMA CAMPANA 2 -Y-GEN ELECT	TH	TG	43.4%	107	48%	01/01/2018	
LINC	CT LINCOLN - SOENERGY	TH	DI	38.4%	15	43%	Operative	
CAST	CT CASTELLI - AGGREKO	TH	DI	39.3%	15	49%	Operative	
ALEM	CT ALEM - AGGREKO	TH	DI	39.3%	15	38%	Operative	
SROQHI	EPEC GENERACION	REN	PAH	100%	24	35%	Operative	
ARA2EO	PARQUE EOLICO ARAUCO II SAPEM	REN	EOL	100%	25	26%	Operative	
SMIG	CT SAN MIGUEL NORTE III-ENARSA	REN	BG	100%	12	53%	Operative	
TUNAHI	AES JURAMENTO	REN	PAH	100%	11	57%	Operative	
HUEM	SINOPEC Arg. - El Huemul	REN	SFV	100%	3	61%	01/04/2018	2018
BVIL	CT BELL VILLE - SULLAIR	TH	DI	39.1%	16	37%	Operative	
ISVE	CT ISLA VERDE - AGGREKO	TH	DI	39.5%	25	19%	Operative	
LCAM	CT LOMA CAMPANA 1 - YPF	TH	TG	43.8%	105	21%	01/10/2017	

CENTRAL	Description	Source	Technology	Eff.	Max Power	Capacity Factor	Date in	Date out
PINA	CT PINAMAR - EMGASUD	TH	TG	29.2%	21	41%	Operative	
CASSHI	EPEC GENERACION	REN	PAH	100%	16	45%	Operative	
CATD	CT CATAMARCA - SECCO	TH	DI	38.2%	19	28%	Operative	
LRIO	GENERACION RIOJANA SA	TH	TG	29.0%	88	4%	Operative	
ETIGHI	H. DIAMANTE SA	REN	PAH	100%	14	36%	Operative	
CEMO	UGEM 17 - CENTRO - ENARSA	TH	DI	40.0%	70	5%	Operative	
PVIEHI	HIDROELECTRICA TUCUMAN SA	REN	PAH	100%	15	45%	Operative	
PICA	CT PARQUE INDUSTR.CATAM-SECCO	TH	DI	39.4%	15	28%	Operative	
FSIMHI	EPEC GENERACION	REN	PAH	100%	11	56%	Operative	
REOLHI	EPEC GENERACION	REN	PAH	100%	33	27%	Operative	
CADIHI	HIDROELECTRICA TUCUMAN SA	REN	PAH	100%	13	40%	Operative	
COLB	CT COLON BS.AS - SULLAIR	TH	DI	38.9%	15	28%	Operative	
OCAM	CT VILLA OCAMPO - SECCO	TH	DI	49.0%	50	16%	01/10/2017	
PARA	CT PARANA - EMGASUD	TH	TG	34.4%	40	17%	Operative	2029
PMORHI	EPEC GENERACION	REN	PAH	100%	6	51%	Operative	
DIADEO	HYCHICO P. EOLICO DIADEMA	REN	EOL	100%	6	48%	Operative	
PTR1	C.T. PATAGONICAS SA	TH	TG	22.4%	45	16%	Operative	2021
OLAD	CT OLAVARRIA - EMGASUD	TH	TG	33.9%	39	18%	Operative	2029
ARRE	CT ARRECIFES-AGGREKO	TH	DI	36.1%	20	22%	Operative	
MATHEU	CT MATHEU - EMGASUD	TH	TG	33.7%	40	16%	Operative	2029
CSAR	CT CAPITAN SARMIENTO - SECCO	TH	DI	36.4%	5	68%	Operative	
FORD	CT FORMOSA - APR ENERGY	TH	DI	36.4%	30	12%	Operative	
CHLE	CT CHILECITO - SECCO	TH	DI	38.0%	10	30%	Operative	
CURU	CT CONC.DEL URUGUAY - EMGASUD	TH	TG	34.1%	42	14%	Operative	2029
LVINHI	EPEC GENERACION	REN	PAH	100%	16	22%	Operative	
COROHI	GENERADORA ELECTRICA MENDOZ.SA	REN	PAH	100%	7	46%	Operative	
ARIS	CT ARISTOBU.DEL VALLE-SOENERGY	TH	DI	38.0%	15	22%	Operative	
SANDHI	CENTRAL SALTO ANDERSEN	REN	PAH	100%	8	37%	Operative	
BBLM	CT PIEDRABUENA MG(L.LATA)	TH	DI	45.9%	100	32%	01/01/2018	
CHAR	CT CHARATA - SULLAIR	TH	DI	40.3%	20	14%	Operative	
CESPHI	CENTRAL HIDRAULICA CESPEDES	REN	PAH	100%	5	54%	Operative	
VGAD	CT GRAL. VILLEGAS - AGGREKO	TH	DI	39.6%	24	20%	Operative	
VANG	CT VILLA ANGELA - AGGREKO	TH	DI	39.4%	15	17%	Operative	
RREYHI	HIDROELECTRICA REYES EJSEDSA	REN	PAH	100%	7	33%	Operative	

CENTRAL	Description	Source	Technology	Eff.	Max Power	Capacity Factor	Date in	Date out
ROMEHI	CENTRAL JULIAN ROMERO 5 SALTOS	REN	PAH	100%	6	53%	Operative	
SPEN	CT SAENZ PEÑA - APR ENERGY	TH	DI	37.5%	20	12%	Operative	
PIRA	CT PIRANE - SULLAIR	TH	DI	38.2%	16	15%	Operative	
CORR	CT CORRIENTES - AGGREKO	TH	DI	39.4%	20	15%	Operative	
MDAJ	C.COSTA ATLANTICA	TH	TG	20.5%	30	10%	Operative	2020
CVIEHI	HIDR.CUESTA DEL VIENTO - EPSE	REN	PAH	100%	11	30%	Operative	
RAW3EO	P.EOLICO RAWSON III - GENNEIA	REN	EOL	100%	25	47%	01/01/2018	
ARAUEO	PARQUE EOLICO ARAUCO SAPEM	REN	EOL	100%	25	12%	Operative	
IND1	CT INDEPEND. ETAPA1 G MEDITERR	TH	TG	32.0%	50	11%	01/10/2017	
TINO	CT TINOGASTA - SULLAIR	TH	DI	37.9%	15	14%	Operative	
SMARHI	GENERADORA ELECTRICA MENDOZ.SA	REN	PAH	100%	6	32%	Operative	
SVIC	CT SAN VICENTE BsAs - ENARSA	TH	DI	34.8%	28	13%	Operative	2029
SCHA	CT SAN MARTIN Chaco - ENARSA	TH	DI	34.1%	15	13%	Operative	2029
EZEI	CT EZEIZA ETAPA2 G MEDITERRANE	TH	TG	33.4%	152	4%	05/04/2017	
SROS	CT SANTA ROSA - TURBODISEL	TH	DI	39.3%	7	25%	Operative	
REAL	CT REALICO - SECCO	TH	DI	39.6%	24	11%	Operative	
SPE2	CT SAENZ PEÑA II-AGGREKO	TH	DI	39.7%	15	13%	Operative	
BARD	CT BARRANQUERAS Chaco- ENARSA	TH	DI	37.6%	22	8%	Operative	
PEHU	CT PEHUAJO - SOENERGY	TH	DI	39.1%	22	32%	Operative	
CIPOHI	CENTRAL HIDRAULICA CIPOLLETTI	REN	PAH	100%	5	59%	Operative	
SARC	HIDROTERMICA SAN JUAN	TH	TG	19.4%	30	11%	Operative	2020
ANAT	CT AÑATUYA - SULLAIR	TH	DI	39.8%	31	9%	Operative	
TERV	CT TEREVINTOS - SECCO	TH	DI	37.1%	8	14%	Operative	
LPLA	CT LA PLATA - SULLAIR	TH	DI	39.9%	40	8%	Operative	
MIR1	CT MIRAMAR I - ENERGYST	TH	DI	40.5%	20	17%	Operative	
SHEL	SHELL CAPSA PTA. DOCK SUD	REN	PAH	100%	1	53%	01/04/2018	2018
LQUIHI	HIDROELECTRICA RIO HONDO SA	REN	PAH	100%	2	51%	Operative	
RESCHI	PAH RIO ESCONDIDO-PATAG	REN	PAH	100%	7	37%	01/10/2017	
PROC	CT PRESIDENCIA ROCA - ENARSA	TH	DI	38.0%	6	16%	Operative	
LMO2HI	EPEC GENERACION	REN	PAH	100%	5	48%	Operative	
CRIV	C.T. PATAGONICAS SA	TH	TG	20.8%	73	8%	Operative	2021
ZAPA	CT ZAPPALORTO - APR ENERGY	TH	TG	28.9%	109	2%	20/04/2017	
SFRA	EPEC GENERACION	TH	TG	22.6%	39	13%	Operative	2021

CENTRAL	Description	Source	Technology	Eff.	Max Power	Capacity Factor	Date in	Date out
JUMEEO	C.EOLICA EL JUME Sgo del Ester	REN	EOL	100%	8	13%	01/10/2017	
VMAR	EPEC GENERACION	TH	TG	20.7%	48	7%	Operative	2021
INTA	CT INTA CATAMARCA - SECCO	TH	DI	39.5%	7	12%	Operative	
TARD	CT TARTAGAL - SOENERGY	TH	DI	38.8%	10	13%	Operative	
GOYD	CT GOYA - SECCO	TH	DI	38.0%	13	19%	Operative	
LPAL	CT LAS PALMAS - TURBODISEL	TH	DI	38.6%	7	17%	Operative	
LIBE	CT LIBERTADOR GSM - SULLAIR	TH	DI	38.2%	15	9%	Operative	
ITAT	CT ITATI - TURBODISEL	TH	DI	39.5%	7	12%	Operative	
BRCH	CT BRACHO - Y-GEN ELECTRICA II	TH	TG	36.5%	267	17%	01/12/2017	
CIPO	CT CIPOLLETI - AGGREKO	TH	DI	39.6%	5	15%	Operative	
LBLA	CT LAGUNA BLANCA - SECCO	TH	DI	38.2%	7	12%	Operative	
LDCUHI	PAH CT MENDOZA - ENARSA	REN	PAH	100%	1	51%	Operative	
SMAN	C.T.SAN MARTIN NORTE 3- ENARSA	REN	BG	100%	5	34%	Operative	
HON2FV	C.FOTOV. CAÑADA HONDA 2-ENARSA	REN	SFV	100%	3	22%	Operative	
RTER	GENERADORA CORDOBA S.A.	TH	TG	21.3%	26	10%	Operative	2021
RUFI	CT RUFINO Sta Fe - ENARSA	TH	DI	37.9%	32	5%	Operative	
PPAT	CT PASO LA PATRIA-TURBODISEL	TH	DI	39.5%	7	11%	Operative	
TELL	EDELAR GENERACION	TH	DI	38.5%	3	23%	Operative	
DFUN	EPEC GENERACION	TH	TG	20.3%	32	8%	Operative	2020
CARL	EPEC GENERACION	TH	DI	38.5%	11	6%	Operative	
ANCH	CT ANCHORIS - METHAX	TH	DI	44.0%	40	8%	15/08/2017	
CERE	CT CERES - SECCO	TH	DI	39.3%	18	8%	Operative	
RESC	C.T.REMED.DE ESCALADA -AGGREKO	TH	DI	37.5%	25	8%	Operative	
BAND	CT BANDERA SgoEstero - ENARSA	TH	DI	33.7%	31	4%	Operative	2029
MAGD	CT MAGDALENA - APR ENERGY	TH	DI	36.6%	25	6%	Operative	
CATA	EDECAT GENERACION	TH	DI	33.7%	18	4%	Operative	2029
SAL2	CT SALTO 2 - SoENERGY	TH	TG	37.3%	63	1%	01/10/2017	
LUJAHI	PAH LA LUJANITA - ENARSA	REN	PAH	100%	2	30%	Operative	
TORDEO	CE EL TORDILLO-VIENTO PATAGON	REN	EOL	100%	3	19%	Operative	
OBER	EMSA GENERACION	TH	TG	20.7%	12	5%	Operative	2021
HON1FV	C.FOTOV. CAÑADA HONDA I-ENARSA	REN	SFV	100%	2	22%	Operative	
CHI1FV	C.FOTOV. CHIMBERAS 1-ENARSA	REN	SFV	100%	2	21%	Operative	
ABRO	C.T. ALMIRANTE BROWN	TH	DI	37.7%	25	7%	Operative	
BRC1	CENTRAL BIOELECTRICA R.CUARTO1	REN	BG	100%	2	43%	01/10/2017	

CENTRAL	Description	Source	Technology	Eff.	Max Power	Capacity Factor	Date in	Date out
LRID	CT LA RIOJA - SECCO	TH	DI	45.0%	19	9%	Operative	
MATE	CT MATHEU II - APR ENERGY	TH	TG	29.9%	229	1%	15/08/2017	2025
JUAR	CT ING JUAREZ - SECCO	TH	DI	37.9%	4	12%	Operative	
BRKE	CT BARKER - UGEN SA	TH	TG	37.9%	142	7%	01/12/2017	
RAFA	CT RAFAELA - SECCO	TH	DI	39.2%	19	6%	Operative	
VTUD	CT VENADO TUERTO - SECCO	TH	DI	39.1%	19	8%	Operative	
ESQD	CT ESQUINA - SOENERGY	TH	DI	38.0%	17	6%	Operative	
LPAZ	CT LA PAZ Entre Rios - ENARSA	TH	DI	37.6%	11	5%	Operative	
VIAL	CT VIALE - AGGREKO	TH	DI	39.4%	10	8%	Operative	
SJUAFV	PTA FOTOVOLTAICA S.JUAN I-EPSE	REN	SFV	100%	1	22%	Operative	
ORAD	CT ORAN - SECCO	TH	DI	38.5%	15	10%	Operative	
DIQU	CENTRAL DIQUE S.A.	TH	TG	20.6%	55	3%	Operative	2020
LRIS	CT LA RIOJA SUR- SECCO	TH	DI	39.4%	10	6%	Operative	
SOES	EPEC GENERACION	TH	TG	23.1%	100	2%	Operative	2021
RCUA	EPEC GENERACION	TH	TG	20.4%	32	3%	Operative	2020
CEJEHI	EPEC GENERACION	REN	PAH	100%	1	19%	Operative	
LBAN	GENERACION LA BANDA S.A.	TH	TG	20.2%	26	8%	Operative	2020
BARI	CT BARILOCHE - SOENERGY	TH	DI	40.0%	20	4%	Operative	
OLPA	EDELAR GENERACION	TH	DI	38.8%	2	12%	Operative	
MJUA	EPEC GENERACION	TH	DI	35.8%	13	2%	Operative	
BERI	EMSA GENERACION	TH	DI	37.7%	2	7%	Operative	
SSAL	CT SAN SALVADOR E.Rios -ENARSA	TH	DI	37.5%	11	5%	Operative	
NEMO	UGEM 05 - NEA - ENARSA	REN	EOL	100%	2	61%	Operative	2017
PZUE	EDELAR GENERACION	TH	DI	38.3%	3	9%	Operative	
ALUM	CT ALUMINÉ - SECCO	TH	DI	39.0%	6	8%	Operative	
SPEV	ENERGIA AGRO S.A.U	REN	BG	100%	1	57%	01/01/2018	
SANA	EMSA GENERACION	TH	DI	34.9%	1	16%	Operative	2029
SALOHI	C.H. SALTO DE LA LOMA SIEyE	REN	PAH	100%	1	24%	Operative	
CAVI	CT CAVIAHUE - SECCO	TH	DI	36.7%	5	4%	Operative	
YANQ	YANQUETRUZ - ACA	REN	BG	100%	2	7%	01/10/2017	
DFUM	EPEC GENERACION	TH	DI	40.5%	3	2%	01/10/2017	
NOMO	UGEM 10 - NOA - ENARSA	REN	PAH	100%	18	6%	Operative	2017
CHEP	EDELAR GENERACION	TH	DI	35.4%	2	13%	Operative	
NIDE	NIDERA SAFORCADA-Junin	REN	EOL	100%	0	8%	01/04/2018	2018
RCHI	CT RIO CHICO - SPSE	TH	TG	20.5%	35	8%	Operative	2020
NECOEO	SEA ENERGY PARQUE EOLICO	REN	EOL	100%	0	4%	Operative	
CHIL	EDELAR GENERACION	TH	DI	45.0%	5	0%	Operative	
SGUIHI	C.H. SAN GUILLERMO SIEyE	REN	PAH	100%	0	7%	Operative	

CENTRAL	Description	Source	Technology	Eff.	Max Power	Capacity Factor	Date in	Date out
TRAP	CHEVRON ARGENTINA - HUANTRAICO	REN	EOL	100%	3	13%	01/04/2018	2018
ALUAR	ALUAR SA - GENERADOR	TH	TG	28.6%	152	6%	01/12/2017	
CAFA	EDESASA GENERACION	REN	PAH	N/A	0	0%	Operative	2019
CALEHI	EPEC GENERACION	REN	PAH	100%	4	13%	Operative	
CDPI	C. TERMICAS MENDOZA SA	TH	TG	30.0%	14	0%	Operative	2019
CVIS	PRAXAIR B. VISTA- EX LIQ.CARB.	REN	PAH	N/A	11	0%	01/04/2018	2019
DIVIHI	APELP	REN	PAH	N/A	10	0%	Operative	2019
ELEP	ELECTROPATAGONIA-C.RIV-C.COMB.	TH	CC	23.2%	63	21%	Operative	2021
EMBA	NUCLEOELECTRICA ARG. SA	NU	Nuclear	100%	648	34%	01/01/2019	
FILO	C.T. FILO MORADO	TH	TG	30.0%	63	0%	Operative	2019
GROCHI	EMP DE ENERGIA DE RIO NEGRO SA	REN	PAH	N/A	2	0%	Operative	2019
HON3FV	C.FOTOV. CAÑADA HONDA 3-ENARSA	REN	SFV	N/A	3	0%	01/04/2018	2019
HUMA	EMP.JUJENIA DE ENER.GENERACION	TH	DI	36.1%	2	1%	Operative	
IND2	CT INDEPEND. ETAPA2 G MEDITERR	TH	TG	30.7%	49	3%	01/12/2017	
LORP	EMP.DIS.S.ESTERO GENERACION	REN	EOL	100%	50	0%	01/04/2018	2018
LRIP	EDELAR GENERACION	TH	DI	35.0%	7	0%	Operative	2019
LROB	EDELAR GENERACION	TH	DI	37.7%	1	5%	Operative	
LUJB	CT LUJAN II - ARAUCARIA ENERGY	REN	PAH	N/A	2	0%	01/04/2018	2019
LVAR	EPEC GENERACION	TH	DI	38.3%	6	6%	Operative	
NESP	EMP.DIS.S.ESTERO GENERACION	REN	EOL	100%	0	53%	01/04/2018	2018
PEDR	CT SAN PEDRO - SPI ENERGY SA	HI	Hydroelectric	40%	472	35%	01/04/2018	2018
PMAD	C.T. PATAGONICAS SA	TH	TG	30.0%	42	0%	Operative	2019
POSA	EMSA GENERACION	TH	TG	30.0%	21	0%	Operative	2019
SALT	C.T. NOA	REN	PAH	N/A	1	0%	01/04/2018	2019
SCTP	EDEA GENERACION	TH	DI	30.0%	14	0%	Operative	2019
SFR2	EPEC GENERACION	TH	DI	38.6%	17	6%	Operative	
SLTA	CT SALTA - ENARSA	REN	SFV	N/A	1	0%	Operative	2019
SMAR	EDECAT GENERACION	TH	DI	30.0%	3	0%	Operative	2019
VGEP	COOP. VILLA GESELL GENERACIÓN	TH	DI	30.0%	3	0%	Operative	2019
VMA2	CT VILLA MARIA - UENSA SA	TH	TG	39.3%	142	15%	01/12/2017	
Res21_1		TH	CC	50%	476		10/03/2018	
Res21_2		TH	CC	50%	476		10/09/2018	
Res 287		TH	CC	60%	1810		01/04/2020	
P.E. Pampa		REN	EOL	100%	100	48%	12/03/2019	
P.E. Miramar		REN	EOL	100%	98	48%	08/09/2019	
P.E. Vientos de Necochea 1		REN	EOL	100%	38	48%	11/12/2019	
P.E. La Banderita		REN	EOL	100%	37	48%	17/06/2019	

CENTRAL	Description	Source	Technology	Eff.	Max Power	Capacity Factor	Date in	Date out
	P.E. Pomona I	REN	EOL	100%	100	48%	05/09/2019	
	P.E. Del Bicentenario	REN	EOL	100%	100	52%	02/02/2019	
	P.E. Loma blanca 6	REN	EOL	100%	100	43%	29/12/2019	
	P.E. Achiras	REN	EOL	100%	48	49%	26/09/2018	
	P.E. Arauco II (Etapa 3 y 4)	REN	EOL	100%	95	48%	17/12/2019	
	P.E. El Sosneado	REN	EOL	100%	50	39%	17/12/2019	
	P.S. Saujil	REN	SFV	100%	23	28%	18/09/2018	
	P.S. Tinogasta	REN	SFV	100%	15	28%	10/09/2018	
	P.S. Fiambalá	REN	SFV	100%	11	28%	18/09/2018	
	P.S. Cafayate	REN	SFV	100%	80	29%	17/05/2019	
	P.S. Nonogasta	REN	SFV	100%	35	28%	25/10/2018	
	P.S. Anchoris	REN	SFV	100%	21	28%	18/06/2019	
	P.S. PASIP	REN	SFV	100%	1	28%	10/06/2020	
	P.S. Sarmiento	REN	SFV	100%	35	28%	02/12/2018	
	P.S. La Cumbre	REN	SFV	100%	22	28%	05/09/2018	
	P.S. Ullum N1	REN	SFV	100%	25	28%	17/11/2018	
	P.S. Lujan de Cuyo	REN	SFV	100%	22	28%	10/06/2020	
	P.S. Caldenes del Oeste	REN	SFV	100%	25	28%	02/06/2018	
	P.S. Lavalle	REN	SFV	100%	18	28%	10/06/2020	
	P.S. Iglesia - Guañizuli	REN	SFV	100%	80	28%	25/09/2018	
	P.S. Ullum N2	REN	SFV	100%	25	28%	17/11/2018	
	P.S. General Alvear	REN	SFV	100%	18	28%	10/06/2020	
	P.S. La Paz	REN	SFV	100%	14	28%	10/06/2020	
	P.S. Las Lomitas	REN	SFV	100%	2	28%	31/08/2018	
	P.S. Ullum3	REN	SFV	100%	32	28%	22/12/2018	
	P.S. Ullum 4	REN	SFV	100%	14	28%	17/05/2019	
	P.E. García del Rió	REN	EOL	100%	10	54%	24/12/2018	
	P.E. Vientos del Secano	REN	EOL	100%	50	47%	15/04/2019	
	P.E. Villalonga	REN	EOL	100%	50	52%	04/05/2019	
	P.E. Los Meandros	REN	EOL	100%	75	43%	08/05/2019	
	P.E. Cerro Alto	REN	EOL	100%	50	35%	04/04/2019	
	P.E. Corti	REN	EOL	100%	100	55%	24/06/2018	
	P.E. Garayalde	REN	EOL	100%	24	39%	12/01/2019	
	P.E. La Castellana	REN	EOL	100%	99	51%	20/08/2018	
	P.E. Kosten	REN	EOL	100%	24	47%	15/08/2019	
	P.E. Vientos Los Hércules	REN	EOL	100%	97	45%	15/08/2019	
	P.E. Chubut Norte	REN	EOL	100%	28	46%	04/04/2019	
	P.E. Arauco II (Etapa 1 y 2)	REN	EOL	100%	100	47%	15/08/2019	
	P.S. Cauchari 1	REN	SFV	100%	100	25%	18/05/2018	
	P.S. Cauchari 2	REN	SFV	100%	100	25%	18/05/2018	
	P.S. Cauchari 3	REN	SFV	100%	100	25%	18/05/2018	
	P.S. La Puna	REN	SFV	100%	100	33%	02/02/2020	
	C.T. Biogás Ricardone	REN	BG	100%	1	52%	26/06/2018	
	C.T. Río Cuarto 1	REN	BG	100%	2	100%	22/07/2017	

CENTRAL	Description	Source	Technology	Eff.	Max Power	Capacity Factor	Date in	Date out
	C.T. Río Cuarto 2	REN	BG	100%	1	100%	14/10/2018	
	C.T. Yanquetruz	REN	BG	100%	1	51%	09/08/2017	
	C.T. San Pedro Verde	REN	BG	100%	1	51%	01/11/2017	
	C.T. Huinca Renancó	REN	BG	100%	2	51%	24/07/2018	
	C.T. Generación Biomasa Santa Rosa	REN	BM	100%	13	4%	04/10/2018	
	C.T. Pincó Eco	REN	BM	100%	2	20%	25/08/2017	
	P.A.H. Canal Cacique Guaymallén - Salto 8	REN	PAH	100%	1	52%	02/02/2019	
	P.A.H. Canal Cacique Guaymallén - Salto 6	REN	PAH	100%	1	31%	02/02/2019	
	P.A.H. Dique Tiburcio Benegas	REN	PAH	100%	2	51%	02/02/2019	
	P.A.H. Triple Salto Unificado	REN	PAH	100%	1	51%	02/02/2019	
	P.A.H. Rio Escondido	REN	PAH	100%	7	51%	05/08/2017	
	P.E. Loma Blanca I	REN	EOL	100%	50	43%	29/12/2019	
	P.E. Loma Blanca II	REN	EOL	100%	50	43%	28/02/2019	
	P.E. Loma Blanca III	REN	EOL	100%	50	43%	29/12/2019	
	P.E. Koluel Kayke II	REN	EOL	100%	25	52%	21/05/2019	
	P.E. Malaspina I	REN	EOL	100%	50	39%	17/11/2019	
	P.E. Puerto Madryn I	REN	EOL	100%	70	43%	28/05/2019	
	P.E. Puerto Madryn II	REN	EOL	100%	150	43%	26/11/2019	
	C.T. Biomásica La Florida	REN	BM	100%	45	4%	15/08/2022	
	P.S. Solares de la Punta	REN	SFV	100%	5	28%	20/01/2019	
	P.S. Cerros del Sol	REN	SFV	100%	5	28%	20/01/2019	
	C.T. ENSENADA	REN	BRS	100%	5	47%	25/01/2019	
	C.T. GONZALEZ CATAN	REN	BRS	100%	5	47%	21/12/2018	
	C.T. RICARDONE II	REN	BRS	100%	3	47%	07/10/2019	
	C.T. BIOMASA UNITAN	REN	BM	100%	7	20%	05/01/2020	
	C.T. GENERACIÓN LAS JUNTURAS	REN	BM	100%	1	20%	16/05/2019	
	C.T. PRODEMAN BIOENERGIA	REN	BM	100%	9	20%	14/07/2018	
	C.T. GENERACION VIRASORO	REN	BM	100%	3	20%	17/11/2019	
	C.T. LA ESCONDIDA	REN	BM	100%	10	20%	08/08/2019	
	C.T. KUERA SANTO TOME	REN	BM	100%	13	20%	10/03/2021	
	C.T. FERMOSA S.A.	REN	BM	100%	6	20%	25/03/2020	
	C.T. ROJAS	REN	BM	100%	7	20%	05/11/2020	
	C.T. TICINO BIOMASA S.A.	REN	BM	100%	3	20%	14/07/2018	
	C.T. CAPITAN SARMIENTO	REN	BM	100%	7	20%	14/04/2020	
	C.T. BM MM BIOENERGIA	REN	BM	100%	3	20%	19/06/2020	
	C.T. LAS LOMITAS	REN	BM	100%	10	20%	25/08/2020	
	C.T. COGENERACIÓN INGENIO LEALES	REN	BM	100%	2	20%	10/04/2019	
	C.T. SAN ALONSO	REN	BM	100%	37	20%	31/10/2020	
	C.T. GENERAL VILLEGAS	REN	BG	100%	1	51%	14/04/2020	
	C.T. ARREBEEF ENERGIA	REN	BG	100%	2	51%	03/10/2019	
	C.T. BOMBAL BIOGAS	REN	BG	100%	1	51%	09/11/2019	
	C.T. RESENER I	REN	BG	100%	1	51%	06/11/2019	
	C.T. CITRUSVIL	REN	BG	100%	3	51%	21/12/2018	

CENTRAL	Description	Source	Technology	Eff.	Max Power	Capacity Factor	Date in	Date out
	C.T. JAMES CRAIK	REN	BG	100%	2	51%	09/11/2019	
	C.T. SAN FRANCISCO	REN	BG	100%	2	51%	09/11/2019	
	C.T. POLLOS SAN MATEO	REN	BG	100%	2	51%	09/11/2019	
	C.T. BIO JUSTO DARACT	REN	BG	100%	1	51%	22/10/2019	
	C.T. JIGENA I	REN	BG	100%	1	51%	17/10/2019	
	C.T. DEL REY	REN	BG	100%	1	51%	14/03/2019	
	C.T. RECREO	REN	BG	100%	2	51%	09/11/2019	
	C.T. BELLA ITALIA	REN	BG	100%	2	51%	09/11/2019	
	C.T. EL ALEGRE BIO	REN	BG	100%	1	51%	06/11/2019	
	C.T. AVELLANEDA	REN	BG	100%	6	52%	03/01/2019	
	C.T. VILLA DEL ROSARIO	REN	BG	100%	1	51%	17/10/2019	
	AMPLIACION BIOELECTRICA DOS	REN	BG	100%	1	51%	14/12/2018	
	C.T. DON NICANOR	REN	BG	100%	1	51%	14/03/2019	
	C.T. DON ROBERTO BIO	REN	BG	100%	1	51%	06/11/2019	
	AMPLIACION 2 CENTRAL BIOELECTRICA	REN	BG	100%	1	51%	25/06/2019	
	P.A.H. LUNLUNTA	REN	PAH	100%	6	51%	19/06/2019	
	P.A.H. CRUZ DEL EJE	REN	PAH	100%	1	0%	26/12/2019	
	P.A.H. PICHANAS	REN	PAH	100%	1	0%	25/01/2020	
	P.A.H. BOCA DEL RIO	REN	PAH	100%	1	60%	26/12/2019	
	P.A.H. SALTO DE LA LOMA	REN	PAH	100%	1	40%	20/01/2019	
	P.A.H. SALTO 7	REN	PAH	100%	1	41%	25/01/2020	
	P.A.H. SALTO 11	REN	PAH	100%	1	38%	14/04/2020	
	P.A.H. SALTO 40	REN	PAH	100%	1	40%	14/04/2020	
	P.A.H. LAS TUNAS	REN	PAH	100%	10	51%	14/04/2020	
	P.E. ENERGETICA I	REN	EOL	100%	80	48%	06/12/2019	
	P.E. CHUBUT NORTE IV	REN	EOL	100%	83	43%	15/02/2020	
	P.E. CHUBUT NORTE III	REN	EOL	100%	58	43%	15/02/2020	
	P.E. VIENTOS FRAY GUEN	REN	EOL	100%	100	48%	30/01/2020	
	P.E. LA GENOVEVA	REN	EOL	100%	87	48%	04/04/2020	
	P.E. CAÑADA LEON	REN	EOL	100%	99	52%	26/11/2019	
	P.E. GENERAL ACHA	REN	EOL	100%	60	48%	24/02/2020	
	P.E. ARAUCO II (ETAPA 5 Y 6)	REN	EOL	100%	100	48%	25/09/2019	
	P.S. TINOGASTA II	REN	SFV	100%	7	28%	25/08/2018	
	P.S. SAUJIL II	REN	SFV	100%	20	28%	11/03/2019	
	P.S. NONOGASTA II	REN	SFV	100%	20	28%	21/02/2019	
	P.S. ALTIPLANO I	REN	SFV	100%	100	29%	13/03/2020	
	P.S. LA PIRKA	REN	SFV	100%	100	28%	08/08/2019	
	P.S. ULLUM X	REN	SFV	100%	100	28%	08/08/2019	
	P.S. VERANO CAPITAL SOLAR ONE	REN	SFV	100%	100	28%	13/08/2019	
	P.S. V.MARIA DEL RIO SECO	REN	SFV	100%	20	28%	11/11/2018	
	P.S. CURA BROCHERO	REN	SFV	100%	17	28%	11/11/2018	
	P.S. VILLA DOLORES	REN	SFV	100%	27	28%	09/07/2019	
	P.S. AÑATUYA I	REN	SFV	100%	6	28%	08/08/2019	
	P.S. ARROYO DEL CABRAL	REN	SFV	100%	40	28%	14/04/2020	

CENTRAL	Description	Source	Technology	Eff.	Max Power	Capacity Factor	Date in	Date out
C.T. BIOMASA LA FLORIDA		REN	BM	100%	19	20%	14/03/2021	
C.T. VENADO TUERTO		REN	BM	100%	7	20%	15/12/2020	
C.T. PACUCA		REN	BG	100%	1	20%	14/02/2020	
C.T. PERGAMINO		REN	BG	100%	2	20%	06/11/2019	
C.T. BIOCAÑA		REN	BG	100%	3	20%	14/02/2020	
C.T. BIOGENERADORA SANTA CATALINA		REN	BG	100%	2	20%	17/03/2020	
C.T. VENADO TUERTO		REN	BG	100%	2	20%	04/05/2020	
C.T. SANTIAGO		REN	BG	100%	3	20%	15/05/2019	
C.T. ENRECO		REN	BG	100%	2	20%	14/04/2020	
C.T. GENERAL ALVEAR		REN	BG	100%	1	20%	14/02/2020	
C.T. YANQUETRUZ II		REN	BG	100%	1	20%	14/02/2020	
C.T. EL MANGRULLO		REN	BG	100%	2	20%	14/02/2020	
C.T. AB ENERGIA		REN	BG	100%	2	20%	14/02/2020	
P.E. DIADEMA II		REN	EOL	100%	28	43%	15/08/2019	
P.E. PAMPA CHUBUT		REN	EOL	100%	100	43%	30/04/2020	
P.E. SAN JORGE		REN	EOL	100%	100	52%	14/05/2020	
P.E. EL MATACO		REN	EOL	100%	100	52%	14/05/2020	
P.S. TOCOTA		REN	SFV	100%	72	28%	27/03/2020	
P.S. ZAPATA		REN	SFV	100%	37	28%	12/09/2019	
P.S. NONOGASTA IV		REN	SFV	100%	1	28%	21/02/2019	
P.S. GUAÑIZUIL II		REN	SFV	100%	100	28%	16/10/2019	
P.S. LOS ZORRITOS		REN	SFV	100%	50	28%	07/09/2019	
EBAR_ext		TH	CC	55%	847		01/06/2022	
VOBL_ext		TH	CC	55%	847		01/04/2021	
BLOP_ext		TH	CC	55%	420		01/09/2018	
ROCA_ext		TH	TG	30%	290		01/06/2018	
RTUR_ext		TH	TV	30%	240		01/04/2020	
SNIC_ext		TH	CC	50%	1050		10/01/2021	
TAND_ext		TH	CC	53%	653	0%	20/11/2017	
LDLA_ext		TH	CC	47%	765	61%	01/10/2017	
GBMO_ext		TH	DI	41%	50		01/01/2018	
MMAR_ext		TH	TG	36%	95		01/01/2018	
El Tambolar		HI	Hydroelectric	100%	70	70%	10/04/2022	
Aña Cuá		HI	Hydroelectric	100%	270	70%	10/03/2023	
YACHI_1		HI	Hydroelectric	100%	465	70%	02/02/2024	
Condor Cliff		HI	Hydroelectric	100%	950	70%	02/03/2025	
La Barrancosa		HI	Hydroelectric	100%	360	70%	20/03/2025	
Chihuido1		HI	Hydroelectric	100%	637	70%	16/02/2026	
Portezuelo del Viento		HI	Hydroelectric	100%	216	70%	29/02/2028	
Carem25		NU	Nuclear	100%	27	75%	25/06/2023	

Table A2: List of electricity generation plants from CAMMESA, operative or with COD planned.

A.4.2 Proposed Evolution on BAU Scenario

CENTRAL	Description	Source	Technology	Eff.	Max Power	Capacity Factor	Date in
	Renovar3.0 - 1	REN	EOL	100%	700	40%	01/03/2021
	Renovar3.0 - 2	REN	EOL	100%	700	40%	20/08/2021
	Renovar3.5	REN	PAH, BM, BG	100%	600	40%	03/12/2021
	Renovar 4 - 1	REN	SFV	100%	700	40%	04/04/2022
	Renovar4 - 2	REN	EOL	100%	800	40%	04/10/2022
	Renovar 4.5	REN	EOL	100%	800	45%	10/04/2023
	Renovar 5 – 1	REN	SFV	100%	800	40%	10/04/2024
	Renovar 5 - 2	REN	PAH, BM, BG	100%	500	40%	10/04/2025
	Renovar 5 – 3	REN	SFV	100%	750	55%	01/06/2026
	Renovar 5 – 4	REN	EOL	100%	500	55%	10/07/2025
	Renovar 5.5 – 1	REN	SFV	100%	500	50%	10/03/2027
	Renovar 5.5 – 2	REN	EOL	100%	500	50%	10/09/2027
	Renovar 6 – 1	REN	SFV	100%	700	50%	29/02/2028
	Renovar 6 – 2	REN	EOL	100%	700	50%	04/05/2028
	Renovar 6.5 – 2	REN	PAH, BM, BG	100%	750	55%	22/11/2028
	Renovar 6.5 – 3	REN	SFV	100%	1000	55%	02/01/2029
	Renovar 6.5 – 4	REN	SFV	100%	1000	55%	03/09/2029
	Renovar 7	REN	EOL	100%	1000	55%	10/09/2030
	Renovar 7.5	REN	SFV	100%	500	55%	04/03/2031
	Renovar7.5 - 1	REN	SFV	100%	500	55%	01/01/2033
	Renovar7.5 - 2	REN	SFV	100%	1200	60%	04/06/2032
	Renovar 8	REN	EOL	100%	1500	55%	01/01/2034
	Renovar 8.5	REN	SFV	100%	1500	55%	01/01/2036
	Renovar 9	REN	EOL	100%	1500	55%	01/01/2038
	Renovar 9.5	REN	PAH, BM, BG	100%	2000	55%	01/01/2039
	Renovar 10	REN	EOL	100%	2000	51%	01/01/2042
	Renovar10.5	REN	EOL	100%	3000	51%	01/01/2044
	Renovar 11	REN	SFV	100%	2000	55%	01/01/2046
	Renovar 11.5	REN	EOL	100%	1000	50%	10/10/2046
	Renovar 12 – 1	REN	EOL	100%	2000	55%	01/01/2047
	Renovar 12 - 2	REN	SFV	100%	1000	55%	15/07/2049
	Renovar 12.5 - 1	REN	PAH, BM, BG	100%	1200	55%	01/11/2049
	Renovar 12.5 – 2	REN	SFV	100%	1250	55%	01/06/2050
	THERM – 1	TH	CC	53%	1000		03/09/2023
	THERM – 2	TH	CC	56%	900		03/04/2026
	THERM – 3	TH	CC	55%	1000		02/04/2029
	THERM – 4	TH	CC	59%	1400		02/06/2036
	THERM – 5	TH	CC	59%	1200		02/06/2038
	THERM – 6	TH	CC	57%	1200		15/06/2040
	THERM – 7	TH	CC	57%	1200		25/05/2044
	THERM – 8	TH	CC	57%	1200		20/04/2046
	THERM – 9	TH	CC	58%	1500	55%	01/01/2048

CENTRAL	Description	Source	Technology	Eff.	Max Power	Capacity Factor	Date in
	HI_1	HI	Hydroelectric	100%	700	70%	03/09/2032
	HI_2	HI	Hydroelectric	100%	700	70%	15/03/2034
	HI_3	HI	Hydroelectric	100%	700	70%	15/03/2040
	HI_4	HI	Hydroelectric	100%	700	70%	15/03/2045
	IV Central	NU	Nuclear	100%	700	75%	09/02/2025
	V Central	NU	Nuclear	100%	650	75%	29/03/2027
	VI Central	NU	Nuclear	100%	650	75%	27/02/2028
	VII Central	NU	Nuclear	100%	1500	75%	02/01/2031
	VIII Central	NU	Nuclear	100%	1200	75%	29/03/2034
	IX Central	TH	CC	55%	2000	75%	29/03/2040
	X Central	TH	CC	55%	1500	75%	29/05/2042

Table A3: Assumption of aditional plants that will come in service to CAMMESA up to year 2050 in a BAU electricity generation scenario.

A.4.3 Proposed Evolution on Efficient Scenario

CENTRAL	Description	Source	Technology	Eff.	Max Power	Capacity Factor	Date in
	Renovar3.0 - 1	REN	EOL	100%	700	40%	01/03/2021
	Renovar3.0 - 2	REN	PAH, BM, BG	100%	700	40%	20/08/2021
	Renovar3.5	REN	SFV	100%	700	40%	04/04/2022
	Renovar4	REN	EOL	100%	800	45%	10/04/2023
	Renovar4 - 1	REN	SFV	100%	800	40%	10/04/2024
	Renovar 4.5	REN	PAH, BM, BG	100%	700	40%	10/10/2024
	Renovar 5	REN	SFV	100%	500	55%	01/06/2026
	Renovar 5 - 1	REN	EOL	100%	500	55%	10/07/2025
	Renovar 5 - 2	REN	SFV	100%	500	50%	10/03/2027
	Renovar 5.5 - 1	REN	EOL	100%	500	50%	10/09/2027
	Renovar 5.5 - 2	REN	SFV	100%	700	50%	29/02/2028
	Renovar 6 - 1	REN	EOL	100%	600	55%	22/11/2028
	Renovar 6 - 2	REN	SFV	100%	500	55%	02/01/2029
	Renovar 6.5 - 1	REN	EOL	100%	500	55%	03/09/2029
	Renovar 6.5 - 2	REN	PAH, BM, BG	100%	500	55%	10/09/2030
	Renovar 6.5 - 3	REN	SFV	100%	500	55%	04/03/2031
	Renovar 6.5 - 4	REN	SFV	100%	900	60%	04/06/2032
	Renovar 7	REN	SFV	100%	500	55%	01/01/2033
	Renovar 7.5	REN	EOL	100%	700	55%	01/01/2034
	Renovar7_1	REN	SFV	100%	700	55%	01/01/2036
	Renovar7_2	REN	EOL	100%	700	55%	01/01/2038
	Renovar 8	REN	EOL	100%	1300	55%	01/01/2039
	Renovar 8.5	REN	EOL	100%	1300	50%	15/06/2040
	Renovar 9	REN	EOL	100%	1300	50%	01/01/2042
	Renovar 9.5	REN	EOL	100%	1000	52%	25/05/2044
	Renovar 10	REN	PAH, BM, BG	100%	1300	50%	01/01/2044

CENTRAL	Description	Source	Technology	Eff.	Max Power	Capacity Factor	Date in
	Renovar10_1	REN	SFV	100%	1200	55%	01/01/2046
	Renovar11	REN	EOL	100%	2200	55%	01/01/2047
	Renovar11_1	REN	SFV	100%	2000	55%	01/01/2048
	Renovar12	REN	PAH, BM, BG	100%	2000	55%	01/11/2049
	Renovar12_1	REN	SFV	100%	2000	55%	01/06/2050
	THERM - 1	TH	CC	53%	1000		03/09/2023
	THERM - 2	TH	CC	59%	1200		02/04/2029
	THERM - 3	TH	CC	62%	800		02/06/2036
	HI_1	HI	Hydroelectric	100%	700	70%	03/09/2032
	HI_2	HI	Hydroelectric	100%	700	70%	15/03/2034
	IV Central	NU	Nuclear	100%	800	75%	09/02/2025
	VI Central	NU	Nuclear	100%	1250	75%	27/02/2028
	VII Central	NU	Nuclear	100%	1500	75%	02/01/2031
	VIII Central	NU	Nuclear	100%	1200	75%	29/03/2034
	IX Central	NU	Nuclear	100%	2000	75%	29/03/2040

Table A4: Assumption of aditional plants that will come in service to CAMMESA up to year 2050 in an electricity efficient generation scenario.