SD modelling for assessing the long-term effects of PV penetration in the Brazilian distribution industry

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Introduction

Preliminary remarks

Presentation objective

Show a simulation model, which is a quantitative, systemic and flexible tool.

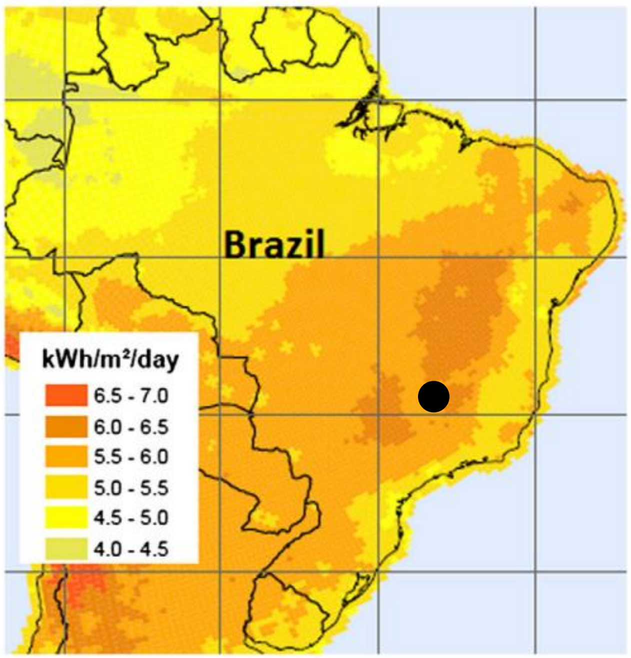
For assessing financial impacts of distributed PV on Energisa

Get feedback to improve the simulation model

Introduction
Global PV market

- Solar PV cost is leading the cost decline of renewable energy cost; **PV** has reached **grid parity** in many locations (Irena, 2015; Bayod-Rújula, 2009).
- Solar PV is a fast growing market: between 2000 to 2014 the annual growth. Rate of PV installations was 44% (Fraunhofer, 2015).
- There is an energy trend from centralized to decentralized system of power generation, which poses technical challenges (EPRI, 2014).

This simulation model has been adapted to the Energisa MG case



Annual averages of the daily total of solar irradiation.
Source: SWERA project.

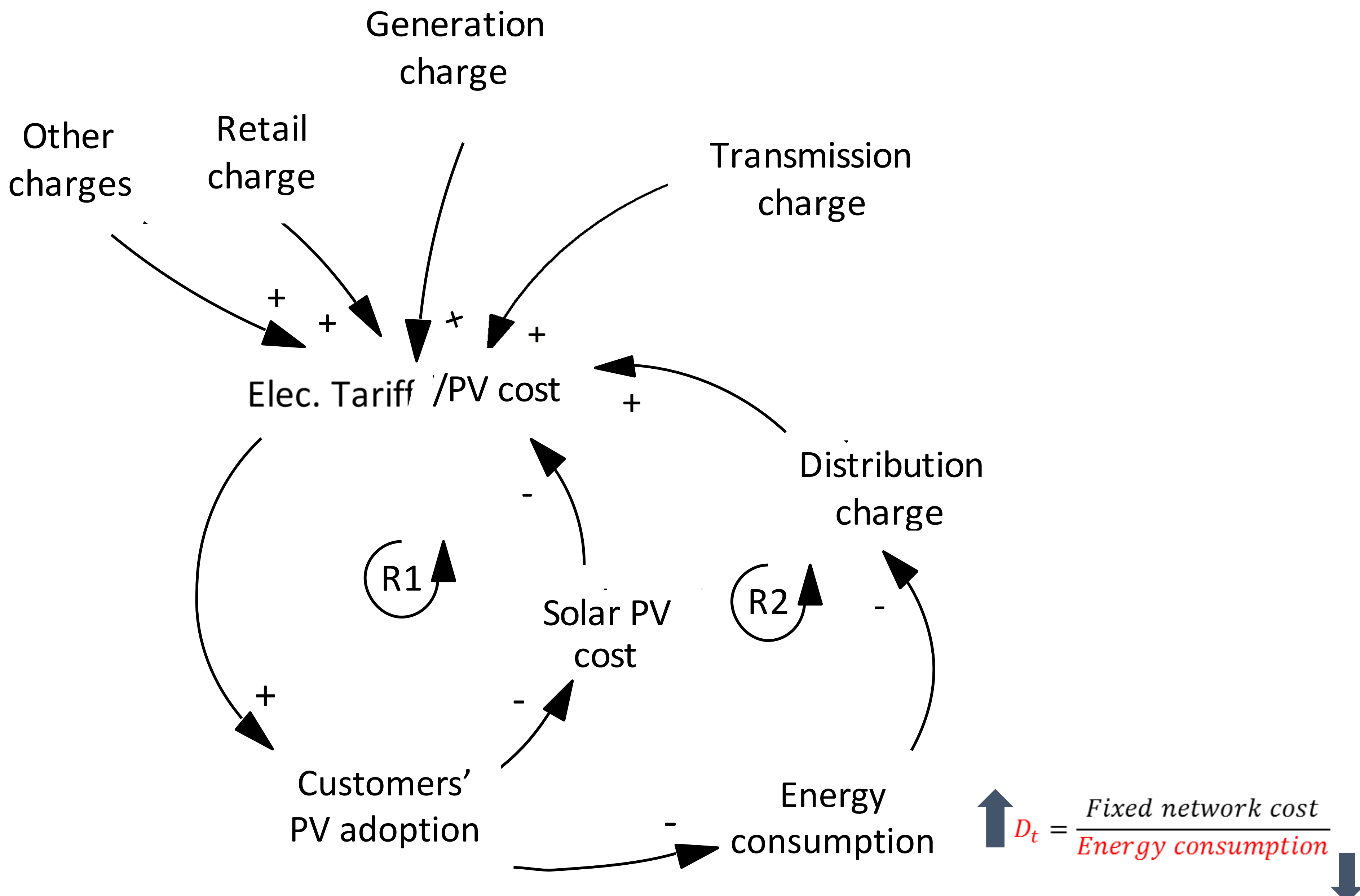
- 70% Hydropower and renewable energies, and more to come…
- 28% Thermal power
- 2% Nuclear power
- Regulated contracting environment

(Abeeolica, 2016)

Favourable conditions for solar PV (Martins et al., 2008; Mints, 2009):

- Net metering
- Low PV system costs,
- High-quality solar radiation
- High end-consumer electricity tariffs

Death spiral …



Objectives

- Identify the **long-term** dynamic **effects of Solar PV** deployment on the distribution utility Energisa.
- Develop a **thinking framework** that includes modelling applied to Energisa.

In the long-term:

- Identify **threats** and **opportunities** for this distribution utility.
- Propose actions to take advantages from opportunities and mitigate threats.

Some studies about the problem in Brazil…

Table 3. Literature review

Author	Title
Holdermann et al., (2014), Jannuzzi and Melo (2013), Ramos and Bueno (2011), Mitscher and Ruther (2012), ABINEE (2012), EPE (2012)	Studies about the possible economic viability of PV systems in the Brazilian residential sector before the introduction of the net metering regulation.
Rego and Parente (2013), Rego (2013)	Brazilian experience in electricity auctions

Assumptions (1/2)

- Non additional network investment is considered for adapting the grid to microgeneration
- X factor of productivity is not considered
- Transmission charge is modelled exogenously
- Grid loses impact is not taken into account
- The application case includes Energisa Minas Gerais, Brazil
- Learning curve is modelled as a function of global learning
- Population willing to adopt depends on LCOE from PV and end-consumer tariff
- Taxes benefits are not included in the calculation of LCOE for solar PV

Assumptions (2/2)

- Consumption patterns remain constant
- Battery storage and grid defection are not included
- PV adoption of the residential, industrial and commercial low voltage consumers is the focus of this study
- Average PV size installed by customer allows to be at least zero net energy demand
- Parameters of technology diffusion (word-of-mouth and advertising effects) are calibrated
- Roof percentage is not yet included, but solar PV potential in the residential level for Minas Gerais is 3675MW (EPE, 2014)
- Energy contracts rise according to electricity demand projections, which are calculated endogenously

Inputs (1/4)
Tariffs information

Variable	Value	Source
Distribution charge	25.73 %	(Energisa, 2016)
Transmission charge	7.96 %	
Energy charge	31.70 %	
Other charges	34.61 %	
End- consumer tariff without taxes (urban households)	0.44 R$/kW	(Aneel, 2016)
End- consumer tariff without taxes (rural households)	0.34 R$/kW	
End- consumer tariff without taxes (industrial and commercial)	0.43 R$/kW	
End- consumer tariff without taxes (commercial)	0.47 R$/kW	

- Energy contracts information is taken from CCEE (2016)

Inputs (2/4)
Customers information

Parameter	Value		Source
Number of households (urban)	321179	Consumers	(Aneel, 2016)
Number of households (rural)	67857	Consumers	
Number of industry consumers	3646	Consumers	
Number of commercial consumers	35120	Consumers	
Monthly average consumption of urban households	129	kWh/month	
Monthly average consumption of rural households	209	kWh/month	
Monthly average consumption of industry consumers	3519	kWh/month	
Monthly average consumption of commercial consumers	611	kWh/month	

Inputs (3/4)

Tariffs information

Parameter	Value		Source
Solar capacity factor	15.5	%	(Januzzi and Melo, 2013)
PV-system size for urban households	1.2	kW	Own calculations
PV-system size for rural households	2	kW	Own calculations
PV-system size for industrial consumers	31.5	kW	Own calculations
PV-system size for commercial consumers	5.5	kW	Own calculations
Brazil electricity demand growth	3.9	%/year	(EPE, 2014a)
Growth rate of households	1.8	%/year	(EPE, 2014b)

Inputs (4/4)

Solar cost information

Parameter	Value		Source
Cost of the system installed residential	5900	R$/kW	(EPE, 2012)
Cost of the system installed industrial	4625	R$/kW	
Cost of the system installed commercial	5392	R$/kW	
Lifetime	20	years	
Learning rate solar PV	18	%	
Discount rate for household	6	%	(Holdermann et al., 2014)
Discount rate for industrial and commercial	10	%	
O&M cost	0,5	%	(EPE, 2012)
Annual efficiency loss of the PV-system	0.65%	%	

Simulation model
System dynamics methodology

- An SD approach was chosen over other approaches because of its capability of modelling highly dynamic power markets, characterised by investment cycles that involve lags, nonlinearities, and feedbacks (Sterman, 2000).
- System Dynamics (SD) models provide a stylised representation of the dynamics features inherent in complex systems, such models aim to support decision process and devising strategies (Sterman, 2000)

Simulation model

PV diffusion process

1. Analyse the ratio "**Electricity tariff/PV cost**" to define population willing to adopt
2. Model PV diffusion, forming a "S"-shaped penetration curve through:
   - Bass model (rural and urban consumers)
   - Logit model (commercial and industrial consumers)

$$y'(t) = \mathrm{M} \cdot p + (q - p) \cdot \mathrm{N}(t) - \frac{q}{m} \cdot [\mathrm{N}(t)]^2$$

$y'(t)$ *Adoption rate [households/year]*
M *Potential adopters [households]*
N *Potential adopters [households]*
p *Advertising effectiveness*
q *Word of mouth*

Bass model

$$M(t) = \frac{1}{1 + e^{-c(t-t_h)}},$$

where

$M(t)$	is the fraction of market penetration at time t,
t	is the time indexed in years,
t_h	is the time at which half of the market is penetrated, and
c	is the parameter determining the rate of penetration.

Logit model

Simulation model

Feedback between PV adoption and tariffs

1. Energy consumption is calculated (Monthly average energy consumption minus PV self-generation) for following customers:

   -Urban residential

   -Rural residential

   -Commercial (low voltage)

   -Industrial (low voltage)

2. Distribution tariff is recalculated according to future energy consumption, network costs are spread over a shrinking sales base. More PV adoption…less energy consumption and so on….

$$Distribution\ tariff = \frac{Network\ cost}{Energy\ consumption}$$

Simulation model

Energy cost

1. Energy contracts are categorised according to technology: hydro, thermal, others and bilateral

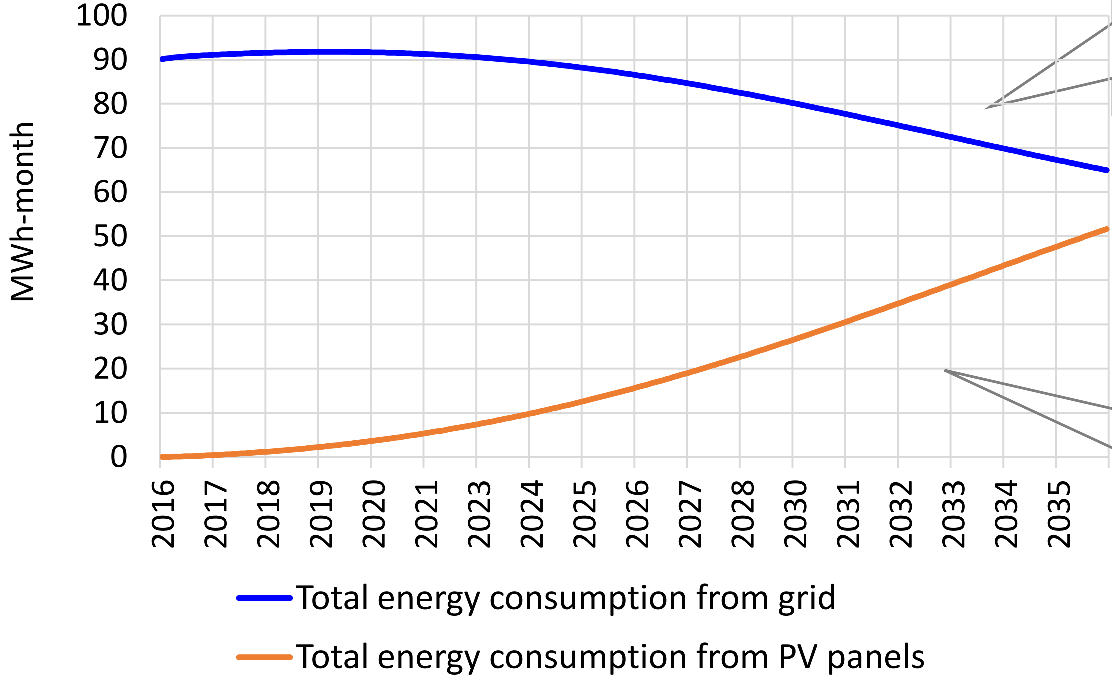
2. Energy price is calculated as a weighted average

3. Energy contracts grow each year pursuant to energy shortage. Energy portfolio remains.

4. Energy contracts decrease according to the expiration date

Results

Energy consumption vs solar PV generation

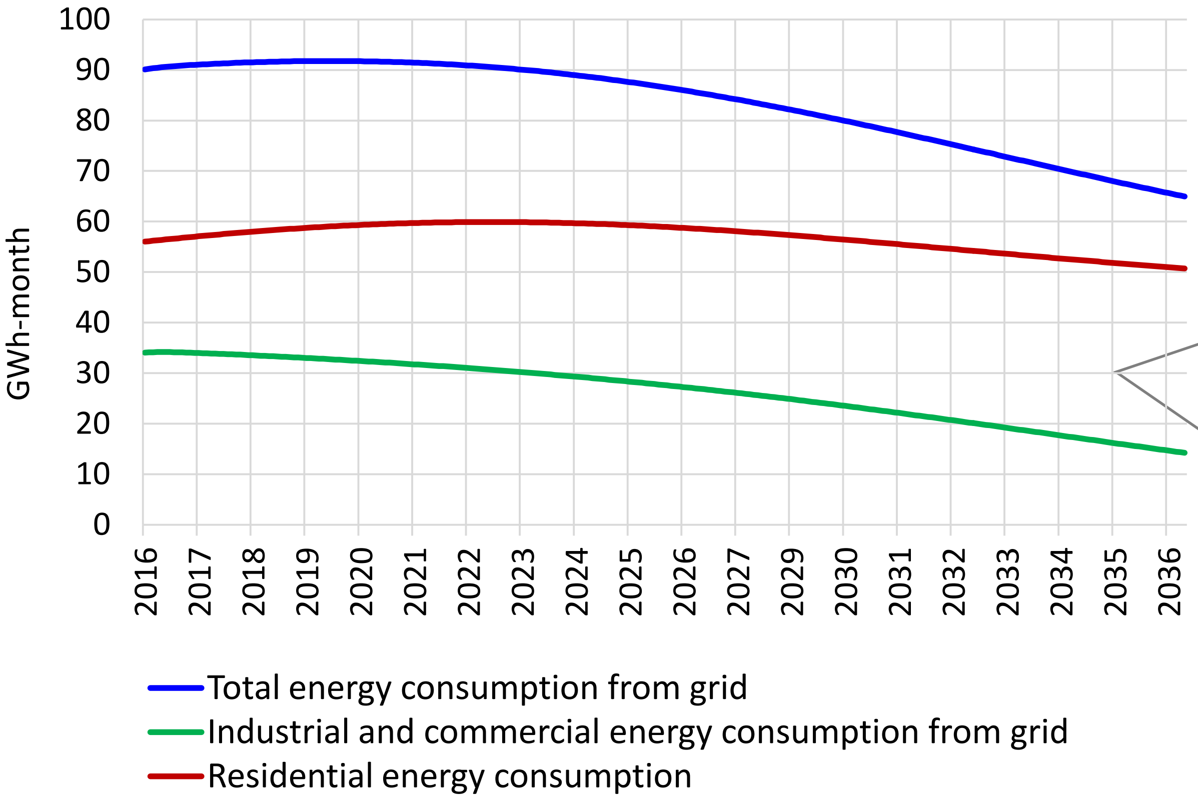


Between 2016 to 2036, energy consumption from the grid decreases at rate of **2%** per year

By 2036, energy consumption from solar PV panels represents **79%** of the energy consumption from grid

Results

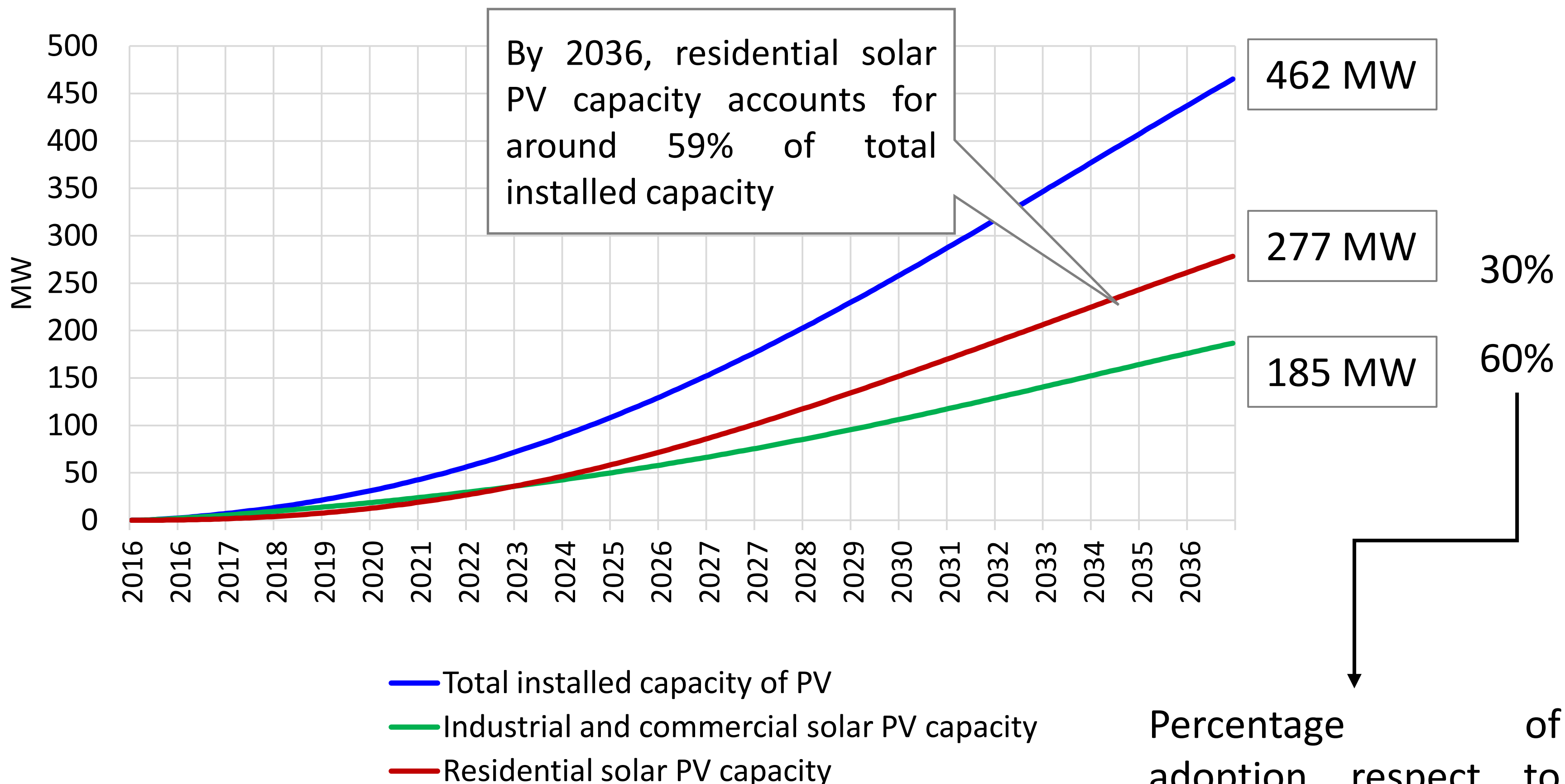
Energy consumption by type



From 2016 to 2036, residential energy consumption decreases at rate of **0.5%** per year, while industrial and commercial energy consumption declines at a rate of **4%** per year

Preliminary results

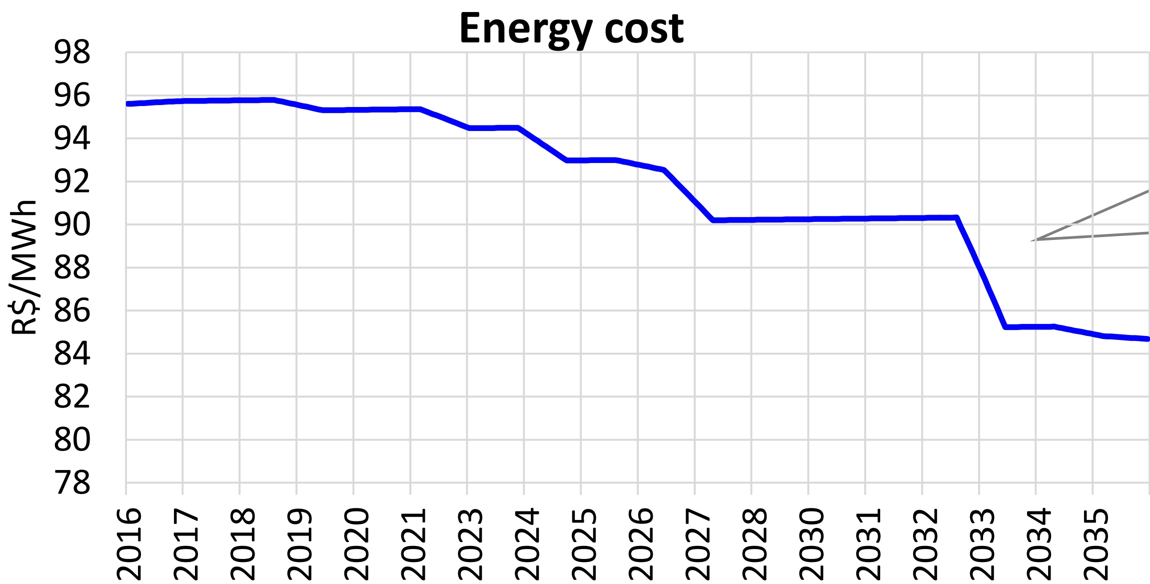
Solar PV installed capacity



Percentage of adoption respect to the total number customers

Preliminary results

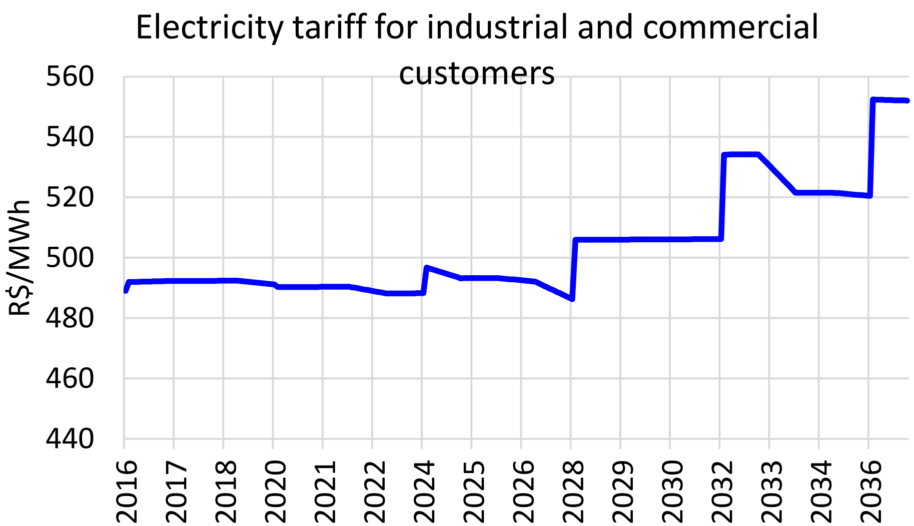
Energy cost



Between 2016 to 2036, energy tariff declined by 11% due to solar PV penetration and contract expiration

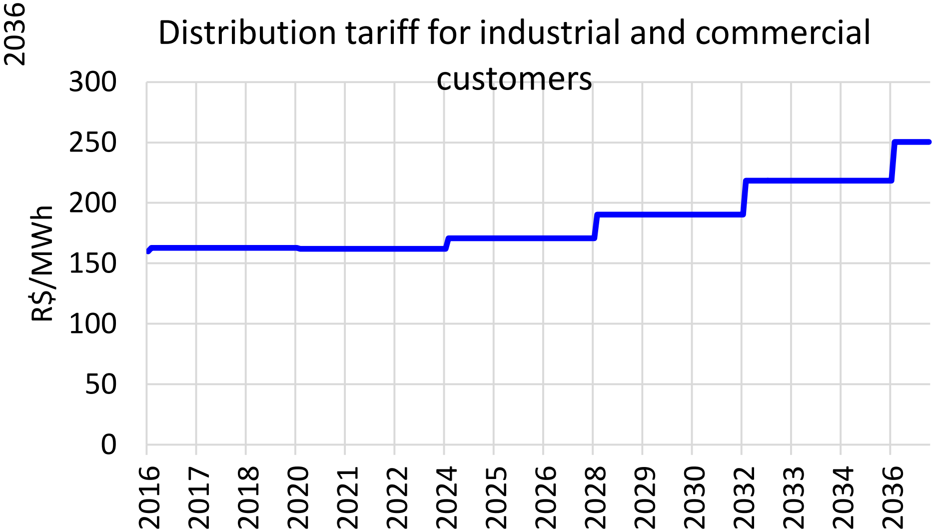
Results

Industrial and commercial tariff



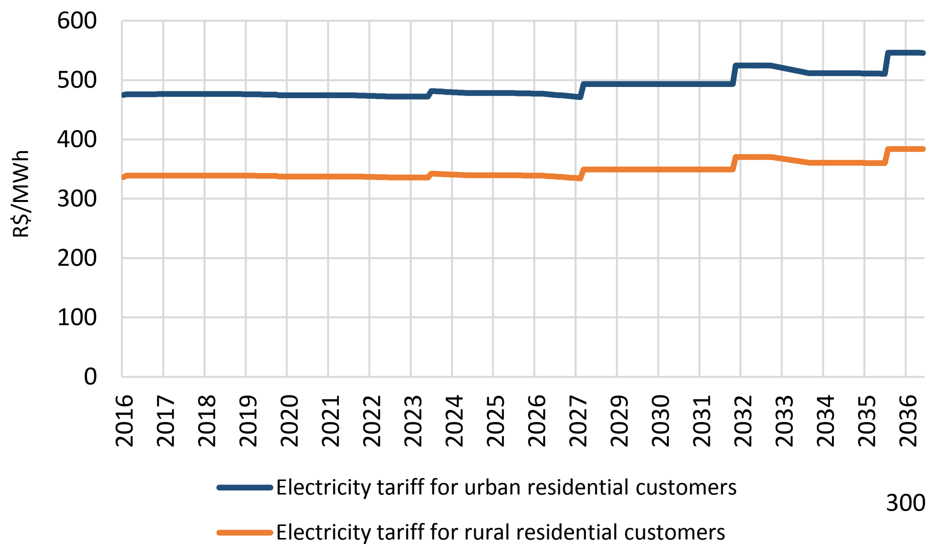
From 2016 to 2036, electricity tariff for industrial and commercial customers grows by **13%**

Between 2016 to 2036, distribution tariff for industrial and commercial customers grows by **56%**

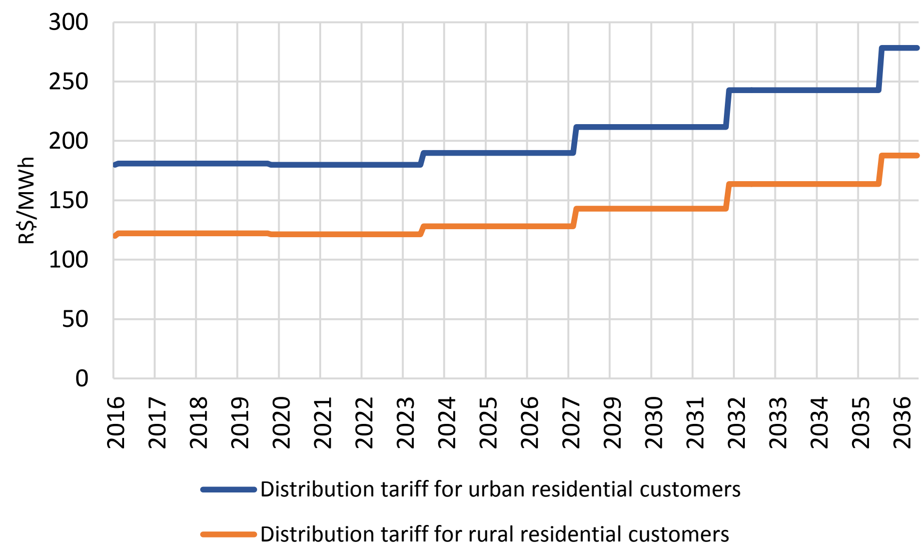


Preliminary results

Residential tariff

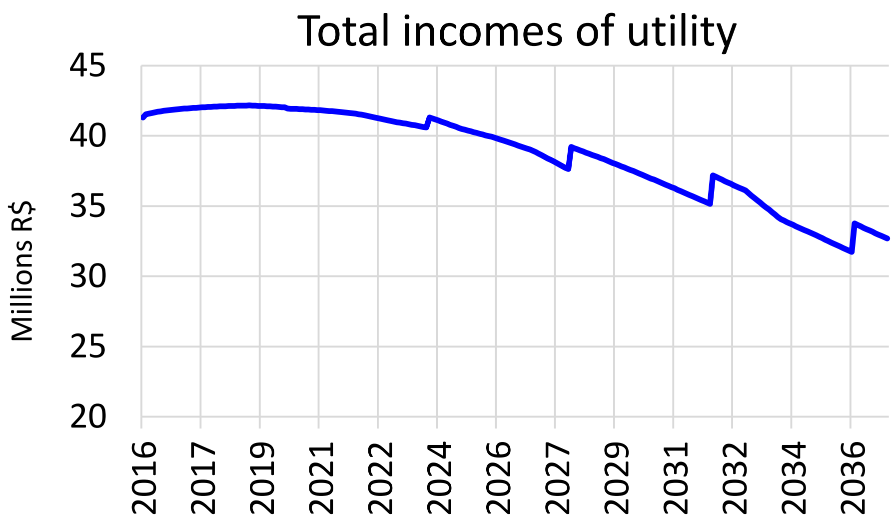


Similar behaviour, energy cost remains almost constant. Between 2016 to 2036, distribution tariff for residential customers rises **55%**



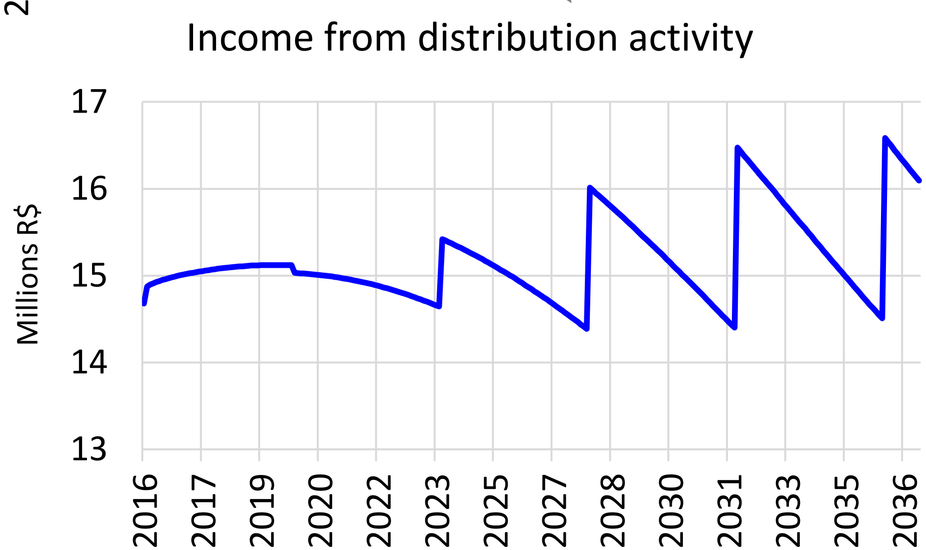
Preliminary results

Income distribution of company



Growing trend of income from distribution activity due to tariff revision each 4 years, losses of income due to PV penetration

Slightly downward trend due to energy cost reduction



Preliminary conclusions

- Distribution tariff review exacerbates death spiral effect, making distribution tariffs higher as a consequence of PV adoption and therefore lower energy consumption
- Residential sector has the highest PV adoption, though reduction in energy consumption is low
- As distribution company has energy contracts with a very long duration, energy cost is not very sensitive to high PV adoption
- A behavior sensitivity test to confirm the high sensitivity of critical variables such as: cost of solar PV, end-consumer tariff, size of PV system, and solar radiation is necessary

Some important references

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