SOLAR ENERGY DIFFUSION IN URBAN AREA:
STRUCTURAL CHANGE AND COMPLEXITY

Matheus Alexandria Sposito
matheus.alexandria@gmail.com

João Basilio Pereima
joaobasilio@ufpr.br

NeX-Nucleo of Economics and Complexity

ECLAC - Summer School
Santiago, Chile - 06/Ago/2019
<table>
<thead>
<tr>
<th>Introduction</th>
<th>Literature</th>
<th>The Model</th>
<th>Simulation</th>
<th>Concluding Remarks</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Motivation</td>
<td>• Literature</td>
<td>• Model and Code</td>
<td>• Results/simulations</td>
<td>• Discussion</td>
<td></td>
</tr>
</tbody>
</table>
MOTIVATION

Cities are in the heart of challenging!

55% of global population lives in cities

65% of global energy demand

75% of global carbon dioxide emission

**FIGURE:** Estimated Renewable Energy Share - 2017

**FIGURE 1.** Estimated Renewable Share of Total Final Energy Consumption, 2017

- **Fossil fuels**: 79.7%
- **Nuclear energy**: 2.2%
- **Traditional biomass**: 7.5%
- **Wind/solar/biomass/geothermal/ocean power**: 10.6%
- **Modern renewables**
  - **Hydropower**: 3.6%
  - **Biomass/solar/geothermal heat**: 4.2%
  - **Biofuels for transport**: 1.0%

Note: Data should not be compared with previous years because of revisions due to improved or adjusted data or methodology. Totals may not add up due to rounding.

Source: Based on OECD/IEA and IEA SHC. See endnote 54 for this chapter.

**MOTIVATION**

**Figure:** Renewable Power Shares in Selected Cities, 2017

The figure shows the shares of renewables in the electricity consumption of 340 cities that self-reported to CDP.

Note: City average is calculated based on the 340 cities shown.

Categories include all values below the lower limit of adjacent category.

Figure: Overview of Existing 100% Renewable Energy Targets in Cities, 2018

Number of 100% targets (10 year period aggregate)

- Transport
- Heating and Cooling
- Electricity

50% of cities have a 100% target for two or more sectors

119 cities (one 100% target)
119 cities (two or more 100% targets)

Note: Data included in this figure were compiled by ICLEI and The Global 100% Renewable Energy Platform with material provided by a variety of stakeholders, including CDP, CAN, C40, IRENA, Sierra Club, Renewable cities (2018); and may not be comprehensive.

**FIGURE:** The PV map: Brasil, Paraná State and Europe

Fonte: Tiepolo, 2016
Literature

- Total and Electrical Energy Demand and Efficiency: (REN21, 2019b,a)
- Innovation Diffusion: (Ryan and Gross, 1943; Rogers, 1962; Bass, 1969; Chow, 1967; Rogers, 2003)
- Social Networks (Small World): (Milgram, 1967; Travers and Milgram, 1969; Watts and Strogatz, 1998; Wasserman and Faust, 1994)
- Interdependent Utility Function: (Veblen, 1899; Granovetter, 1973, 1985; Mauss, 2003; Christakis and Fowler, 2009)
- Consumer Behaviour - Understanding the path to purchase: (Sproles and Kendall, 1986; Rogers, 2003; Shridhar, 2019)
- Agent-based models: (Dawid, 2006)
- Agent-based models of decentralized solar power generation: Zhao et al. (2011); Palmer et al. (2015); Robinson et al. (2013)
Efficiency and Conservation

- In 2018, the IPCC presented several pathways for mitigating climate change and reduce average temperature by 1.5°C Celsius above pre-industrial levels.
- The major recommendations are based at reducing global energy demand.
- Reducing energy demand requires advances in both
  - energy efficiency (technology-specific) and
  - energy conservation (behaviour-specific).

The three main determinants of total final energy demand

- Sectoral structural changes within economies
- Changes in the level of activity in each economic sector (economic growth)
- Changes in the efficiency of energy use in each sector
**ELECTRICITY CONSUMPTION**

**Figure:** Average Electricity Consumption per Electrified Household, Selected Regions and World, 2012 and 2017

Note: CIS = Commonwealth of Independent States.

Source: Enerdata. See endnote 71 for this chapter.

Ryan and Gross (1943); Rogers (1962); Bass (1969); Chow (1967); Rogers (2003)

**FIGURE**: Bass Diffusion Curve

![Bass Diffusion Curve](image_url)

Source: Bass (1969)
# Consumer Behaviour and the Path to Purchase

<table>
<thead>
<tr>
<th>Type</th>
<th>% Pop</th>
<th>Female</th>
<th>Dictum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impulsive Spender</td>
<td>15%</td>
<td>55%</td>
<td>“I love finding bargains”</td>
</tr>
<tr>
<td>Conservative Homebody</td>
<td>13%</td>
<td>51%</td>
<td>“Family matters most to me”</td>
</tr>
<tr>
<td>Minimalist Seeker</td>
<td>12%</td>
<td>55%</td>
<td>“I choose to focus on the simpler”</td>
</tr>
<tr>
<td>Secure Traditionalist</td>
<td>12%</td>
<td>52%</td>
<td>“I am content with where I am in life”</td>
</tr>
<tr>
<td>Undaunted Striver</td>
<td>10%</td>
<td>56%</td>
<td>“I want to have and be the best”</td>
</tr>
<tr>
<td>Empowered Activist</td>
<td>9%</td>
<td>51%</td>
<td>“I believe I have the power to affect change”</td>
</tr>
<tr>
<td>Inspired Adventurer</td>
<td>8%</td>
<td>53%</td>
<td>“I strive to get more out of life”</td>
</tr>
<tr>
<td>Digital Enthusiast</td>
<td>6%</td>
<td>54%</td>
<td>“I incorporate technology in all areas of my life”</td>
</tr>
<tr>
<td>Balanced Optimist</td>
<td>5%</td>
<td>51%</td>
<td>“I am confident in myself and the future”</td>
</tr>
<tr>
<td>Cautious Planner</td>
<td>4%</td>
<td>51%</td>
<td>“I know what I want in life”</td>
</tr>
</tbody>
</table>

AGENT-BASED MODELS OF PV ENERGY

- Zhao et al. (2011) (USA)
- Palmer et al. (2015) (Itália)
- Robinson et al. (2013) (USA)
**Dynamics**

- Temporal dynamics: hourly, monthly and annual accounting
- Spatial dynamics: diffusion by residence and neighbourhood within a city
- Climatic layer: solar radiation by hourly and monthly average
- Electrical network IEE 33 bar system
- Social Network tying heterogeneous households
<table>
<thead>
<tr>
<th>ALGORITHMS</th>
</tr>
</thead>
</table>

- Netlogo for main algorithm
- Matlab and Newton-Raphson method for stabilize the electrical network *(Eltamaly et al., 2018)*
- R for analysis
The timeline considers hourly computation of consumed and produced energy.

1 day - 24 hours
1 month - 30 x 1 representative day (all days are equal within a month)
Total computation = 24 x 120 = 2880 steps (as ticks in Netlogo language)

**Figure**: Hourly, monthly and annual computation
### Urban Topology

1. 32 neighbourhoods
2. 120 residences in each neighbourhood
3. 3840 residences in total
4. 1 electrical node (transformer) in each neighbourhood

<table>
<thead>
<tr>
<th></th>
<th>4</th>
<th>8</th>
<th>12</th>
<th>16</th>
<th>20</th>
<th>24</th>
<th>28</th>
<th>32</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>7</td>
<td>11</td>
<td>15</td>
<td>19</td>
<td>23</td>
<td>27</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>10</td>
<td>14</td>
<td>18</td>
<td>22</td>
<td>26</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>9</td>
<td>13</td>
<td>17</td>
<td>21</td>
<td>25</td>
<td>29</td>
<td></td>
</tr>
</tbody>
</table>
Figure: Hypothetical Topology - actual version
The PV panel production depends on the temperature and radiation:

\[ T_{h,t} = \bar{T}_{h,t} + e_{h,t}^1 \quad \text{onde} \quad e_{h,t}^1 N \sim (0, \sigma_{h,t}^1) \] (1)

\[ R_{h,t} = \bar{R}_{h,t} + e_{h,t}^2 \quad \text{onde} \quad e_{h,t}^2 N \sim (0, \sigma_{h,t}^2) \] (2)

where \( h = \{1, \ldots, 24\} \) is the hour of a day and \( t = \{1, \ldots, 12\} \) is the month.
**Figure:** 5 year average, Curitiba, Brazil
IEEE 33 bar system:

**Figure:** IEEE 33 Barras

An adjacent matrix can be easily set to represent any real case.

\[
\begin{bmatrix}
0 & 1 & 0 & 0 & \ldots \\
0 & 1 & 0 & 0 & \ldots \\
0 & 0 & 1 & 1 & \ldots \\
0 & 0 & 0 & 1 & \ldots \\
\vdots & \vdots & \vdots & \vdots & \ddots
\end{bmatrix}
\]
It’s common to use **Feed-in tariffs** for solar energy sellers.

Feed-in tariffs (FIT) are fixed electricity prices that are paid to renewable energy (RE) producers for each unit of energy produced and injected into the electricity grid. The payment of the FIT is guaranteed for a certain period of time that is often related to the economic lifetime of the respective RE project (usually between 15-25 years). Another possibility is to calculate a fixed maximum amount of full-load hours of RE electricity production for which the FIT will be paid. FIT are usually paid by electricity grid, system or market operators, often in the context of Power purchasing agreements (PPA).

Source: [https://energypedia.info/wiki/Feed-in_Tariffs_(FIT)](https://energypedia.info/wiki/Feed-in_Tariffs_(FIT))
Two prices: for buying and selling energy.

\[ P_{i,h,t}^G = \beta_1 + \beta_2 P_{i,h,t}^C \]  

(3)

G - for “generated” energy set in kWh  
C - for “consumption”

When \( \beta_1 = 0 \) and \( \beta_2 = 1 \),

\[ P_{i,h,t}^G = P_{i,h,t}^C \]  

(Brazilian case currently)
The price paid by a household before taxes is set by computing the following equation:

\[
P_{i,h,t}^C = P_{i,h,0}^C(Y_i, \bar{C}_i^{mes}, S) \left[ 1 - \beta_0 \left( \frac{F^{tec}_{ano-1}}{F} \right) \right]
\]  

(4)

**TABLE:** Energy Price in Brazil, Paraná, kWh

<table>
<thead>
<tr>
<th>Tariff Regime (S)</th>
<th>R$/kWh\textsuperscript{[1]}</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Common Tariff (S = 1)</strong></td>
<td></td>
</tr>
<tr>
<td>Baseline Tariff</td>
<td>0.50752</td>
</tr>
<tr>
<td>Low Income\textsuperscript{[2]}-Consumption ≤30 kWh</td>
<td>0.16188</td>
</tr>
<tr>
<td>Low Income-Consumption between 31 kWh e 100 kWh</td>
<td>0.27750</td>
</tr>
<tr>
<td>Low Income-Consumption between 101 kWh e 220 kWh</td>
<td>0.41625</td>
</tr>
<tr>
<td>Low Income-Consumption (geq) 220 kWh</td>
<td>0.46250</td>
</tr>
<tr>
<td><strong>Brazilian White Tariff (S = 2)\textsuperscript{[3]}</strong></td>
<td></td>
</tr>
<tr>
<td>From 18h00 to 21h00</td>
<td>0.91974</td>
</tr>
<tr>
<td>From 17h00 to 18h00 and 21h00 to 22h00</td>
<td>0.59690</td>
</tr>
<tr>
<td>From 22h00 to 17h00</td>
<td>0.43568</td>
</tr>
</tbody>
</table>

Source: Built using data from COPEL, 2019

(1) Price without consumer taxes.
(2) Low income households less than 3 minimum wage
(3) Tariff set hourly.
Price after Taxes

\[ \hat{P}_{i,h,t}^C = P_{i,h,t}^C M^{tr} \] (5)

\[ M^{tr} = \left( \frac{1}{1 - pis} \right) \left( \frac{1}{1 - cofins} \right) \left( \frac{1}{1 - icms} \right) \] (6)

**Table**: Taxes Rate

<table>
<thead>
<tr>
<th>Tax</th>
<th>Rate</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICMS</td>
<td>30%</td>
<td>1,42857</td>
</tr>
<tr>
<td>PIS</td>
<td>0,95%</td>
<td>1,00959</td>
</tr>
<tr>
<td>COFINS</td>
<td>4,45%</td>
<td>1,04657</td>
</tr>
</tbody>
</table>

Source: built using data from COPEL, 2019.
The consumption pattern of a Brazilian household depends on the income level Francisquini (2006).

**Figure:** Average charge of a household who consume less than 100 kWh/month

Source: Adapted from Francisquini (2006).

**Figure:** Average charge of a household who consume between 101 and 200 kWh/month

Source: Adapted from Francisquini (2006).
**Daily Consumption Pattern**

**Figure:** Average charge of a household who consume between 201 e 300 kWh/mês

Source: Adapted from Francisquini (2006).

**Figure:** Average charge of a household who consume between 301 a 500 kWh/mês

Source: Adapted from Francisquini (2006).
**FIGURE:** Average charge of a household who consume between 500 que kWh/mês

Source: Adapted from *Francisquini (2006).*
**INCOME LEVEL AND DISTRIBUTION**

**Table:** Household income level

<table>
<thead>
<tr>
<th>Income Class- R$</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 18.740</td>
<td>A</td>
</tr>
<tr>
<td>9.370 - 18.740</td>
<td>B</td>
</tr>
<tr>
<td>3.748 - 9.370</td>
<td>C</td>
</tr>
<tr>
<td>1.874 - 3.748</td>
<td>D</td>
</tr>
<tr>
<td>0 - 1.874</td>
<td>E</td>
</tr>
</tbody>
</table>

Source: IBGE-Brazilian Institute of Geography and Statistics.
Based on Brazilian rules (ANEEL nº 482/2012):

- Micro producers can not have financial return by selling energy
- The value of production must be monthly compensated by the value of consumption
- If eventually production is higher than consumption, a household can accumulate credit for next 12 months

The monetary amount of new capital adopted by a household \( i \) in month \( t \) \( (K_{i,t}) \) is:

\[
K_{i,t} = \frac{12 \sum_{h=1}^{24} (\bar{C}_{h,i,t} P_{i,t}^{G})}{\sum_{t=1}^{12} \sum_{h=1}^{24} (\Omega_{h,t} P_{i,h,t}^{G})}
\]  

(7)

where:

\[
\Omega_{h,t} = \frac{\bar{R}_{h,t}}{1000W} [1 - 0.0045(\bar{T}_{h,t} + 15)]
\]  

(8)

Trick theory: the consumer becomes also a producer!
INVESTMENT BY HOUSEHOLDS: HOW MUCH POWER TO CREATE

Based on Brazilian rules (ANEEL n° 482/2012):

- Micro producers can not have financial return by selling energy (Amazing rule!!)
- The value of production must be monthly compensated by the value of consumption
- If eventually production is higher then consumption, a household can accumulate credit for next 12 months

The monetary amount of new capital adopted by a household $i$ in month $t$ ($K_{i,t}$) is:

$$K_{i,t} = \frac{12 \sum_{h=1}^{24} (\bar{C}_{h,i,t} P_{i,t})}{\sum_{t=1}^{12} \sum_{h=1}^{24} (\Omega_{h,t} P_{i,h,t})}$$

(9)

where:

$$\Omega_{h,t} = \frac{\bar{R}_{h,t}}{1000W} [1 - 0.0045(\bar{T}_{h,t} + 15)]$$

(10)

Trick theory: the consumer becomes also a producer!
Each month a household take into account a bunch of internal and external factors (variables):

$$D_{i,t} = \alpha_1 \mathcal{F}_1(ROI_{i,t}) + \alpha_2 \mathcal{F}_2(Links_{i,t}) + \alpha_3 \mathcal{F}_3(Y_i) + \alpha_4 \mathcal{F}_4(Profile_i)$$ (11)

where $D_{t,i}$ is linear combination of other four functions which depends on the both: ROI, return of investment rate, social network (Links), income (Y) and individual profile towards technology (Profile), following Rogers (2003) typology. The parameters $\alpha_1...4$ represents the weight of each function. The functions $\mathcal{F}_1...4$ and its functional form will be defined later.
The probability of a household adopt a PV plant and became a producer is, therefore:

\[ P(D)_{i,t} = \frac{2}{1 + e^{-\theta_0 D_{i,t}}} - 1 \]  

which follow a logistic curve. Parameters \( \theta_0 \) and \( \theta_1 \) can be set to shape de S curve.

Such probability is then compared to a uniform random number \( U_{i,t} \)

\[ f(n)_{i,t} = \begin{cases} 0, & \text{se } P(e)_{i,t} \leq U_{m,i}^1 \\ 1, & \text{se } P(e)_{i,t} > U_{m,i}^1 \end{cases} \]

and

\[ K_{i,t}^e = f(n)_{i,t} K_{i,t} \]

where, \( K_{i,t}^e \) is the effective installed capacity of household \( i \) in time \( t \).

The installed capacity cost (investment) is:

\[ P^K_{i,t} = (1 - \phi)(\beta_3 + \beta_4 K_{i,t}^e) \]

where \( \phi \) is a subsidy rate and \( \beta_3 \) and \( \beta_4 \) are price parameters of PV panels in kWh.
**Baseline parameters**

**Table**: Parameters of the baseline simulation

<table>
<thead>
<tr>
<th>Description</th>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of the City</td>
<td></td>
<td>$88 \times 44$</td>
</tr>
<tr>
<td>Number of households</td>
<td>$F$</td>
<td>3840</td>
</tr>
<tr>
<td>Number of neighbourhoods</td>
<td>$N$</td>
<td>32</td>
</tr>
<tr>
<td>Parameters for buying price</td>
<td>$\beta_0$</td>
<td>0.70</td>
</tr>
<tr>
<td>Weight of ROI</td>
<td>$\alpha_1$</td>
<td>0.175</td>
</tr>
<tr>
<td>Weight of Social links</td>
<td>$\alpha_2$</td>
<td>0.400</td>
</tr>
<tr>
<td>Weight of income</td>
<td>$\alpha_3$</td>
<td>0.150</td>
</tr>
<tr>
<td>Weight of Consumer Profile</td>
<td>$\alpha_4$</td>
<td>0.150</td>
</tr>
<tr>
<td>Social Network Density</td>
<td>$\gamma_{1,2}$</td>
<td>0.40, 3.0</td>
</tr>
<tr>
<td>Parameter of Logistic Curve and ROI</td>
<td>$\gamma_{3,4,5}$</td>
<td>15, 2, 0.05</td>
</tr>
<tr>
<td>Tariff Regime</td>
<td>$S$</td>
<td>Common (1)</td>
</tr>
<tr>
<td>Subsidy</td>
<td>$\phi$</td>
<td>0</td>
</tr>
<tr>
<td>Parameters for sale price</td>
<td>$\beta_{1,2}$</td>
<td>0/1</td>
</tr>
<tr>
<td>Price of PV panels</td>
<td>$\beta_{3,4}$</td>
<td>4256.09/4537.69</td>
</tr>
<tr>
<td>Interest Rate</td>
<td>$r$</td>
<td>0.05</td>
</tr>
<tr>
<td>Households Profile</td>
<td></td>
<td>Rogers</td>
</tr>
</tbody>
</table>
**Baseline Parameters**

**Table**: Neighbourhood, Income Distribution and Electric Network

<table>
<thead>
<tr>
<th>Neighbourhood</th>
<th>Social Class</th>
<th>IEEE 33 bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/02/03/04</td>
<td>A</td>
<td>02/02/04/05</td>
</tr>
<tr>
<td>05/06/07/08</td>
<td>B</td>
<td>06/07/08/09</td>
</tr>
<tr>
<td>09/10/11/12</td>
<td>C</td>
<td>10/11/12/13</td>
</tr>
<tr>
<td>13/14/15/16</td>
<td>C</td>
<td>14/15/16/17</td>
</tr>
<tr>
<td>17/18/19/20</td>
<td>C</td>
<td>18/19/20/21</td>
</tr>
<tr>
<td>21/22/23/24</td>
<td>C</td>
<td>22/23/24/25</td>
</tr>
<tr>
<td>25/26/27/28</td>
<td>D</td>
<td>26/27/28/29</td>
</tr>
<tr>
<td>29/20/31/32</td>
<td>E</td>
<td>30/31/32/33</td>
</tr>
</tbody>
</table>
All the results are average values of 100 simulations.

**Figure:** Number of Adopters

**Figure:** Adopters by Social Class
SIMULATION RESULTS

**Figure**: Installed Capacity

**Figure**: Charge and Production
FIGURE: Charge and Production at a representative day
**Simulation Results**

**Figure:** Total Maximum System Voltage

**Figure:** Total Minimum System Voltage

**Figure:** Waste Power
Some Sensibility Analysis

**Figure:** Average Effect of Social Links - Social Network Density
**Some Sensibility Analysis**

**Figure:** Percent of Adopters by Social Network Density (Social Links)

**Figure:** Installed Capacity by Social Network Density (Social Links)

**Figure:** Total Investment by Social Network Density (Social Links)
**Some Sensibility Analysis**

**Table: Different Behaviour/Profiles**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rogers</td>
<td>2.5%</td>
<td>13.5%</td>
<td>34%</td>
<td>34%</td>
<td>16%</td>
</tr>
<tr>
<td>Innovative</td>
<td>25%</td>
<td>30%</td>
<td>25%</td>
<td>15%</td>
<td>5%</td>
</tr>
<tr>
<td>Neutral</td>
<td>10%</td>
<td>25%</td>
<td>30%</td>
<td>25%</td>
<td>10%</td>
</tr>
<tr>
<td>Conservative</td>
<td>5%</td>
<td>15%</td>
<td>25%</td>
<td>30%</td>
<td>25%</td>
</tr>
<tr>
<td>Homogeneous</td>
<td>20%</td>
<td>20%</td>
<td>20%</td>
<td>20%</td>
<td>20%</td>
</tr>
</tbody>
</table>

(1) Innovators  
(2) Early Adopters  
(3) Early Majority  
(4) Late Majority  
(5) Laggards

**Figure: Percent of Adopters to Different Profiles**
**Some Sensibility Analysis**

**Figure:** The effect of $\beta_0$ in the final number of adopters

**Figure:** The effect of $\beta_0$ in the Installed Capacity
### SOME SENSIBILITY ANALYSIS

**Table**: Income Distribution and Electric Network by Neighbourhood

<table>
<thead>
<tr>
<th>Neighbourhood</th>
<th>Social Class</th>
<th>IEEE33 bars</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/02/03/04</td>
<td>A</td>
<td>18/22/33/25</td>
</tr>
<tr>
<td>05/06/07/08</td>
<td>B</td>
<td>17/21/32/24</td>
</tr>
<tr>
<td>09/10/11/12</td>
<td>C</td>
<td>10/11/12/13</td>
</tr>
<tr>
<td>13/14/15/16</td>
<td>C</td>
<td>14/15/16/06</td>
</tr>
<tr>
<td>17/18/19/20</td>
<td>C</td>
<td>02/19/20/07</td>
</tr>
<tr>
<td>21/22/23/24</td>
<td>C</td>
<td>03/23/09/05</td>
</tr>
<tr>
<td>25/26/27/28</td>
<td>D</td>
<td>26/27/28/29</td>
</tr>
<tr>
<td>29/20/31/32</td>
<td>E</td>
<td>30/31/08/04</td>
</tr>
</tbody>
</table>
**Some Sensibility Analysis**

**Figure:** Total Maximum Voltage in the Reconfigured System

**Figure:** Total Minimum Voltage in the Reconfigured System

**Figure:** Waste in the Reconfigured System
**Some Sensibility Analysis**

**Figure:** Percent of Adopters by Interest Rate

**Figure:** Final Adopters by Interest Rate

**Figure:** Final Adopters, Class A, by Interest Rate

**Figure:** Final Adopters, Class B, by Interest Rate
**SOME SENSIBILITY ANALYSIS**

**FIGURE:** Final Adopters, Class C by Interest Rate

**FIGURE:** Final Adopters, Class D by Interest Rate

**FIGURE:** Final Adopters, Class D by Interest Rate

**FIGURE:** Final Adopters, Class D by Interest Rate
**Some Sensibility Analysis**

**Figure:** Percent of Adopters by ICMS Tax Rate (over consumption)

![Figure 1: Percent of Adopters by ICMS Tax Rate](image)

**Figure:** Final Adopters by ICMS Tax Rate

![Figure 2: Final Adopters by ICMS Tax Rate](image)
**Some Sensibility Analysis**

**Figure:** Percent of Adopters by Subsidy Rate

![Figure: Percent of Adopters by Subsidy Rate](image)

**Figure:** Final Adopters by Subsidy Rate

![Figure: Final Adopters by Subsidy Rate](image)

**Figure:** Final Adopters, Classe A by Subsidy Rate

![Figure: Final Adopters, Classe A by Subsidy Rate](image)

**Figure:** Final Adopters, Classe B by Subsidy Rate

![Figure: Final Adopters, Classe B by Subsidy Rate](image)
SOME SENSIBILITY ANALYSIS

**Figure:** Final Adopters, Classe C by Subsidy Rate

**Figure:** Final Adopters, Classe D by Subsidy Rate

**Figure:** Final Adopters, Classe D by Subsidy Rate

**Figure:** Final Adopters, Classe D by Subsidy Rate
Some Sensibility Analysis

**Figure:** Percent of Adopters by Sale Price ($P^G$)

**Figure:** Final Adopters by Sale Price ($P^G$)

**Figure:** Total Installed Capacity by Sale Price ($P^G$)
**Some Sensibility Analysis**

**Figure:** Percent of Adopters by Power Tariff (Price for buying)

![Percent of Adopters by Power Tariff](image)

**Figure:** Installed Capacity by Power Tariff (Price for buying)

![Installed Capacity by Power Tariff](image)

**Figure:** Household Investment by Power Tariff (Price for buying)

![Household Investment by Power Tariff](image)
• Class A and B will be the only benefited in the current Brazilian framework. It is an income concentrator model
• Cities can be self sufficient during the day, even surplus, for residential consumption
• Decentralized power generation can be a drive for reducing demand over fossil fuels
• This is a basic model, which can be expanded in many directions:
  • Inter-temporal credit mechanism to household
  • Analyse the effect of free market to sell unlimited amount of energy
  • Use real topology of Cities
  • Connect decentralised urban generation with total market of energy
  • Build a national network of self sufficient cities connecting then in a pool of cities evolving at the same time, even at different stage
  • Include labour market dynamics considering manufacturer and installers
  • Include endogenous technological change
  • Connect it with electric cars diffusion (new demand pattern)
  • Include new storage technology which can make the system more efficient
  • Explore the complexity of such system by using more encompassing agent-based model

This is a challenging and large research program. We know how to conduct it, but we need resources


Shridhar, A. (2019). Using consumer types to understand the path to purchase.


Thank you!

**NeX**-Nucleo of Economics and Complexity

Complex science for a better World