DESIGNING ELECTRIC VEHICLES CHARGING NETWORKS

NETWORK DESIGN CHALLENGES
LISBON CASE STUDY
ANGRA DO HEROÍSMO CASE STUDY
DESIGNING THE NETWORK FOR AZORES

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EV charging networks highlights

- Charging Points (CP)
  - Slow charge (230-380 V /16-32A / 3.6-7.2 kVA – 8 hours)
  - Fast charge (500V DC / 200 A – 20 minutes)
- Europe
  - London, Oslo, Paris, Helsinki, Frankfurt, Lisbon, Amsterdam
  - EV charging network is designed for:
    - Daylight parking (in the evening cars will charge at “home”)
    - 5-10% in street parking / 90-95% parking garages
    - Autonomy anxiety control

EV network design challenges

- **Most charging will be made at home**
  - Upgrading infrastructure / power reinforcement
- Public network
  - Anxiety control
    - Visible places (main streets, shopping malls)
  - Long distance drivers (taxi drivers, tourists)
    - Public parking places
    - Touristic places
      - Integrated service with parking
  - Commuters recharge (S. Miguel)
    - Work place
    - *Fast charging*

It is all about where people park their car
- Detailed mobility patterns studies

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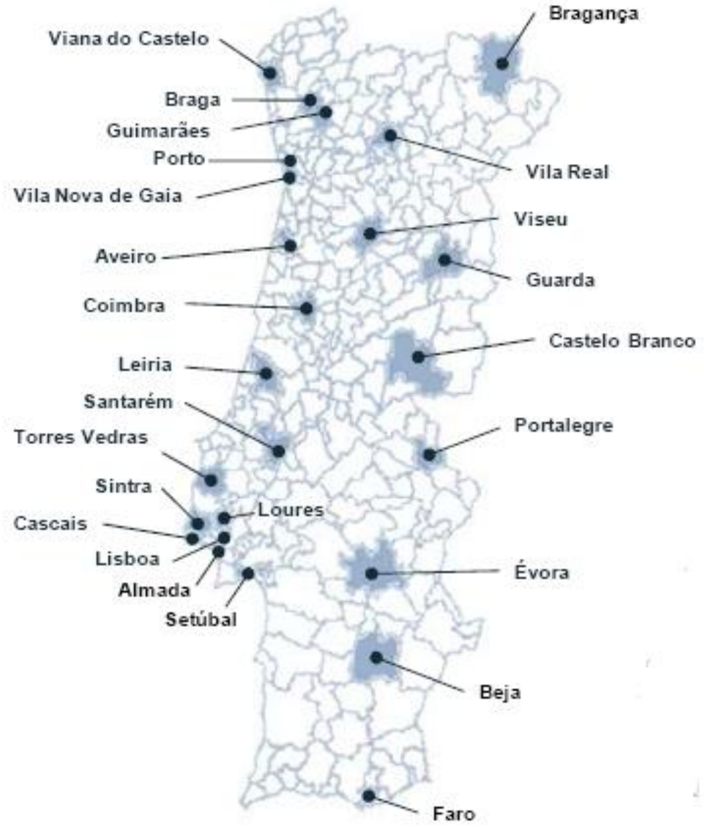
Green Islands AZORES

Early Adopters

- European studies
  - Man under 35 or above 55
  - High, middle high class
  - Higher education instruction
  - Two cars

MOBI.E Highlights

- MOBI.E
  - 1100 CP in 25 municipalities
    - 1 master+ n slaves up to 2011
      - street parking
      - public parking garages
    - Municipalities choose CP location
  - Public space electric parking
    - have to be connected to MOBI.E



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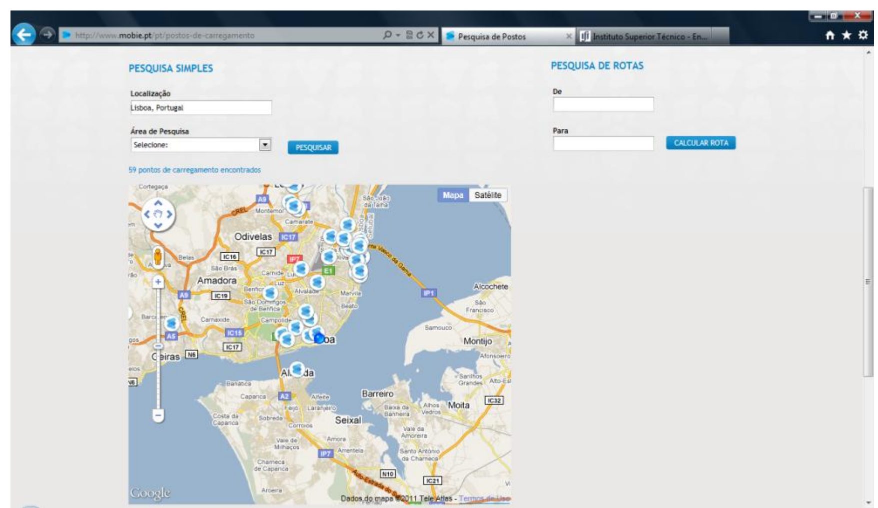
MOBI.E Charging Points



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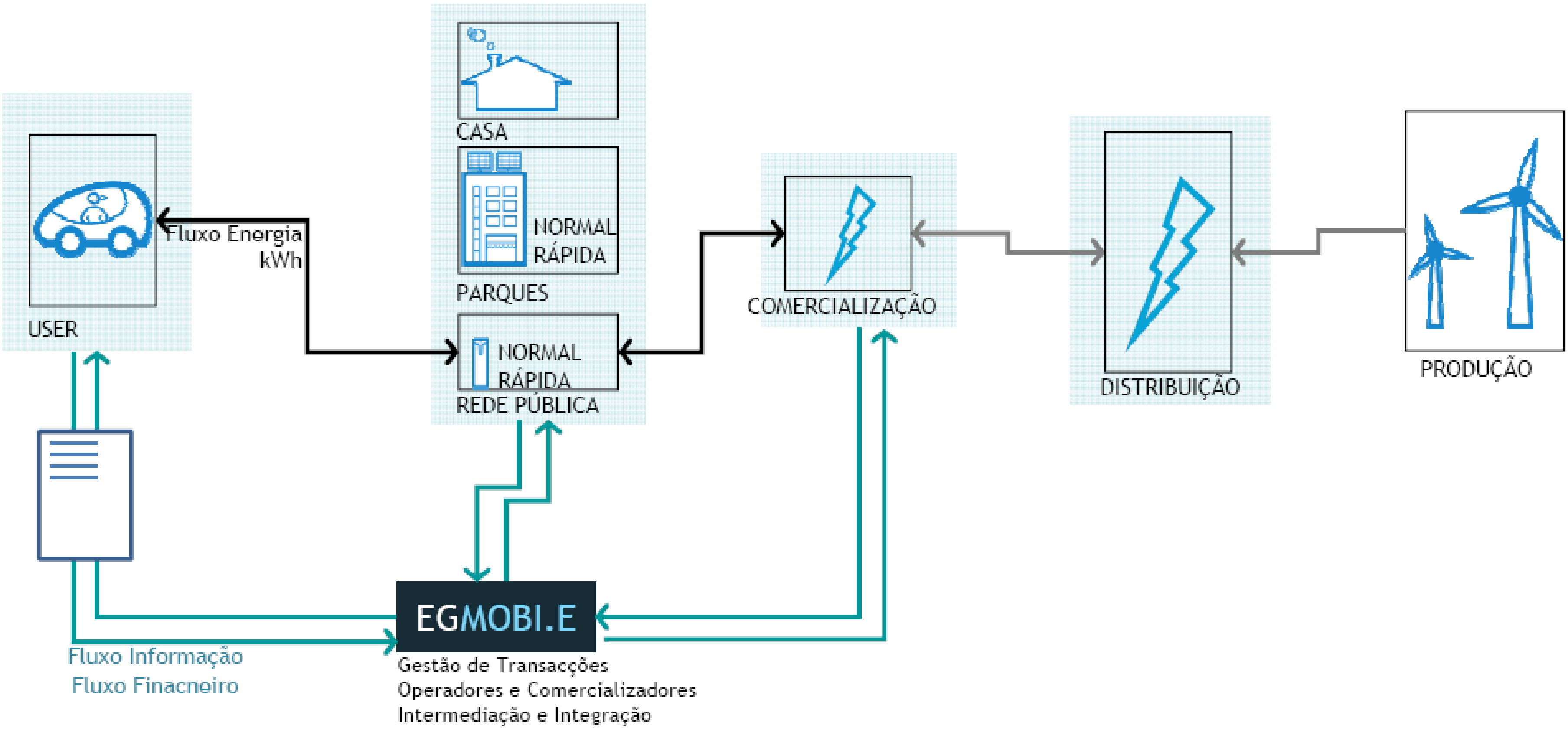
MOBI.E framework



Methodology to design EV charging network

1. Estimate EV penetration in the vehicle fleet
   – Using *MOBI.E study from Roland Berger*
   – Consider a service rate to define number of required CP
2. Characterize region/city/neighborhood
3. Define Criteria for location of CP
4. Use a decision-making algorithm
   – Multi-Atribute (PROMETHEE)

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Methodology Implementation

EV projections for region/city/neighborhood

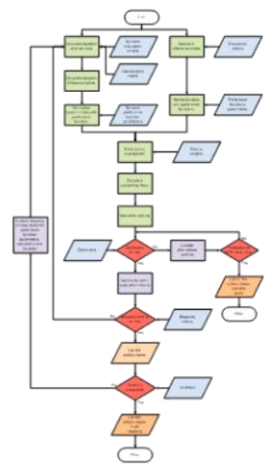
Parking characterization of Region/city/neighborhood (alternatives)

Location Criteria (Decision makers)

Decision-aid tool

For each year (2010 - …):

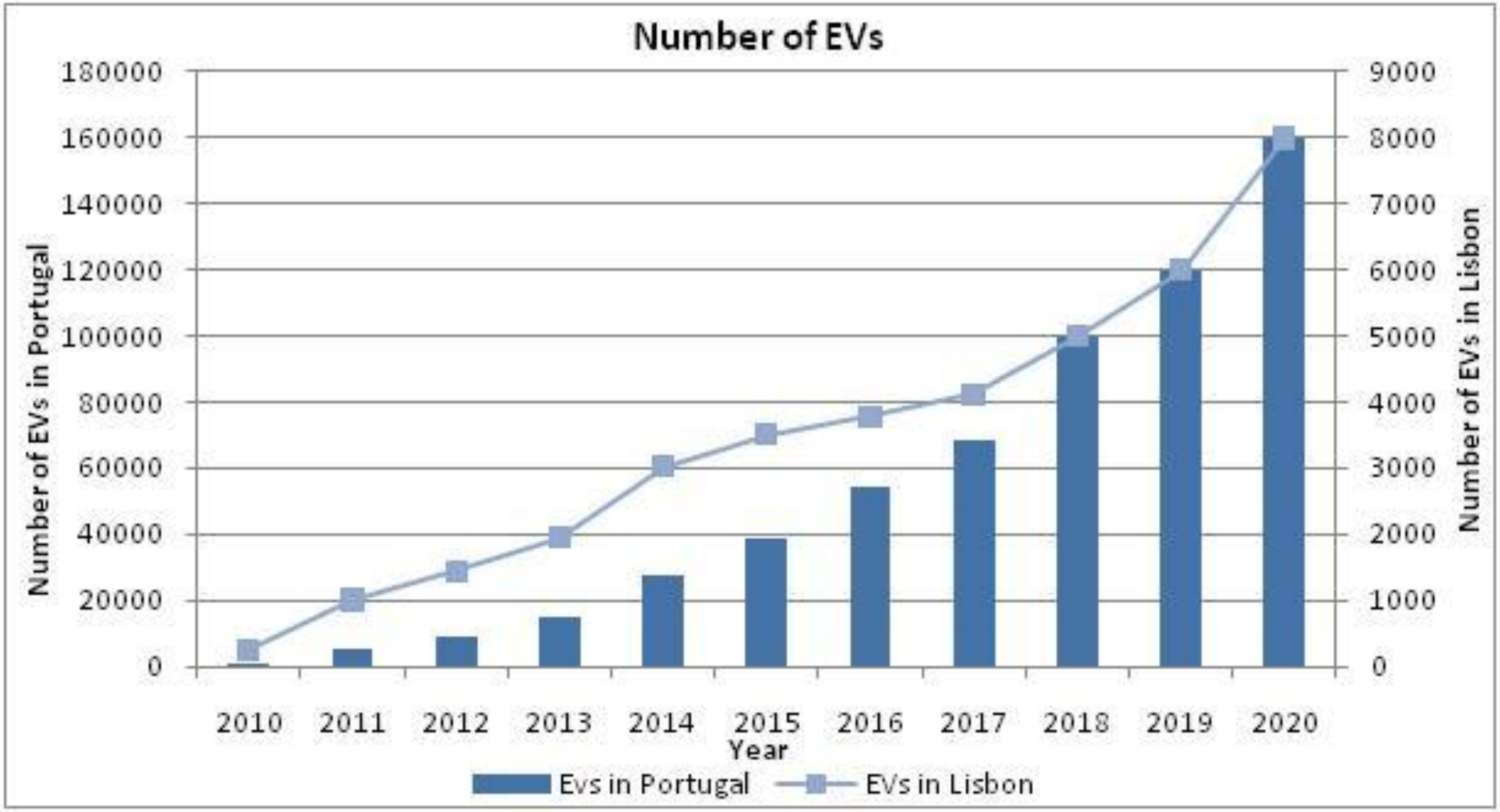
1. Evaluate alternatives
2. Compare alternatives
3. Alocate CP to alternatives



Final CP allocation (alternatives)

LISBON

1 - EV Projections assumptions



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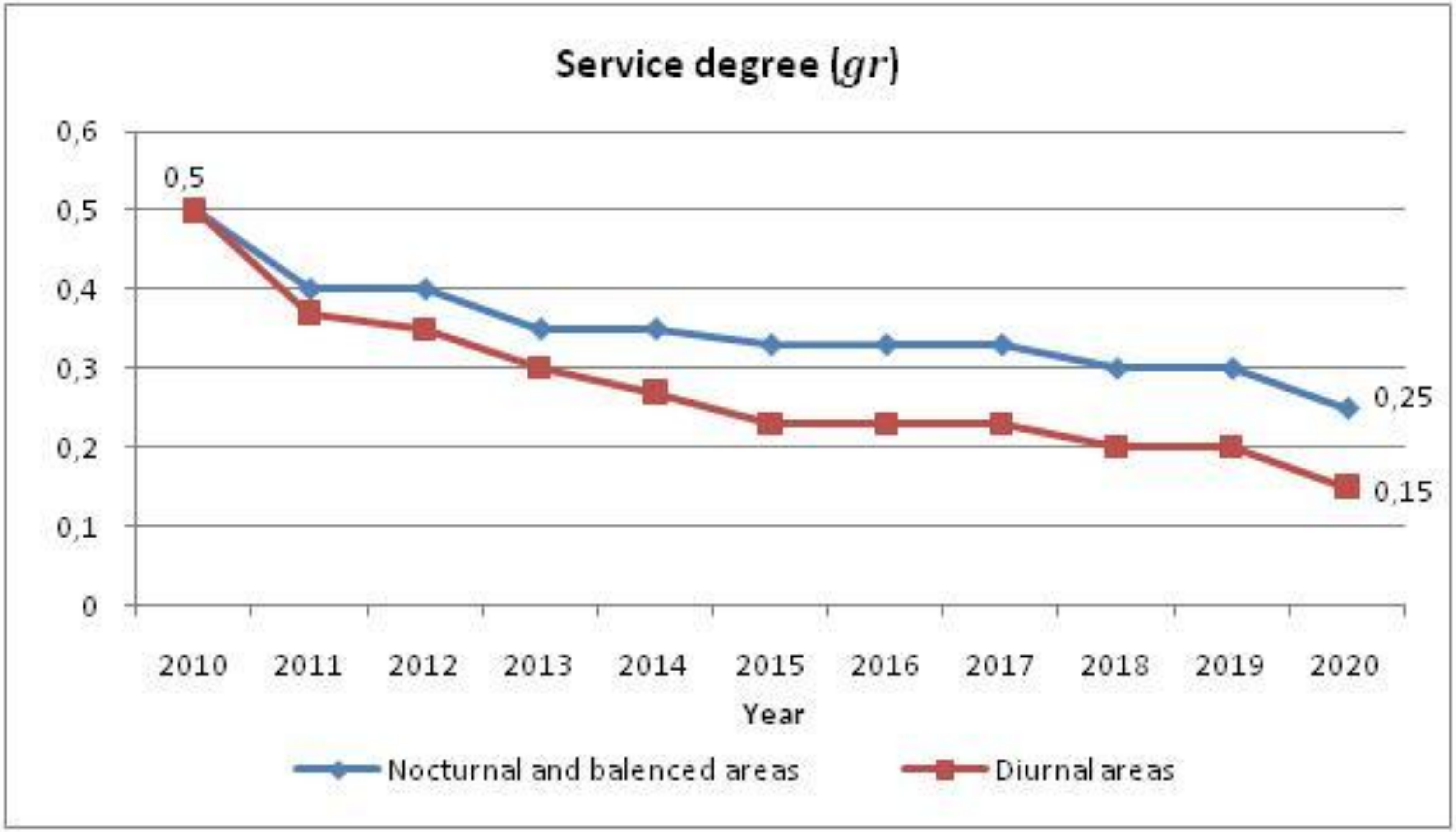
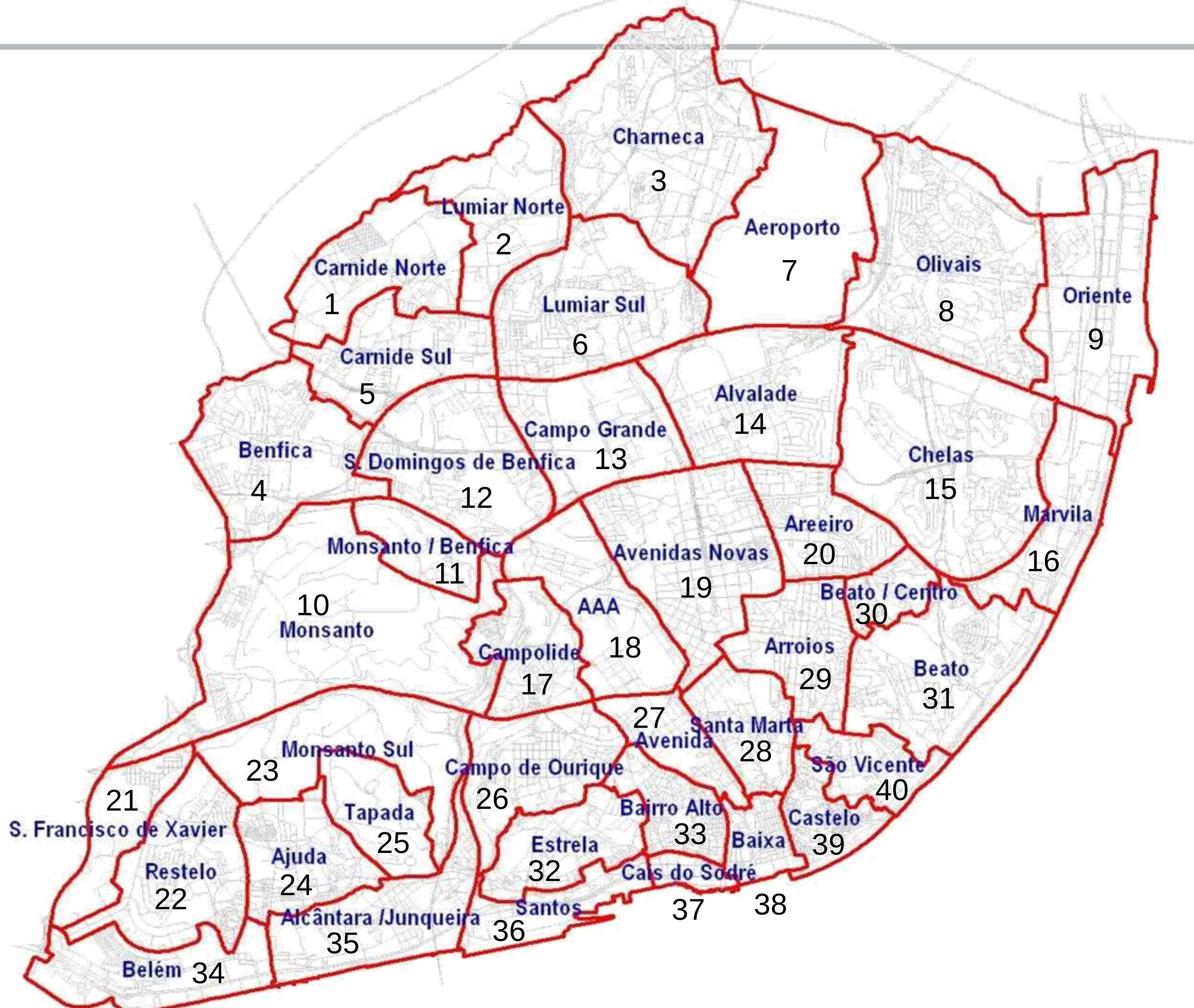
1 – Service Degree



2 - Characterization of the City



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3 - Criteria

Criteria for locating charging points

- 0,3 — Criteria related to offer
  - Parking offer on the public thoroughfare — 0,1
  - Parking offer in parks of public access — 0,1
  - Public access parks for long time periods — 0,1
- 0,3 — Criteria related to demand
  - Parking demand pressure — 0,15
  - Occupation ratio during the day — 0,05
  - Occupation ratio during the night — 0,1
- 0,15 — Other relevant criteria
  - Percentage of still vehicles — 0,05
  - Parking balance for residents — 0,05
  - Unmet parking demand for residents — 0,05
- 0,25 — Dynamic evaluation criterion
  - Number of charging points — 0,25

4 – Decision Making algorithm (PROMETHEE)

1. Initialization
   - Alternatives

$$A = \{a_1, a_2, a_3, \dots, a_n\}$$

   - Criteria

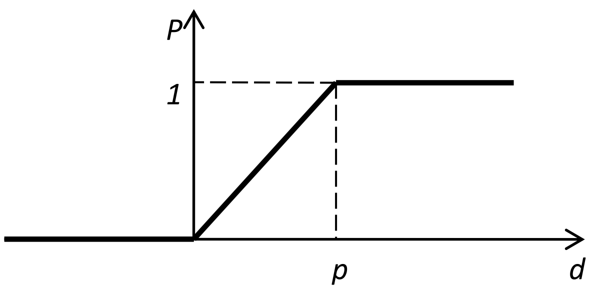
$$G = \{g_1(a_i), g_2(a_i), \dots, g_k(a_i)\} \quad a_i \in A$$

   - Relative weight of criteria

$g_1(a)$	$g_2(a)$	…	$g_k(a)$
w_1	w_2	…	w_k

$$\sum_{j=1}^{k} w_j = 1$$

   - Preference function
     - Maximize / Minimize
     - Shape



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4 - Decision Making algorithm (PROMETHEE)

	Criteria	Parking offer on the public thoroughfare	Parking offer in parks of public access	Deterrent parking	Parking demand pressure	Occupation ratio during the day	Occupation ratio during the night	Percentage of still vehicles [%]	Parking balance for residents	Unmet parking demand for residents [%]	Number charging points
		g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g^d
	Weight [%]	10	10	10	15	5	10	5	5	5	25
	Objective	*Maximize*	*Maximize*	*Maximize*	*Maximize*	*Maximize*	*Maximize*	*Minimize*	*Minimize*	*Minimize*	*Minimize*
	Preference function	V-shape *p=14367*	V-shape *p=7357*	V-shape *p=1950*	Level *p=q=0,5*	V-shape *p=1,31*	V-shape *p=1,56*	V-shape *p=68*	V-shape *p=9100*	V-shape *p=55*	V-shape p^d
1	Carnide Norte	2934	1000	1000	0,5	0,67	0,95	57	1700	0	0
2	Lumiar Norte	813	1581	0	0	0,97	1,49	33	400	0	0
3	Charneca	3337	0	0	1	1,11	1,33	45	200	0	0
4	Benfica	9275	514	0	1	1,17	1,14	46	-800	5	0
5	Carnide sul	3746	7357	415	0,5	1,33	1,36	23	-600	10	0
6	Lumiar sul	7299	2200	1950	0	0,98	1,18	31	4600	0	0
7	Aeroporto	3	600	0	0	0,92	1,08	0	0	0	0
8	Olivais	7390	2193	0	1	1,11	1,17	14	-1800	16	0
9	Oriente	7155	6715	0	0	0,93	0,44	30	4100	0	0
10	Monsanto	164	0	0	0,5	1,1	1,32	0	-600	55	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

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4 – Decision Making algorithm (PROMETHEE)

2. Evaluation

- Difference table

$$d_j(a_i, a_l) = g_j(a_i) - g_j(a_l)$$

- Aggregation

$$\pi(a_i, a_l) = \sum_{j=1}^{k} P_j(a_i, a_l) w_j$$

- Outranking flows

$$\phi^-(a) = \frac{1}{n-1} \sum_{x \in A} \pi(x, a) \qquad \phi^+(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a, x)$$

$$\begin{array}{c|ccccc|c}
 & a_1 & a_2 & a_3 & & a_n & \\
\hline
a_1 & 0 & \pi(a_1,a_2) & \pi(a_1,a_3) & \dots & \pi(a_1,a_n) & \phi^+(a_1) \\
a_2 & \pi(a_2,a_1) & 0 & \pi(a_2,a_3) & \dots & \pi(a_2,a_n) & \phi^+(a_2) \\
a_3 & \pi(a_3,a_1) & \pi(a_3,a_2) & 0 & \dots & \pi(a_3,a_n) & \phi^+(a_3) \\
\dots & \dots & \dots & \dots & \dots & \dots & \dots \\
a_n & \pi(a_n,a_1) & \pi(a_n,a_2) & \pi(a_n,a_3) & \dots & 0 & \phi^+(a_n) \\
\hline
 & \phi^-(a_1) & \phi^-(a_2) & \phi^-(a_3) & \dots & \phi^-(a_n) &
\end{array}$$

- Preference

$$\begin{cases} aP^{II}b & iff \quad \phi(a_i) > \phi(a_l) \\ aI^{II}b & iff \quad \phi(a_i) = \phi(a_l) \end{cases}$$

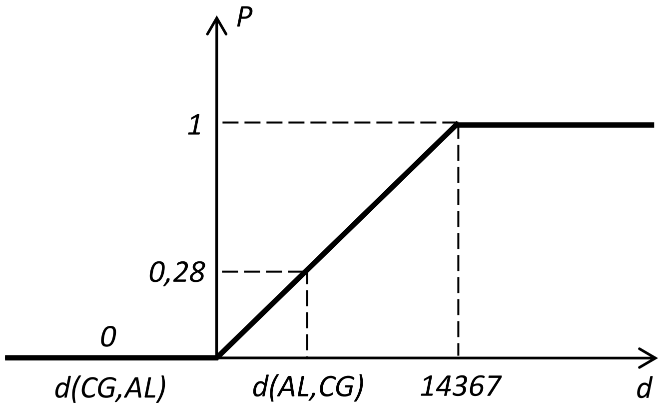
4 – Example of application

Example: CG – Campo Grande
AL – Alvalade

Parking offer on the public thoroughfare *10%*

d(AL,CG)=4052

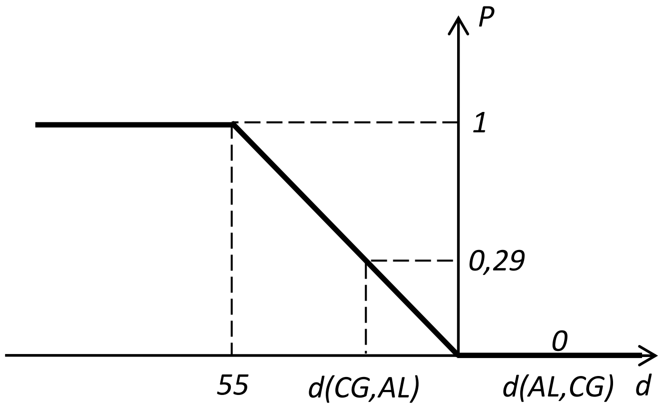
d(CG,AL)=-4052



Percentage of still vehicles *5%*

d(AL,CG)=16

d(CG,AL)=-16



Alvalade > Campo Grande

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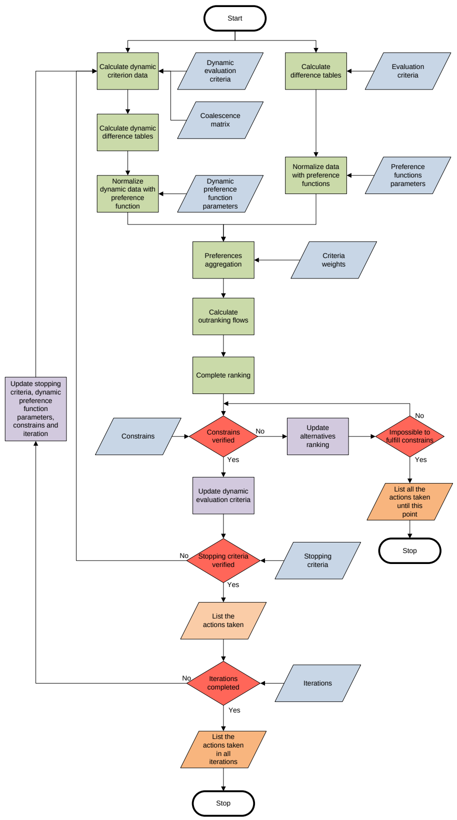
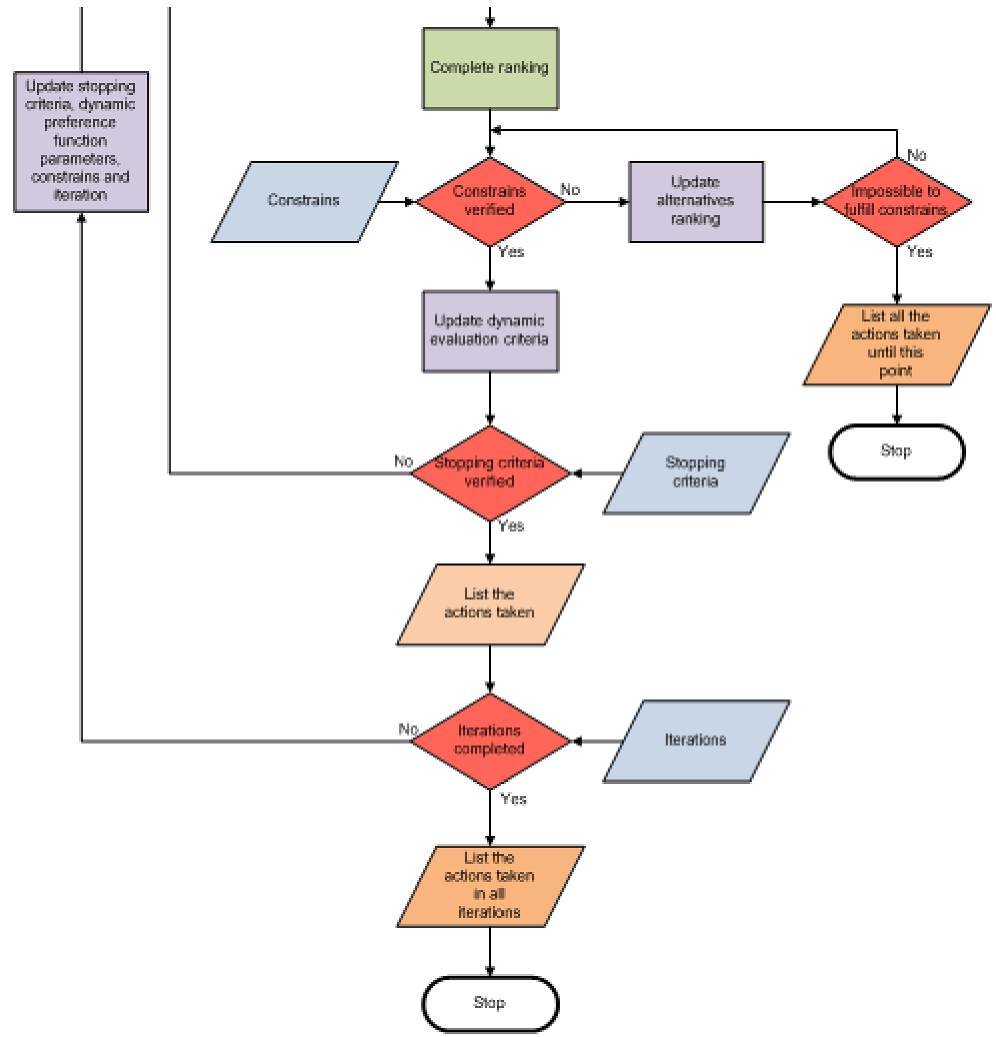
4 – Decision Making algorithm (PROMETHEE)





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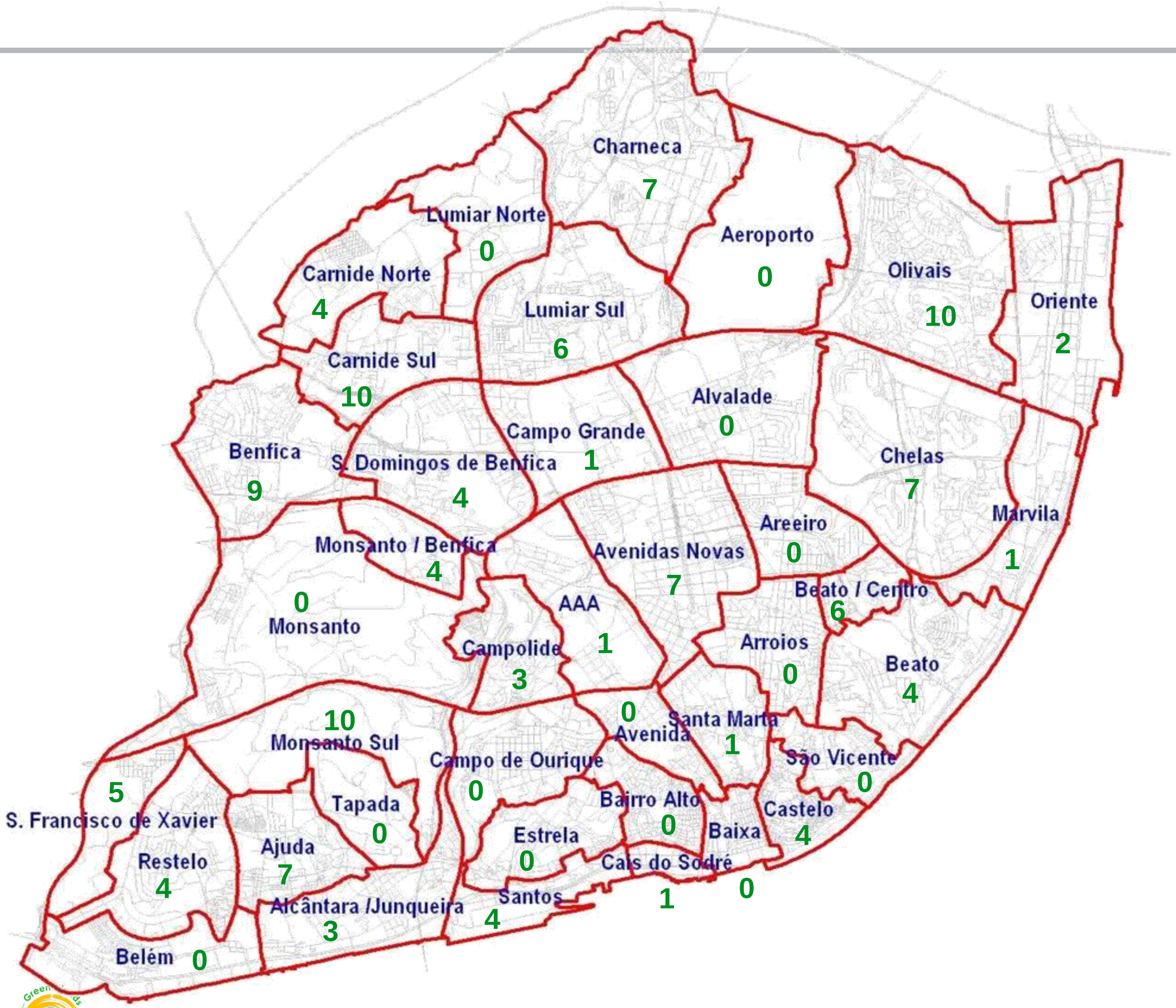
5 – Results (2011 -125CP)



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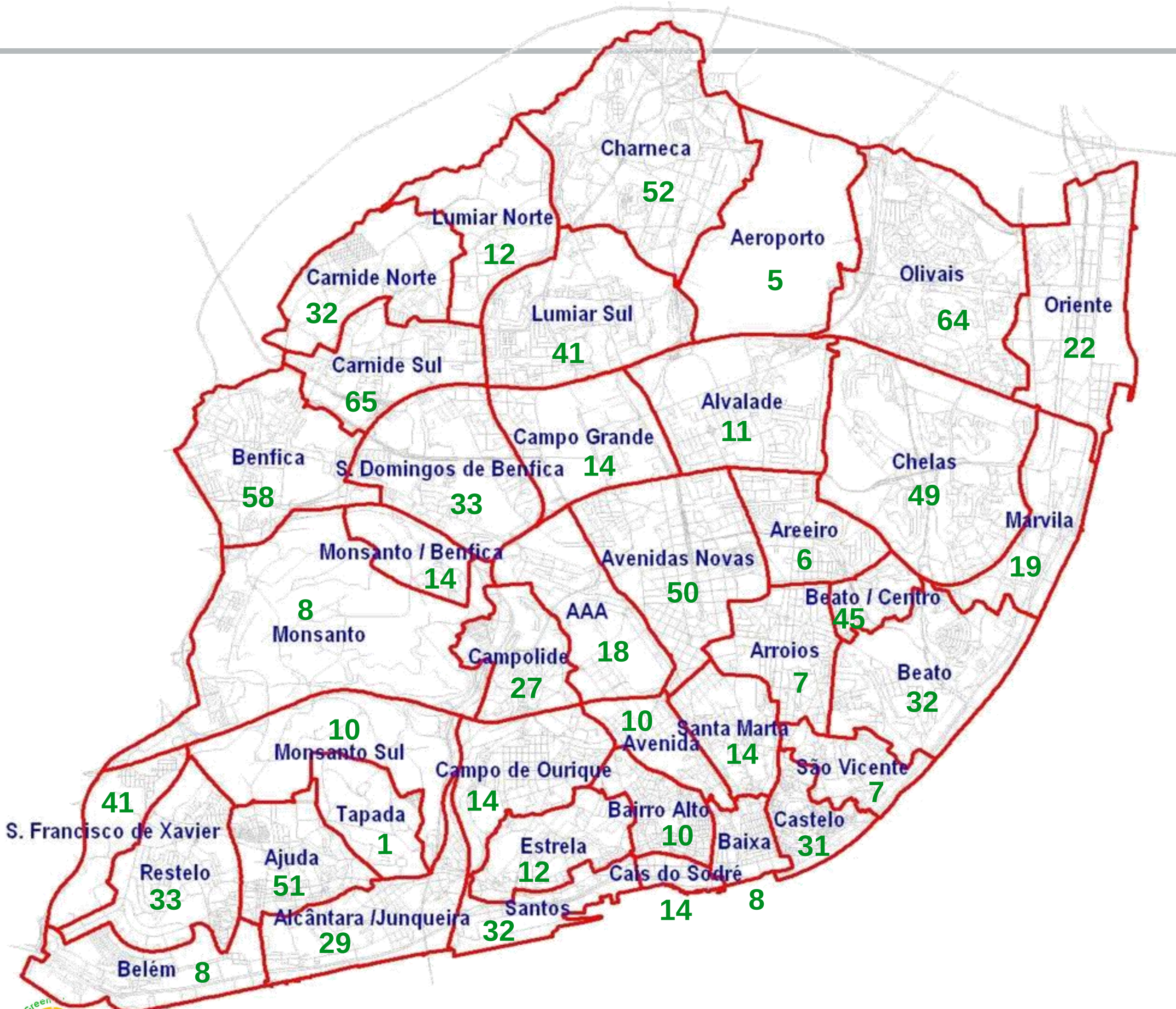
5 – Results (2015 -1009 CP)



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ANGRA DO HEROISMO (TERCEIRA)

1 - EV Projections assumptions

- The ratio between Angra do Heroismo and Portuguese fleet will remain constant (15.5 k / 4.5 m 0,34%)
- Same penetration rate as in Portugal
  - Lisbon considered that at the beginning 50% of EV will be located there and will decrease to the average
  - In Azores, with GIP, it may be expected also higher rates
- The considered area (downtown represents 25% parking places in Angra)

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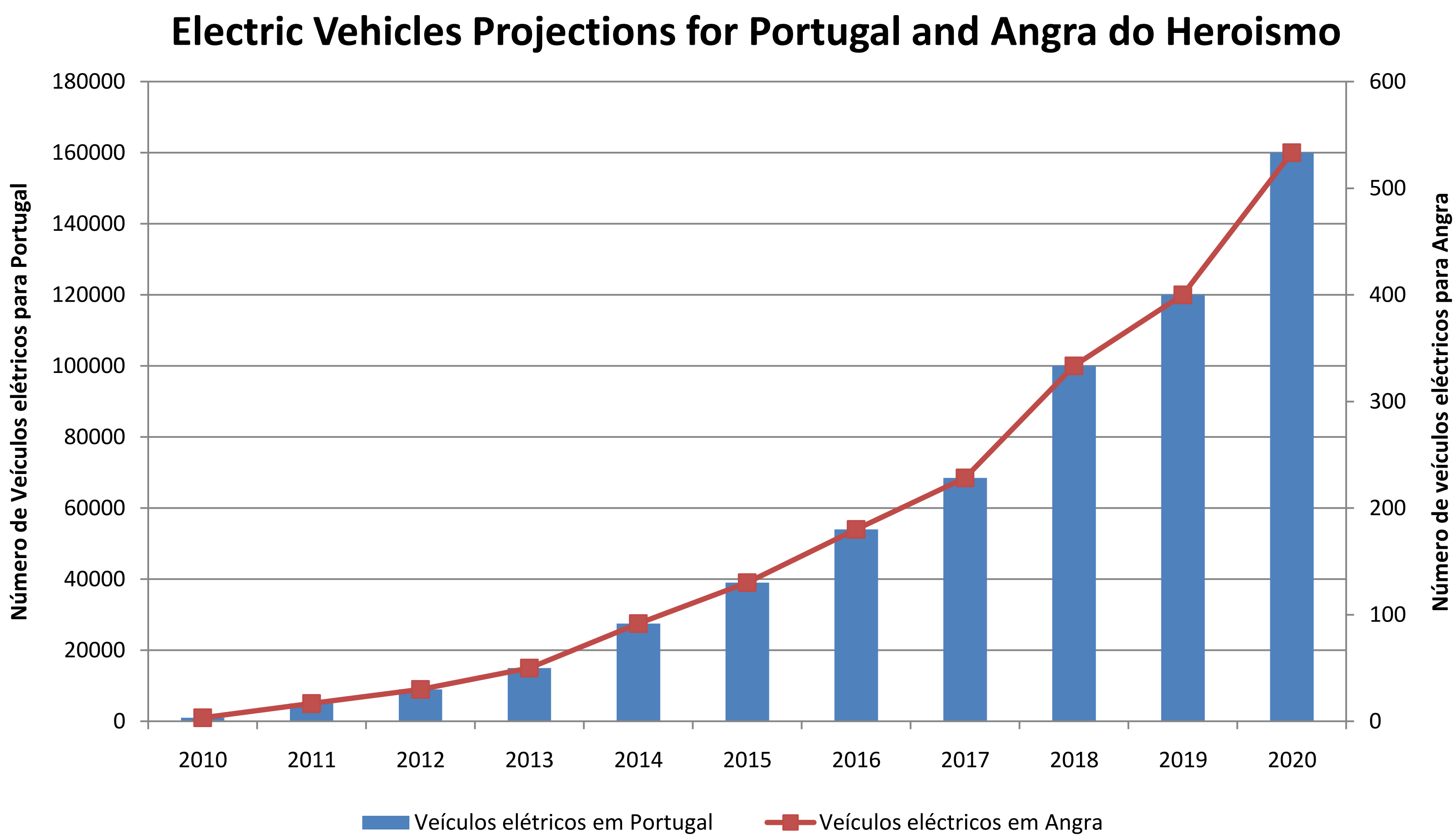
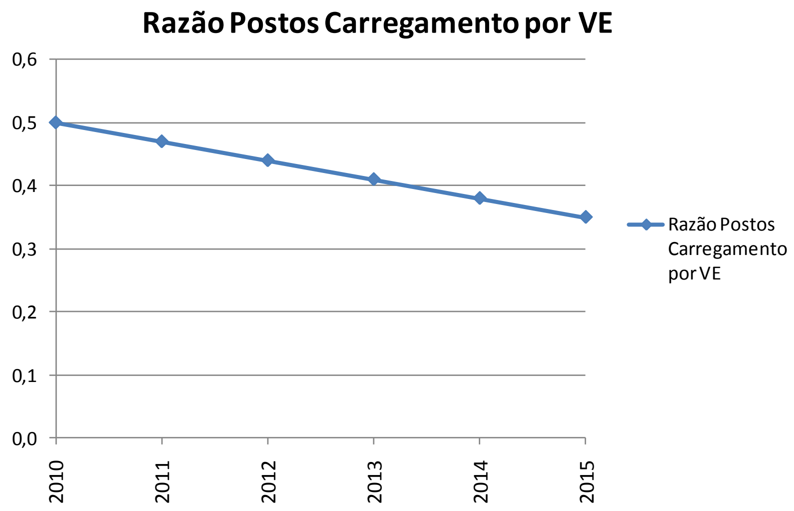
1 - EV Projections results

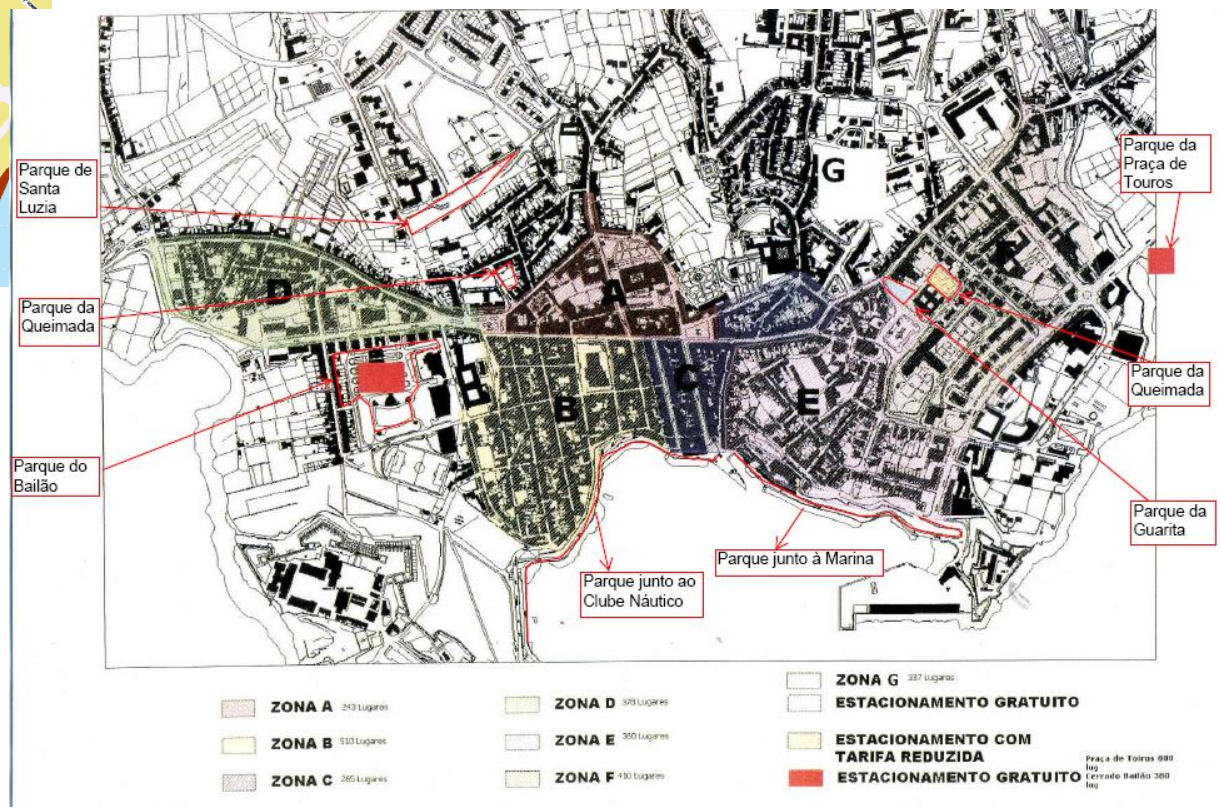


1 - Service Rate

- In 2010, 1 CP for each 2 EV (50% service rate)
- In 2020, 1 CP for each 5 EV (20% service rate)



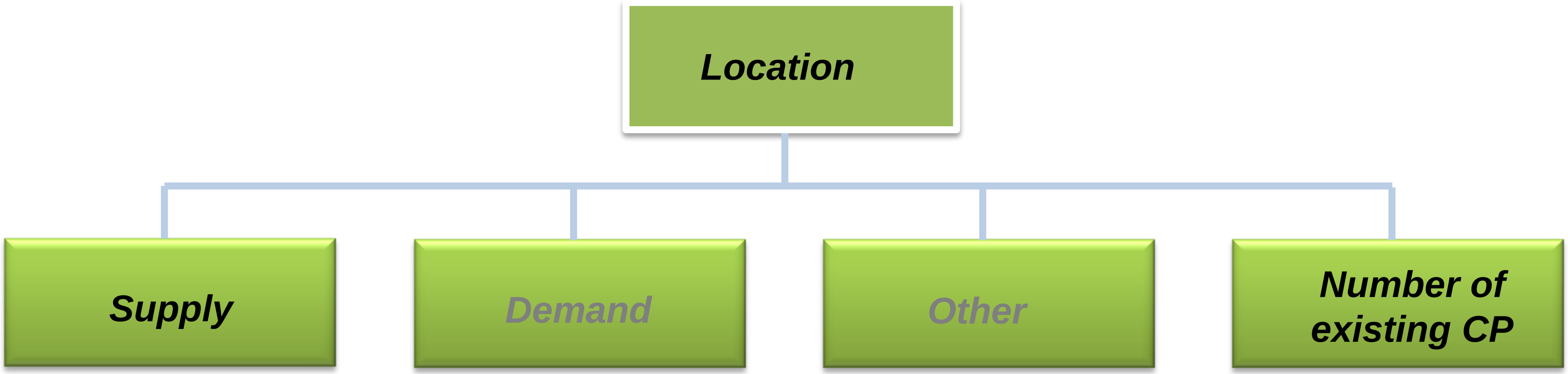
2 – Characterization of city



2 – Number of public parking places

	Lugares de estacionamento	Lugares em Parques
A	273	0
B	510	80
C	265	0
D	378	0
E	360	80
F	410	95
G	337	0
Parque de Santa Luzia	0	80
Parque do Bailão	0	389
Parque da Praça de Touros	0	340

3 – Criteria for Location



Angra do Heroísmo CP network - Criteria

	Lugares de estacionamento	Lugares em Parques	Pontos de carregamento
Peso dos critérios	**30%**	**20%**	**50%**
A	273	0	**0**
B	510	80	**0**
C	265	0	**0**
D	378	0	**0**
E	360	80	**0**
F	410	95	**0**
G	337	0	**0**
Parque de Santa Luzia	0	80	**0**
Parque do Bailão	0	389	**0**
Parque da Praça de Touros	0	340	**0**

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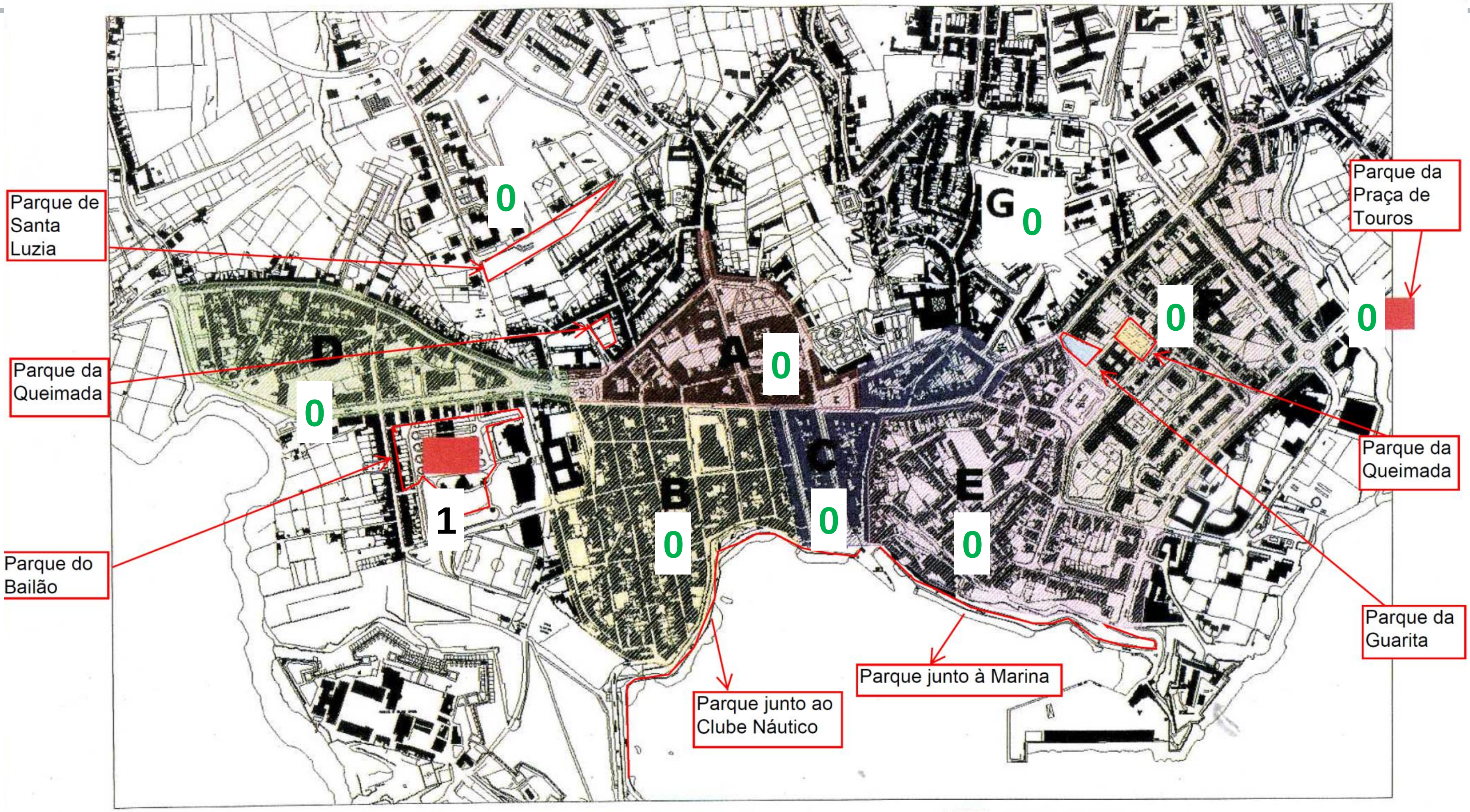
Angra do Heroísmo CP network - Results

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
A	0	0	0	0	0	0	0	0	1	1	1
B	0	0	1	1	2	2	3	3	4	4	5
C	0	0	0	0	0	0	0	0	0	0	0
D	0	0	0	1	1	1	1	1	1	1	2
E	0	0	1	1	1	1	2	2	2	3	3
F	0	0	0	1	1	2	2	2	3	3	3
G	0	0	0	0	0	0	0	1	1	1	1
Santa luzia	0	0	0	0	0	1	1	1	1	1	1
Bailão	1	1	1	1	2	3	3	4	5	5	6
Praça de touros	0	1	1	1	2	2	3	3	4	4	5
Total	1	2	4	6	9	12	15	17	22	23	27

Angra do Heroísmo CP network – 2010 (1CP)



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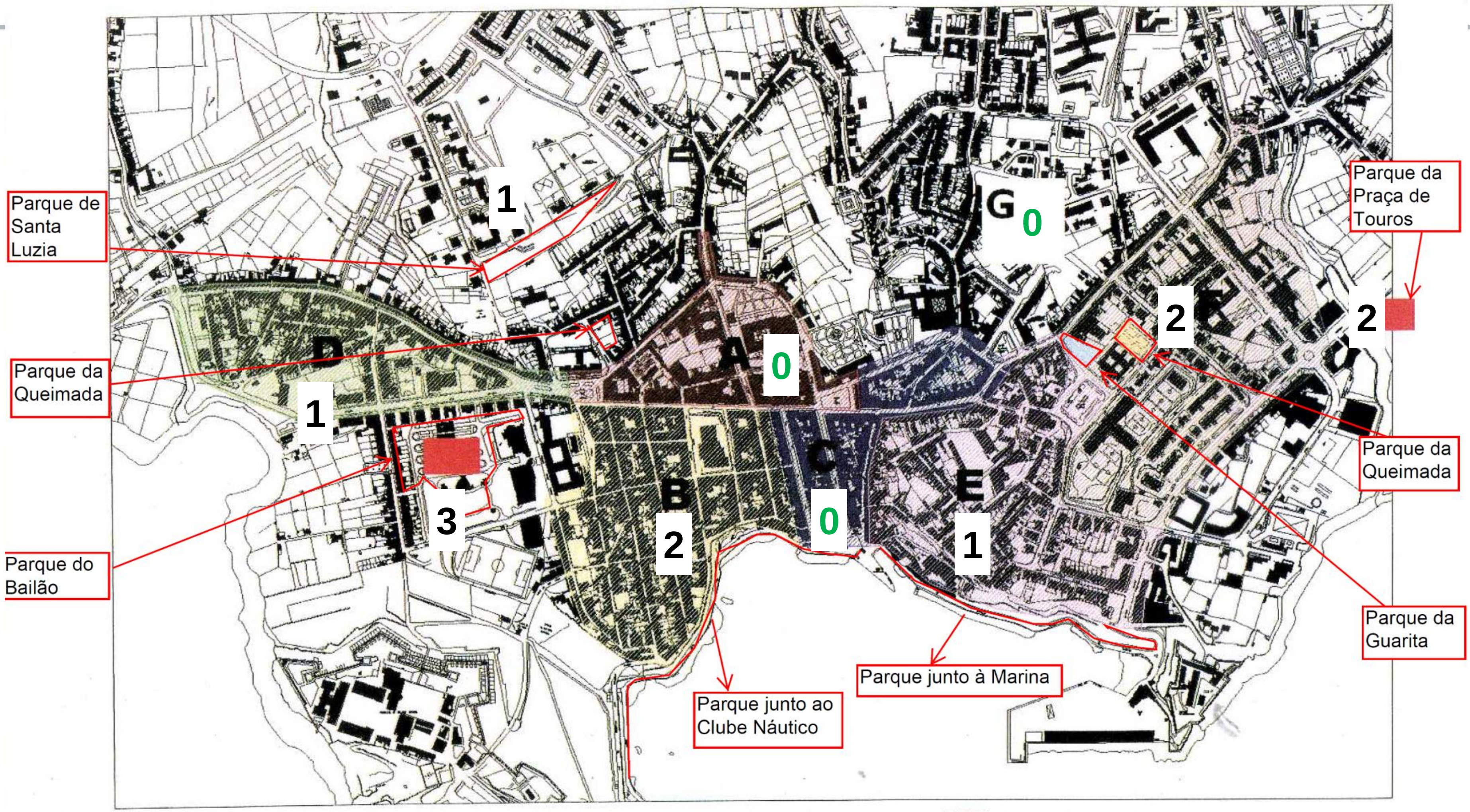
Angra do Heroísmo CP network – 2015 (12CP)



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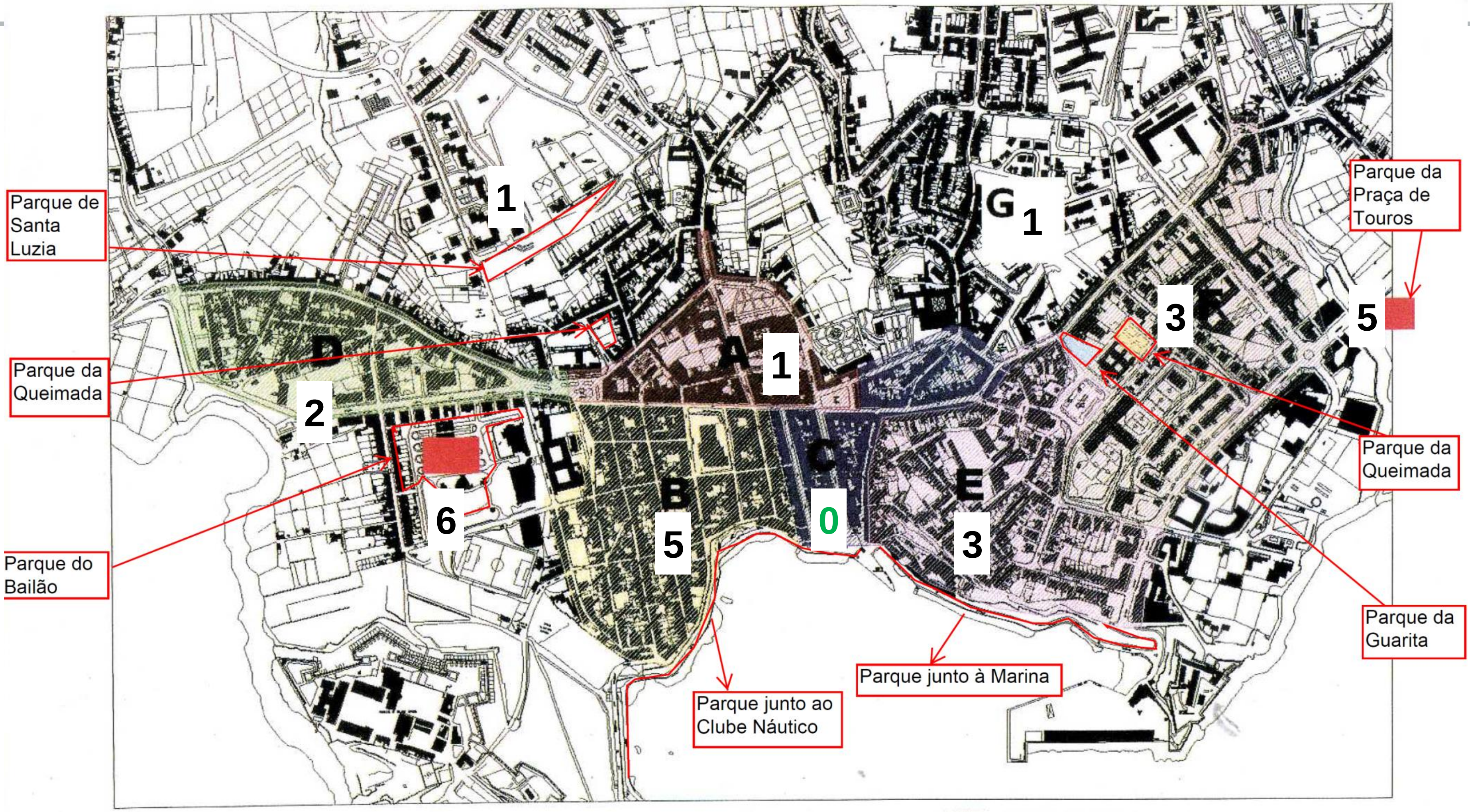
Angra do Heroísmo CP network – 2020 (27CP)



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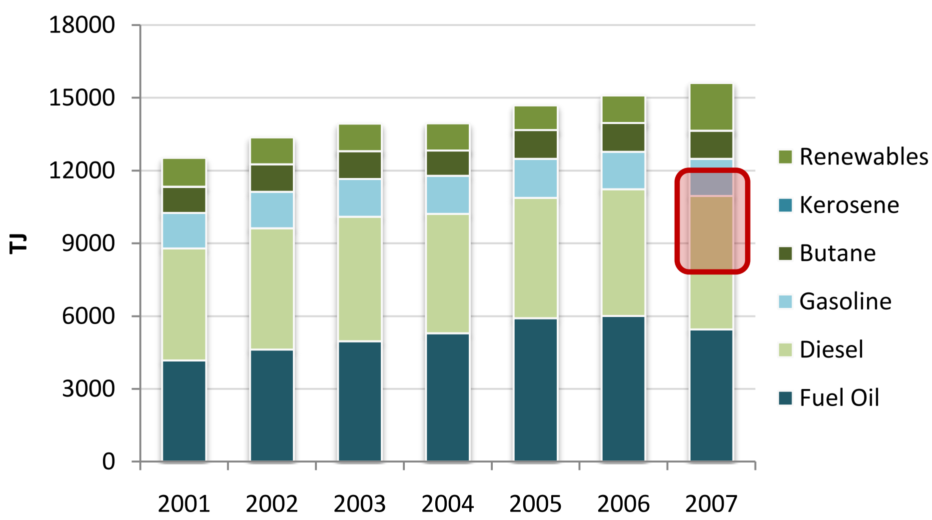
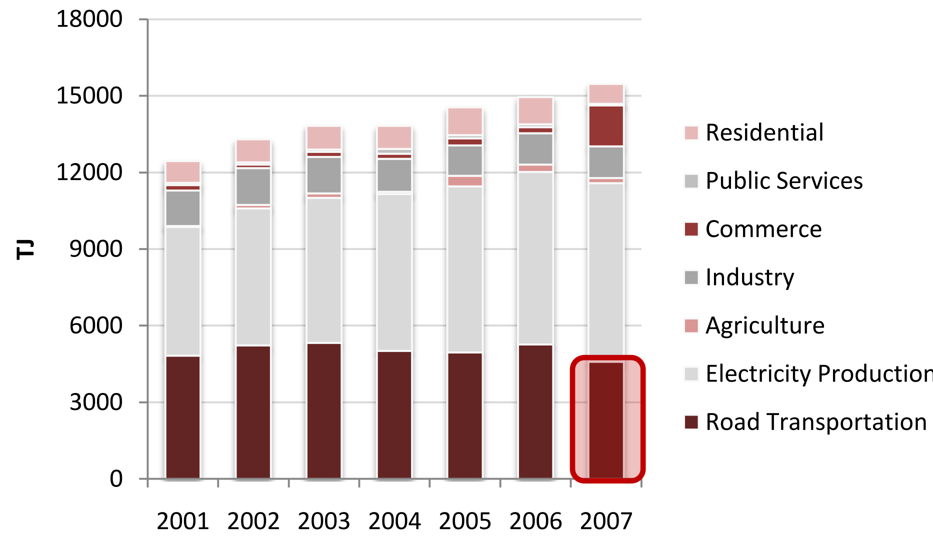
ELECTRIC MOBILITY IN AZORES

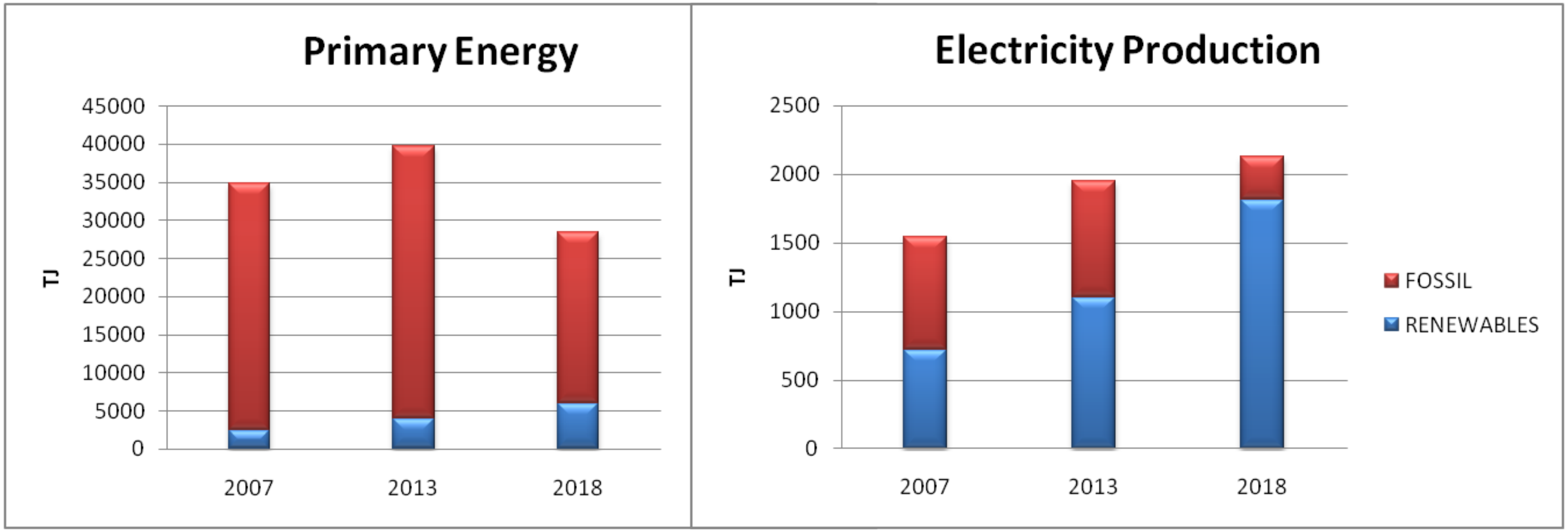
Why EVs in Azores?





- 33% of the primary energy is Azores is used on road transportation
  - 1,38 millions of barrels of oil
  - 85 millions € [80$ per barrel, $=1,3€] + refinery and transportation costs

Electric Mobility Impact (SM)



- Significant reduction in fossil fuels consumption
  - Mild electricity consumption increase (with energy efficiency)
  - Has to be based on renewable electricity

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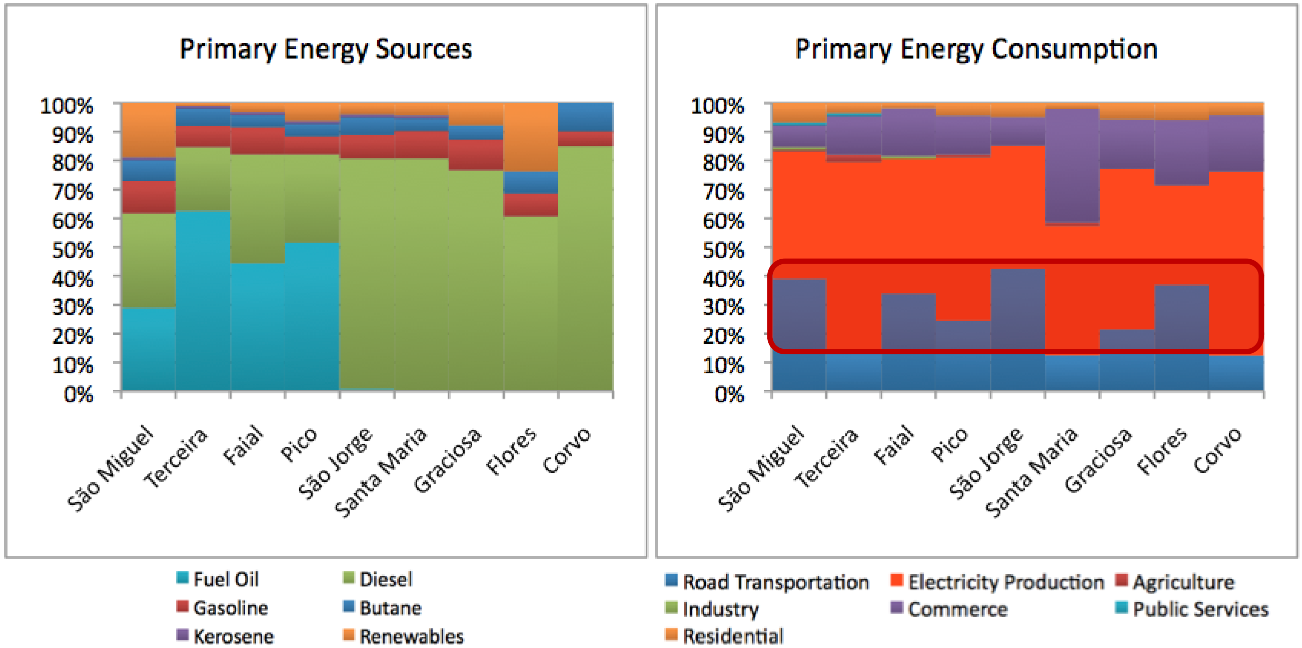
Terceira as the “earlier adopter”

Percentage of Total Primary Energy Sources and Sector Consumption by Island, 2007
(DGEG 2009, EDA 2009a; EDA 2009b)

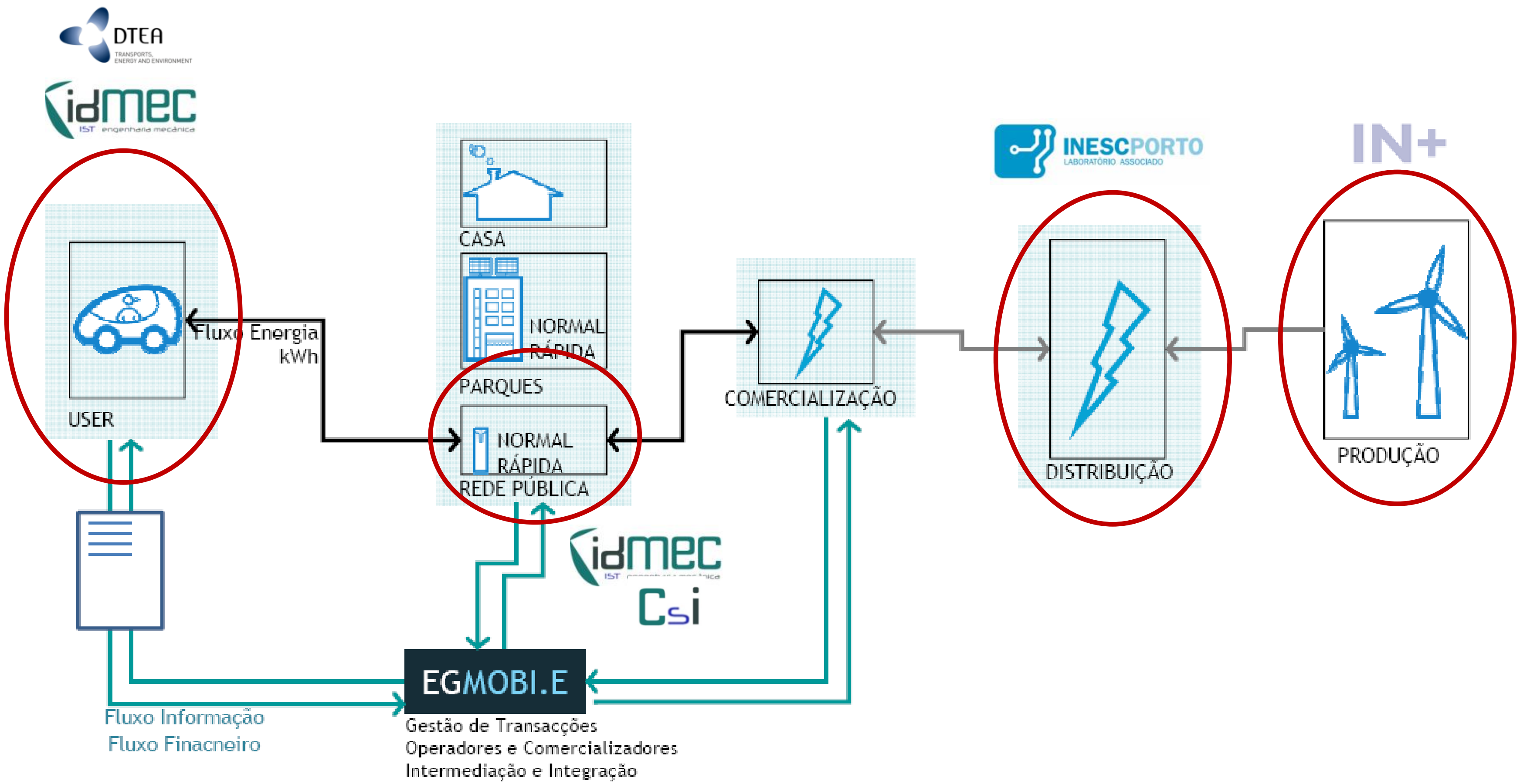


- Lower energy consumption for road transportation in Terceira in average
  - 11% of SM
- Local agents (municipalities, consumers) want EVs!

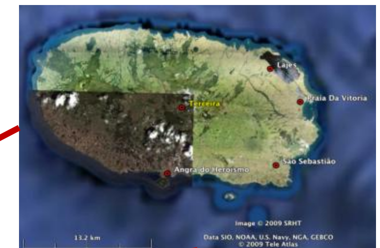
The plan for Azores (public network)

- All islands
  - All municipalities?
    - Technical vs Economic vs Social
- Fast charging
  - Eventually on SM
- **Creating value**
  - Business models
    - Car sharing for tourists
    - Transportation (taxi, shuttles)
    - Parking / energy management
  - *Reconversion*

Designing Electric Mobility for Azores

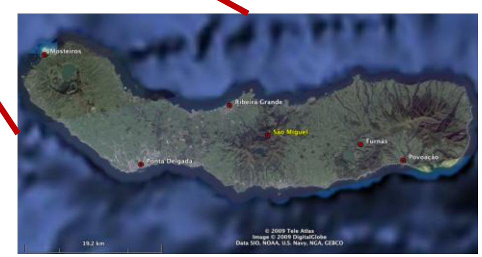


Case Studies



- Charging network

- Fleet
- Production
- Distribution

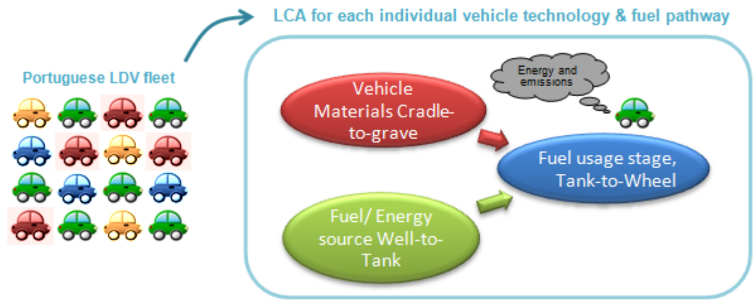


- Fleet
- Production

Patrícia Baptista

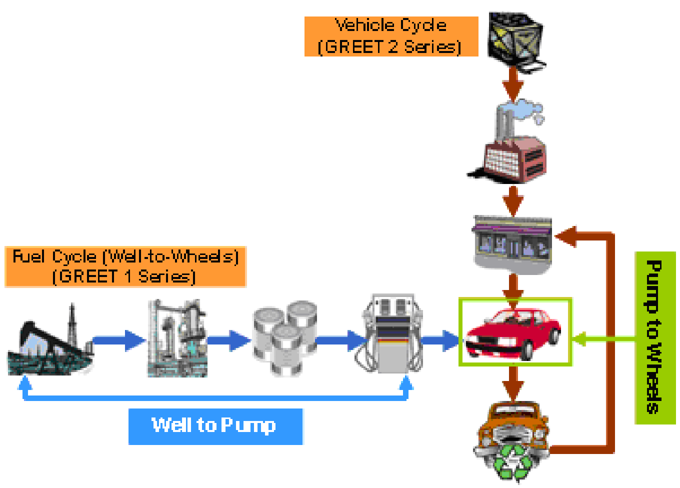
FLEET ANALYSIS (FLORES)

Methodology

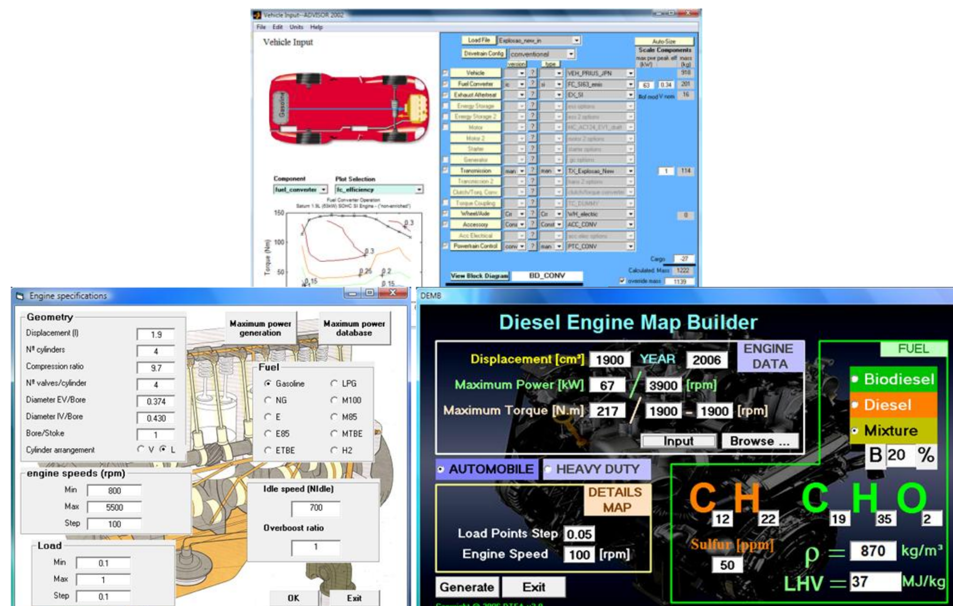


Portuguese fleet LCA structure.

- Life-cycle analysis
- Materials and WTT: GREET, Simapro and other databases



- TTW: ADVISOR, Demb, Siemp, RVS



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Flores Fleet historical data and evolution (ISP)

Category	2000	2001	2002	2003	2004	2005	2006	2007	2008
Light duty vehicles - Passengers	881	974	1,233	1,516	1,610	1,698	1,761	1,800	1,702
Light duty vehicles - Goods	4	50	52	61	60	55	73	82	73
Light duty vehicles - Commercial	48	309	332	298	306	323	305	296	244
Taxis	14	16	17	13	13	11	12	11	10
Rent-a-car vehicles	14	19	37	16	19	8	19	12	8
Other light duty vehicles	10	11	12	10	10	11	11	12	12
Total LDV	**971**	**1,379**	**1,683**	**1,914**	**2,018**	**2,106**	**2,181**	**2,213**	**2,049**
Heavy duty vehicles - Goods	40	40	45	37	37	39	42	41	44
Heavy duty vehicles - Passengers	5	9	8	7	7	7	6	7	5
Other heavy duty vehicles	7	8	8	7	7	7	8	9	10
Total HDV	**52**	**57**	**61**	**51**	**51**	**53**	**56**	**57**	**59**
Tractors for agriculture	95	67	67	67	70	75	73	66	74
Tows for agriculture	0	3	3	1	1	1	0	0	0
Total agriculture	95	70	70	68	71	76	73	66	74
Mopeds	197	140	151	133	133	122	116	96	79
Motorcycles	22	30	40	54	61	67	74	85	83
Total 2W	219	170	191	187	194	189	190	181	162
Others	0	0	0	0	0	1	1	8	3
Tows	8	19	13	5	6	4	4	2	2
Machines (industrial or others)	8	0	0	0	0	0	0	0	0
Total Flores	**1,353**	**1,695**	**2,018**	**2,225**	**2,340**	**2,429**	**2,505**	**2,527**	**2,349**

LDV Motorization index at 498 veh per 1000 inhab

- *expected to stabilize at around 520 veh/ per 1000 inhab*.

- HDV stabilizes at around 15 veh per 1000 inhab.

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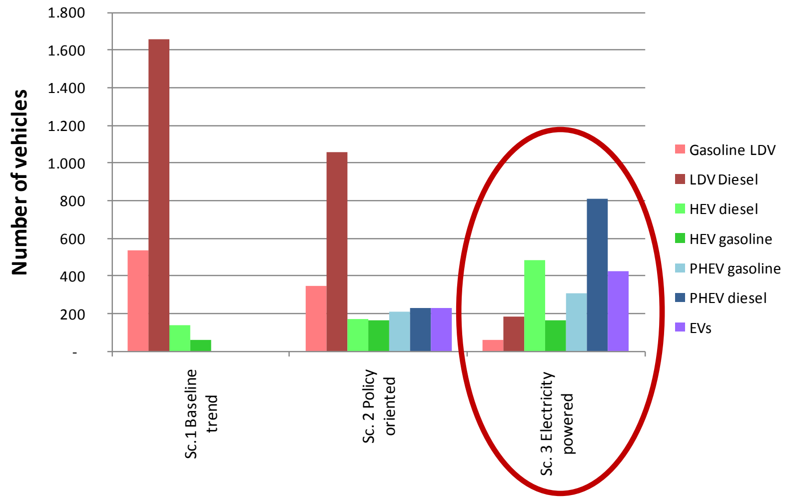
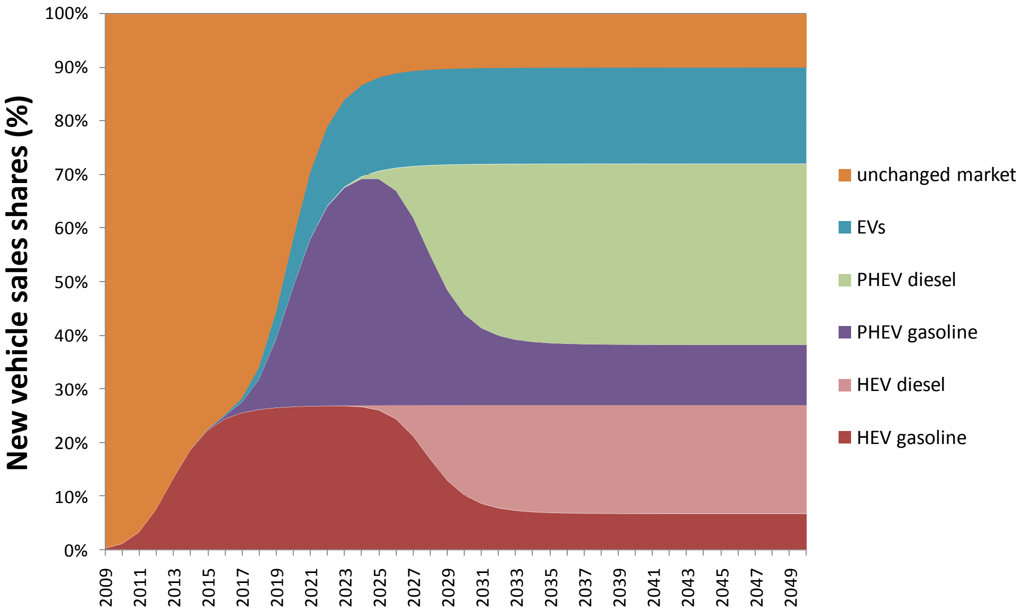
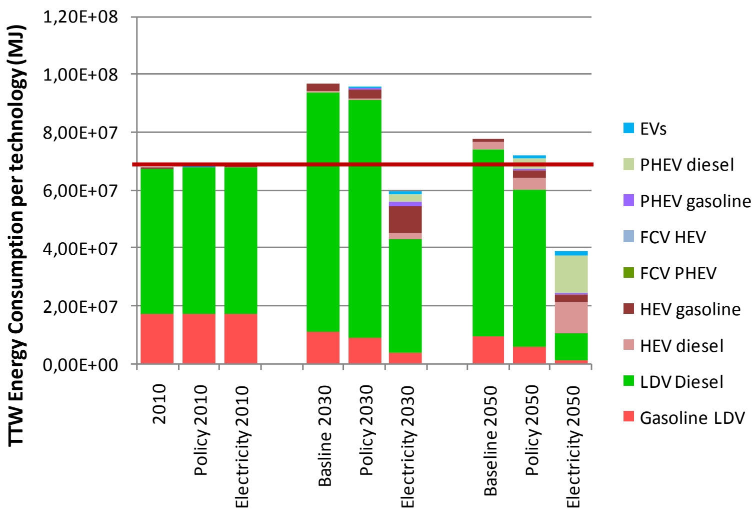
Scenario – Electricity Powered (New Vehicles)

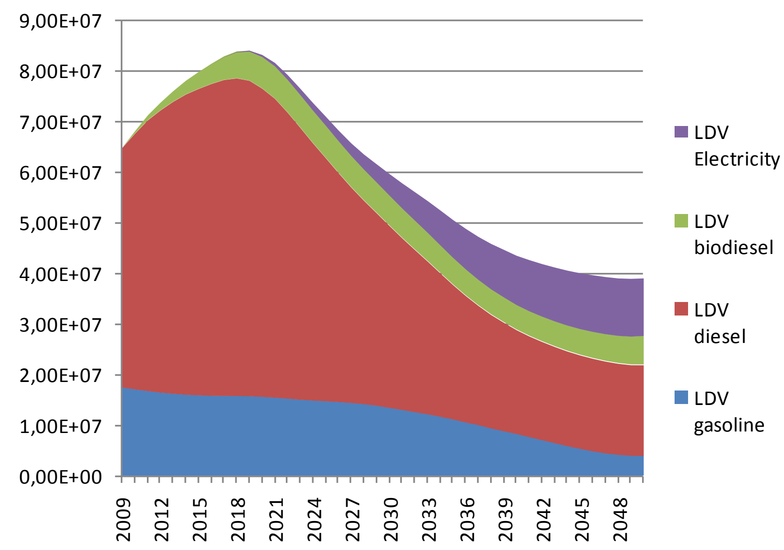




- Alternative fuels: 10% biodiesel in 2020 and 25% in 2050;
- In 2050 90% of vehicle sales will have been shifted from conventional technologies.
- An electricity recharging infrastructure will be available. Both PHEV and EV technologies start entering the market right away.
- The assumed HEV:PHEV:EV ratio for 2050 was 30:50:20; and
- The diesel/gasoline share stabilizes at a 75/25 ratio.

Scenario – Electricity Powered (Energy Tank To Wheel)





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André Pina

ELECTRICITY PRODUCTION (FLORES)

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Flores electricity production system

- The electricity system is a combination of Wind-Hydro-Diesel.

- To maintain frequency and voltage stability at the grid level, a flywheel energy storage system is in place
  - The system is able to achieve 100% renewable electricity
  - In 2009, this happened for several hours of the day in at least 12 days of the year.

- Future investments:
  - Hydro, 1600 kW, 2011.
  - Hydro, 1040 kW, 2012.

Table 1: Installed generation capacity in Flores

Plant	Group	Year	Capacity (KW)
Além-Fazenda (Hydro)	I	1966	296
	II	1966	296
	III	1966	296
	IV	1983	512
Além-Fazenda (Diesel)	VII	1991	500
	VIII	1995	500
	IX	2001	500
	XX	2005	810
Boca da Vereda (Wind)	I	2002	300
	II	2002	300

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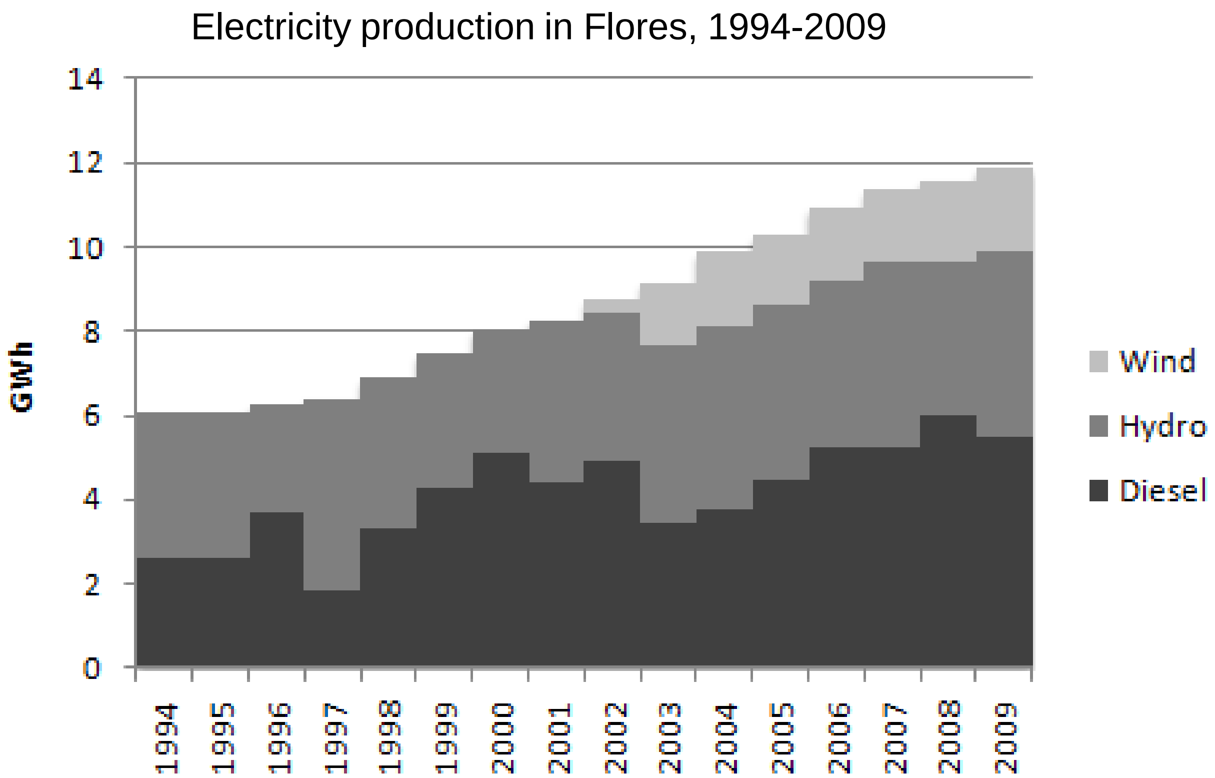
Flores electricity production historical data



- Population of ~4200 habitants
- Area of ~141 km^2
- 54% of renewable electricity in 2009

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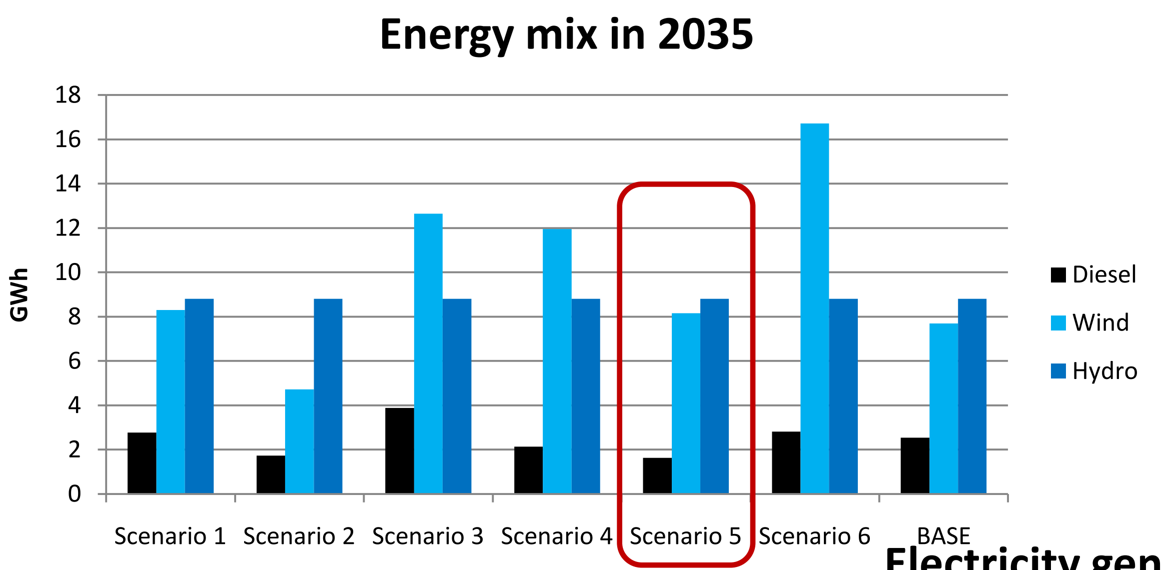
Approach taken

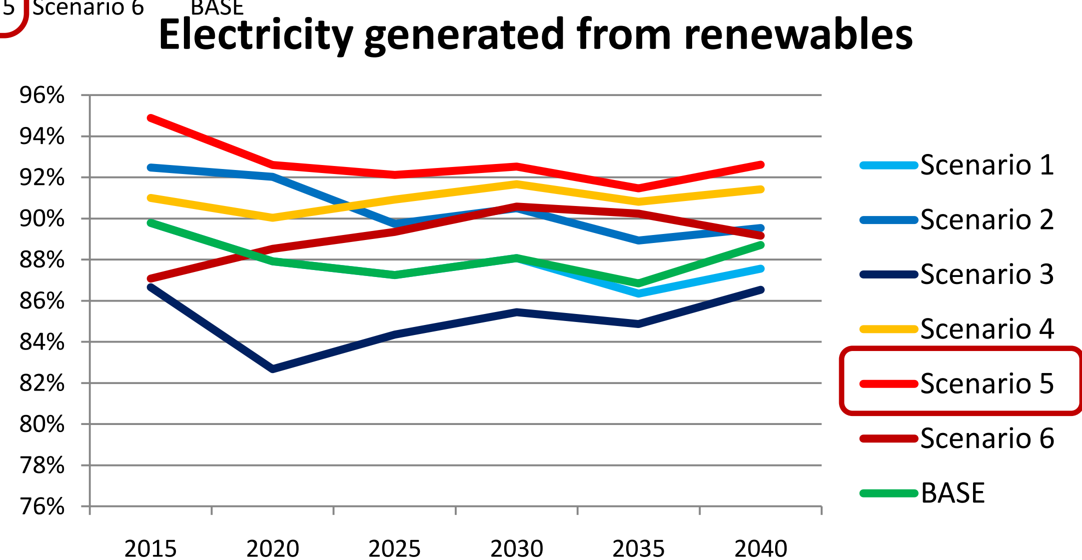
	Consumption Growth Rate	Electric Vehicles Available	Base Year for Price of Fuels
Base	3.0%	No	2007
Scenario 1	3.0%	Yes	2007
Scenario 2	1.5%	Yes	2007
Scenario 3	4.5%	Yes	2007
Scenario 4	3.0%	Yes	2008
Scenario 5	1.5%	Yes	2008
Scenario 6	4.5%	Yes	2008

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
2010	0%	0%	0%	0%	0%	0%
2015	0%	0%	0%	4%	6%	4%
2020	0%	0%	0%	22%	23%	22%
2025	0%	0%	0%	39%	41%	39%
2030	0%	0%	0%	56%	58%	56%
2035	23%	16%	23%	100%	100%	100%
2040	60%	54%	60%	100%	100%	100%

- Main uncertainties studied:
  - Growth rate for electricity demand
  - Fuel prices (2008 prices much higher than 2007 or 2009)
  - EV penetration in fleet

Renewable energy penetration in electricity generation





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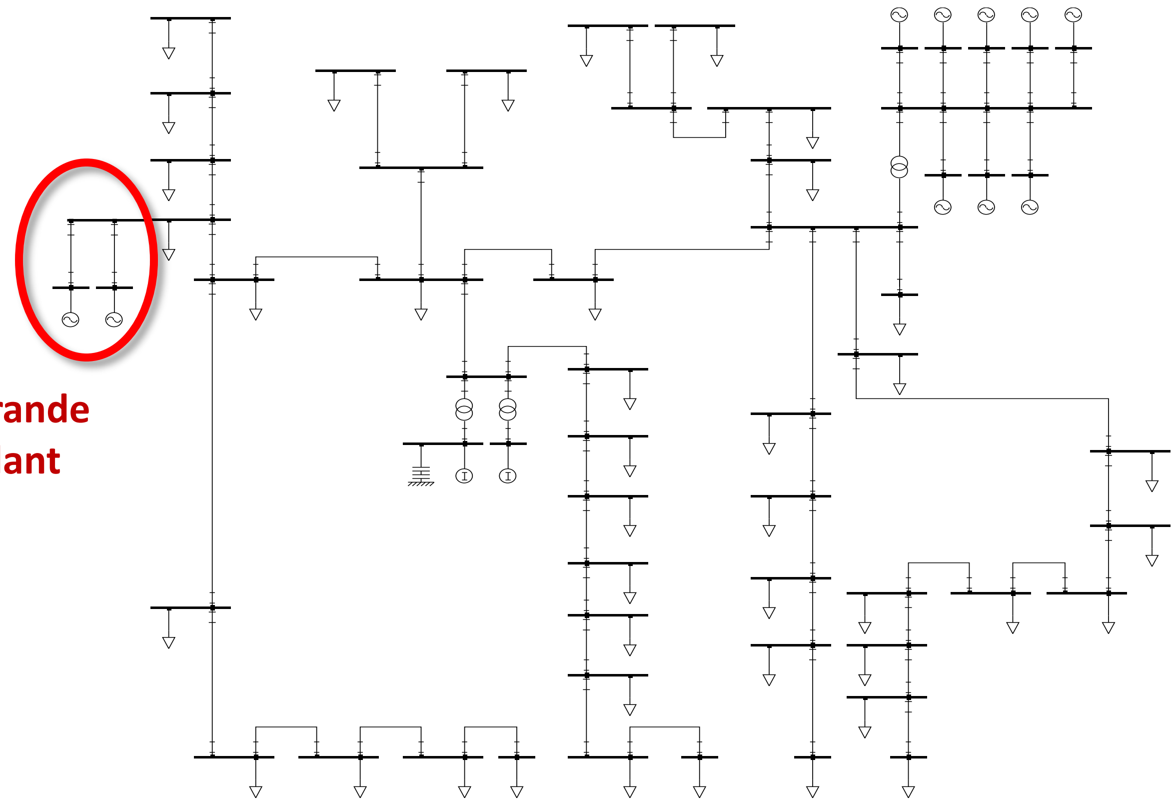
Joel Soares

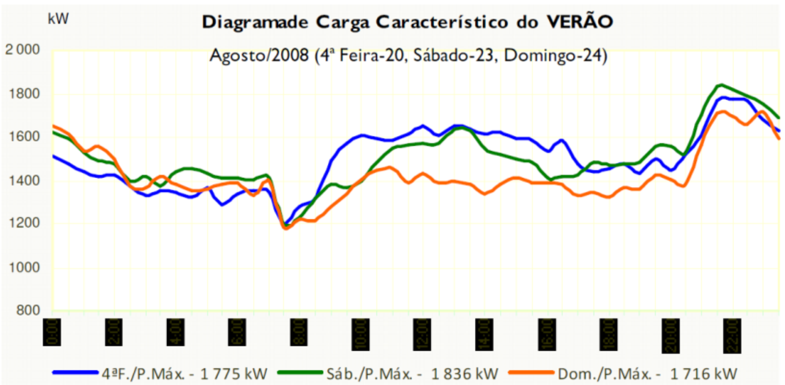
GRID MANAGEMENT (FLORES)

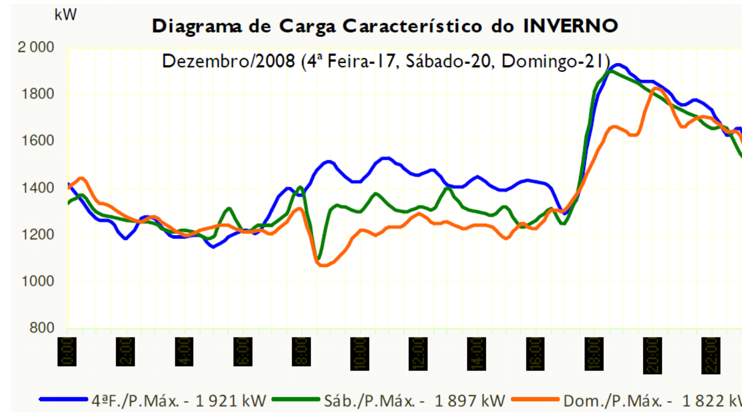
Network Topology

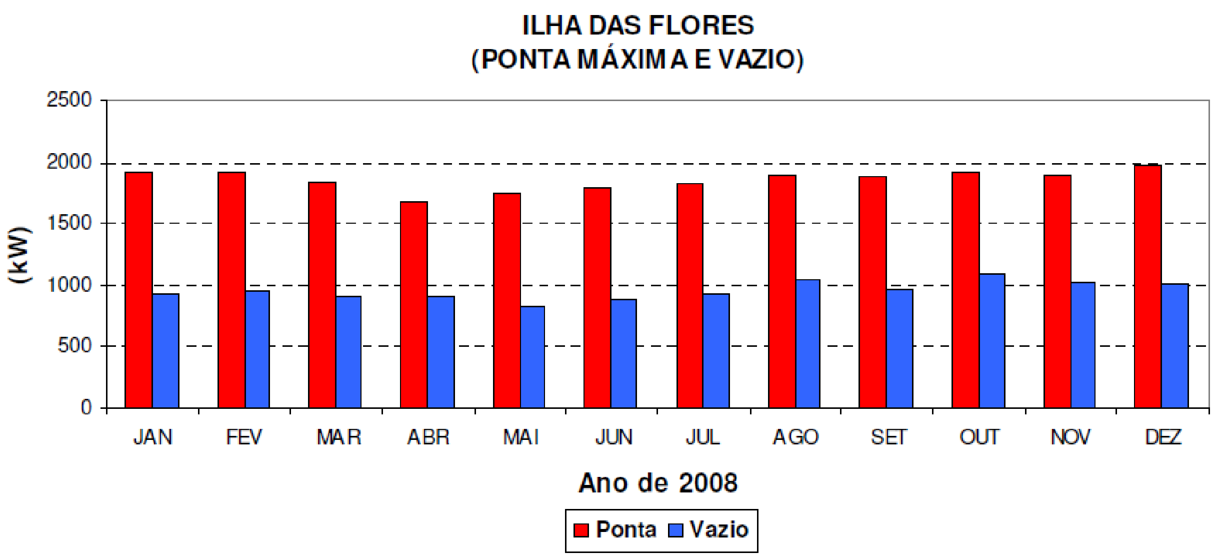


Ribeira Grande PowerPlant

Load diagrams







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Scenarios characterization

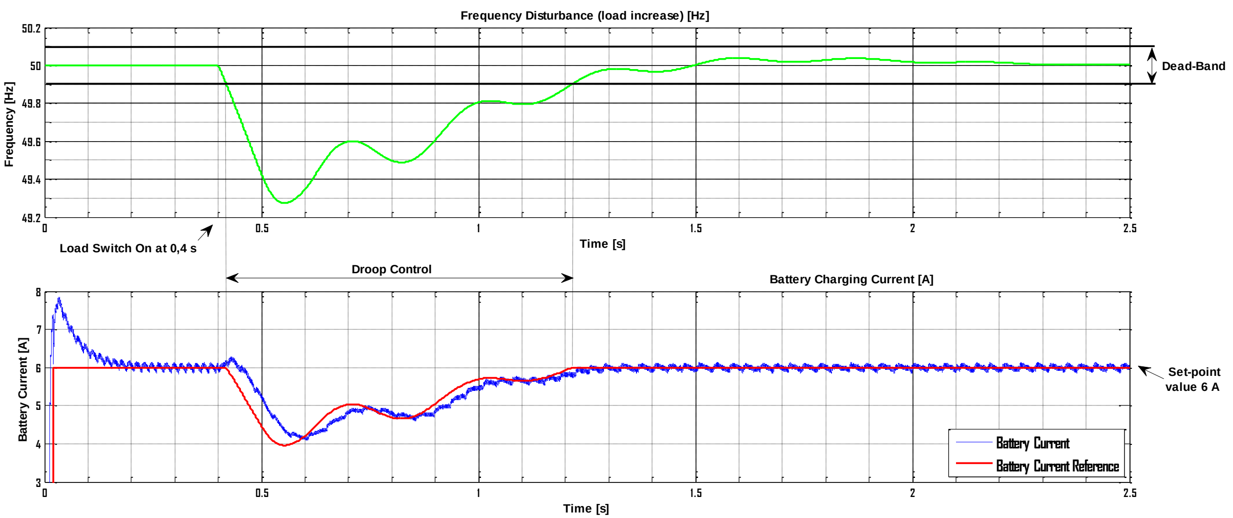
- 50% EV penetration → 1000 EV:
  - 20% PHEV → 1.5 kW rated power / 70% EV1 → 3 kW rated power / 10% EV2 → 6 kW rated power.
- 550 EV charging simultaneously at a charging rate of 0.8 C → **1321 kW + 800 kW of conventional load = total load of 2121 KW**

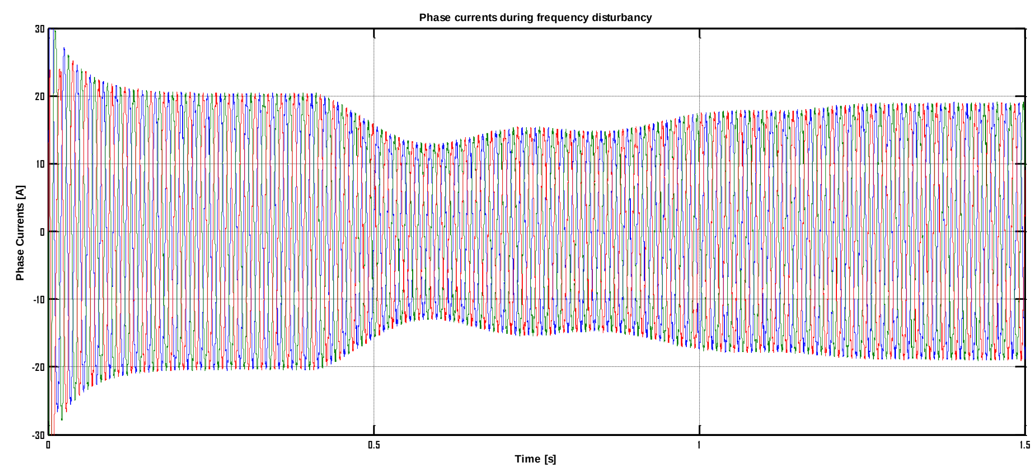
Three scenarios were studied considering 100% renewable electricity:

- **0% of adherents to the smart charging scheme (0 EV) → it was impossible to manage EV load for primary frequency control;**
- **25% of adherents to the smart charging scheme (250 EV) → it was possible to manage EV load between 1108 – 1392 kW for primary frequency control;**
- **100% of adherents to the smart charging scheme (1000 EV) → it was possible to manage EV load between 344 – 1647 kW for primary frequency control.**.

Converter Response

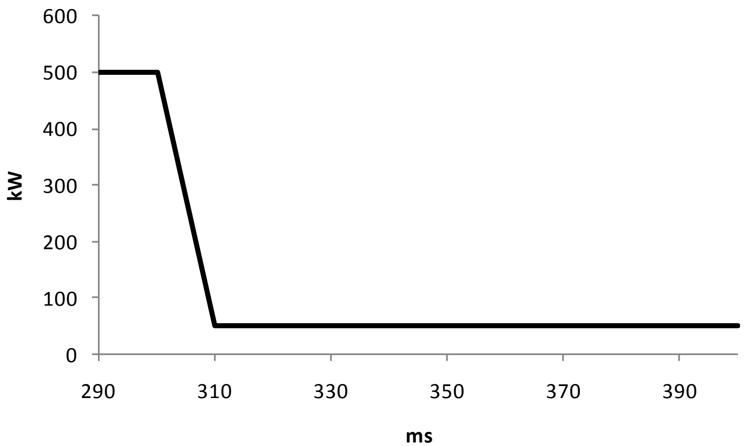
- Frequency disturbance impact on the battery charging current

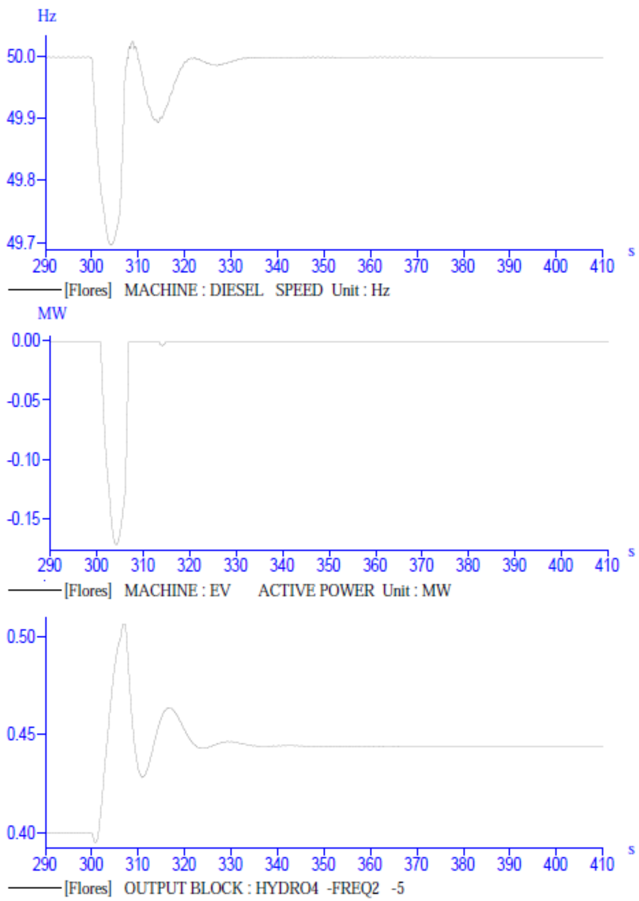




Dynamic Simulation Results

•Wind speed decrease → Shortfall of 450 kW in the wind power production





Scenario 3 :

•1000 EV;

• 550 EV charging simultaneously;

100% smart charging adherents

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