MOBILE ENERGY RESOURCES

IN GRIDS OF ELECTRICITY

ACRONYM: MERGE

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WP 4
TASK 4.1

UPGRADES IN THE DISTRIBUTION NETWORKS WITH HIGH PENETRATION OF EV

DELIVERABLE D4.1

RECOMMENDATIONS REGARDING THE BEST PLANNING PRACTICES COMBINED WITH THE MOST EFFICIENT STRATEGIES FOR CHARGING EV TO BE FOLLOWED BY THE DSO

OCTOBER 2011

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SUMMARY

LIST OF ACRONYMS

EV	Electric Vehicle
LV	Low Voltage
MV	Medium Voltage
RNM	Reference Network Model

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1 INTRODUCTION

This deliverable presents the analysis of the impact in distribution networks reinforcements of the high penetration of EVs. The deliverable corresponds to the Task 4.1 within the MERGE EU Project. The report presents the analysis of typical distribution networks in Spain and Greece (prepared by Iberdrola and PPC, respectively). The initial data of these networks include a detailed characterization of the present status and results of the analysis are focused on the description of reinforcement alternatives to cope with an increase of EV deployment including an estimation of the foreseeable geographic distribution of EV loads for different levels of EV deployment (considering both PHEV and pure EV). Two cases are addressed: EV directly connected in LV grids and aggregated sets of EV connected to MV networks, when special battery charging infrastructures are used.

The analysis is performed using a long term planning model to evaluate the need for investments and grid reinforcements. This model simulates, based on an existing distribution network, and on a geographically-specific characterization of generation and demand, the optimal investments to be carried out.

The report is structured in five sections including this introduction. In Section 2 a description of the methodology used in the analysis is presented. Section 3 presents the detailed input data for the analysis, both the distribution areas and the characterization of the EVs. The results of the impact of EV in distribution network are presented in Section 4. Finally, Section 5 summarizes the main conclusions of the analysis, including network analysis and the distribution areas analyzed. Recommendations following analysis are provided.

2 METHODOLOGY

For performing the analysis of the impact of EV penetration in distribution networks a Reference Network Model (RNM) is used. The model to assess investments has been adapted to deal with large-scale penetration of EV, and is described in Deliverable D2.4 “Functional specification for estimating additional investments in distribution networks with high penetration of electric vehicles”. RNMs have been used as large-scale planning tools in order to design the networks.

The analysis presented in this report requires two steps. First, the RNM will be used to build an initial distribution network from scratch, using the input data described in the following section, such as the location of the loads and the connection to the transmission network. For that purpose the Greenfield version of the RNM will be used. Second, once the distribution networks are built for the considered areas, different sensitivity analysis of EV penetration will be conducted. The expansion planning model version will be used in the second approach. The following sensitivity analysis will be addressed:

- Three EV penetration levels;
- Three EV charging strategies (peak, valley and smart);
- Two EV charging stations locations (distributed and concentrated);
- Six distribution networks (from rural to urban areas, in Spain and Greece).

The main features of the RNM are summarized in Figure 1. The inputs of the model include GPS location as well as contracted/rated power of loads, electric vehicles and distributed generation. There are also geographical constraints and a set of technical and economic parameters, together with a library of standardized electrical equipment. In the case of the expansion version, the initial network topology and electrical data are also required. The inputs used in the analysis are detailed in Section 3. On the other hand, the algorithms used by the RNM include zonal classification, automatic generation of street maps, building a topological grid, sizing electrical equipment, and reinforcing the network when required. A more detailed description of the RNM can be found in Deliverable D2.4.

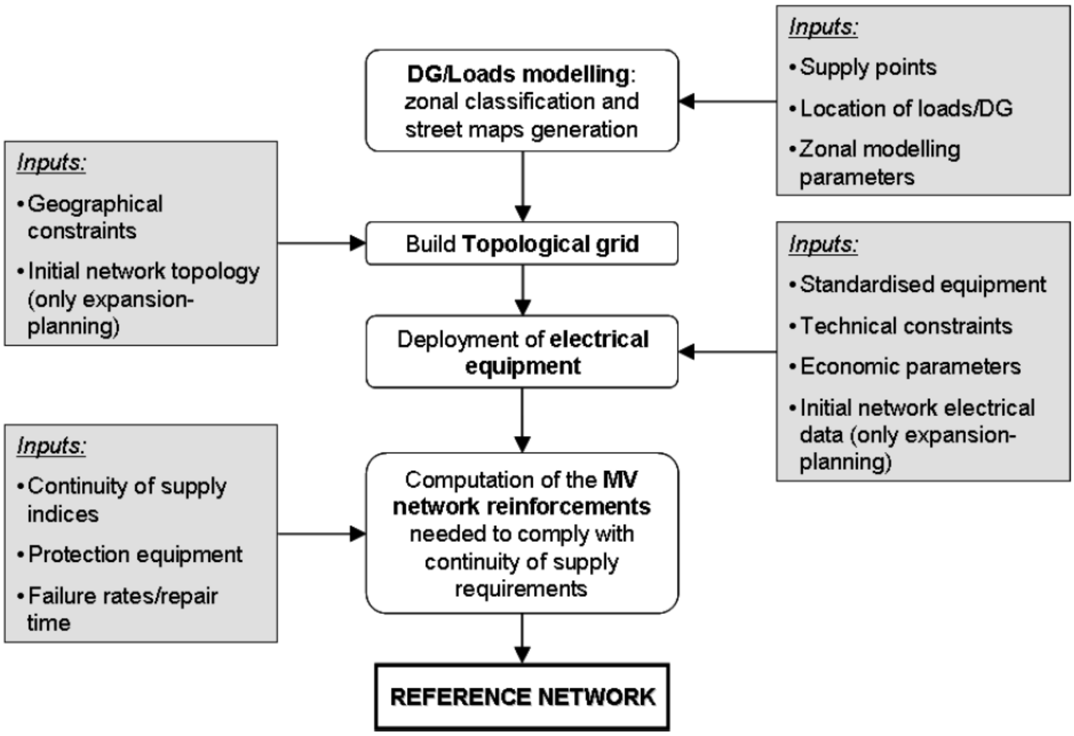


Figure 1. Logical architecture of RNMs: steps involved and relevant input data

3 DESCRIPTION OF THE INPUT DATA

This section presents the input data required by the RNM to perform the analysis under the scope of this report. First, a resume of the main characteristics of the distribution areas selected for the analysis is presented. Then, the EV data used for the different sensitivity analysis is described in detail.

3.1 Characterization of the distribution areas

3.1.1 Distribution area in Greece

Aggregated information for modeling a Greek City has been supplied by PPC, concerning customers (Table 1), distributed generators (Table 2), network lengths (Table 3), MV/LV transformers (Table 4) and HV/MV substations (Table 5).

Table 1, Table 2 and Table 5 have been used to adjust the RNM that builds the initial network for the Greece City. On the other hand Table 3 and Table 4 have been used to check the magnitude order of such network.

TYPE OF CUSTOMER	NUMBER OF CUSTOMERS	NUMBER OF SUPPLY POINTS	TOTAL CONTRACTED POWER (MW)	TOTAL PEAK POWER (MW)
LV Customer	38518	22828	184	74,5
MV Customer	61	61	5.4648	

Table 1. Greek City. Customers

TECHNOLOGY	NUMBER OF DISTRIBUTED GENERATORS	NUMBER OF SUPPLY POINTS	TOTAL INSTALLED POWER (MW)
PV	48	48	0.941
Wind	0	0	0

Table 2. Greek City. Distributed Generators

VOLTAGE LEVEL	AERIAL (km)	UNDERGROUND (km)
LV	78.3	70.1
MV	141.30	31.30

Table 3. Greek City. Network lengths

FACILITY	TYPE	SIZE (kVA)	NUMBER	AVERAGE RATIO DEM / POT (pu)
MV/LV Substation	Aerial	25	1	0.5
		50	45	0.64
		75	10	0.67
		100	99	0.61
		150	13	0.59
MV/LV Substation	Aerial	160	82	0.48
		200	1	0.52
MV/LV Substation	Aerial	250	115	0.64
MV/LV Substation	Aerial	400	43	0.67
MV/LV Substation	Internal	400	3	0.55
MV/LV Substation	Internal	500	3	0.6
MV/LV Substation	Internal	630	58	0.65
MV/LV Substation	Aerial - Compact	630	4	0.62
MV/LV Substation	Internal	1000	1	0.65

Table 4. Greek City. MV/LV Transformers

FACILITY	TYPE	SIZE (MVA)	NUMBER	AVERAGE RATIO DEM / POT (pu)
HV/MV Substation	Urban	150	1	0.62

Table 5. Greek City. HV/MV Substations

The planning model RNM requires the location and contracted power of every single customer and distributed generator. In this case, the street map shown in Figure 2 has been used to help setting the locations of the individual customers. Customers have been located in the contour of the building blocks (in grey).

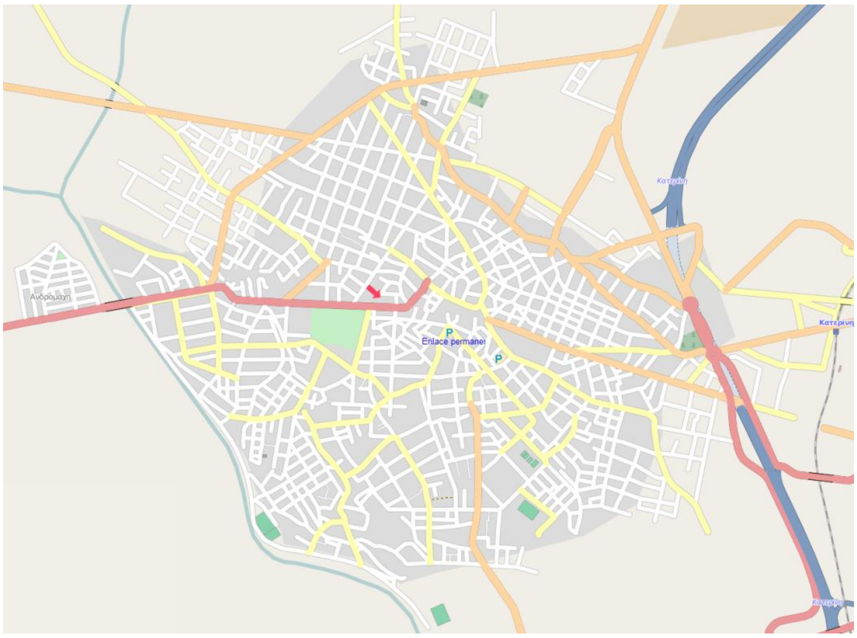


Figure 2. Greek City street map from OpenStreetMap.

3.1.2 Distribution area in Spain

Detailed GPS input data of customers and distributed generators, general technical parameters and standard equipment costs, has been supplied for the Spanish region by IBERDROLA. The information covers five different distribution areas:

- Tourist area
- Rural area
- New city
- Big city with and old distribution network
- Big city with a new distribution network

The following sections present the format that has been used for the ex-change of information of the Spanish Region.

3.1.2.1 GPS Input data

The GPS input data is specific for each of the distribution areas, and includes individual customers, distributed generators, HV/MV substations and MV/LV transformers. Data is not shown in this section, as they comprise hundreds of thousands of elements.

FIELD	REMARK	DESCRIPTION
Code		
Coordinates	X	Coordinates in kilometres
	Y	Coordinates in kilometres
Voltage level	LOW, MEDIUM, HIGH	
Municipality code		
Province code		
Voltage	KV	
Contracted power	KW	

Table 6. Customers

Field	REMARK	DESCRIPTION
Code		
Coordinates	X	Coordinates in kilometres
	Y	Coordinates in kilometres
Voltage level	LOW, MEDIUM, HIGH	
Type	WIND, PHOTOVOLTAIC, HYDRO, OTHER	
Municipality code		
Province code		
Voltage	KV	
Installed power	KW	
Power factor	Unitary units	

Table 7. Distributed Generators

FIELD	REMARK	DESCRIPTION
Code		
Coordinates	X	Coordinates in kilometres
	Y	Coordinates in kilometres
Municipality code		
Province code		

Table 8. Medium to low voltage transformers, high to medium voltage substations and very high to high voltage substations

3.1.2.2 Standardized equipment

This section describes the technical and economic information that IBERDROLA has provided for conductors, HV/MV substations and MV/LV transformers. This data has been used for all distribution areas, not only for Spain but also for Greece. Investment, preventive and corrective maintenance have been provided for the analysis but are not included in this section.

CONDUCTOR	RESISTOR (Ω)	REACTANCE (Ω)	NOMINAL CURRENT (A)	VOLTAGE (kV)
BT_P_01	1.200	0.100	100	0.4
BT_P_02	0.640	0.100	150	0.4
BT_P_03	0.320	0.100	230	0.4
BT_P_04	0.210	0.100	305	0.4
BT_F_02	0.640	0.100	150	0.4
BT_F_01	1.200	0.100	100	0.4
BT_F_03	0.320	0.100	230	0.4
BT_S_02	0.640	0.080	175	0.4
BT_S_03	0.320	0.076	255	0.4
BT_S_04	0.210	0.075	325	0.4
BT_S_05	0.130	0.070	420	0.4
MT_A_02	0.614	0.393	197	20
MT_A_03	0.424	0.386	250	20
MT_A_04	0.307	0.372	314	20
MT_A_06	0.196	0.358	425	20
MT_S_02	0.640	0.130	160	20
MT_S_04	0.200	0.110	300	20
MT_S_05	0.120	0.100	400	20
MT_S_06	0.070	0.090	515	20
AT_A_H1	0.119	0.400	580	66
AT_S_01	0.100	0.120	425	66
AT_S_02	0.061	0.110	555	66
AT_A_H2	0.119	0.400	580	132
AT_S_05	0.029	0.095	750	132

Table 9. Conductors

SUBSTATION	CAPACITY (MVA)	HIGH VOLTAGE (kV)	LOW VOLTAGE (kV)	NO-LOAD LOSSES (MW)	LOAD LOSSES (MW)
SE_I_2a	20	66	20	0.016	0.109
SE_I_4a	40	66	20	0.033	0.219
SE_B_08	120	132	20	0.071	0.523
SE_I_06	80	132	20	0.047	0.349
SE_I_08	120	132	20	0.071	0.523
SE_B_2a	20	66	20	0.016	0.109
SE_B_4a	40	66	20	0.033	0.219
SE_B_06	80	132	20	0.047	0.349

Table 10. HV/MV Substations

SUBSTATION	CAPACITY (MVA)	HIGHER VOLTAGE (kV)	LOWER VOLTAGE (kV)	NO-LOAD LOSSES (kW)	LOAD LOSSES (kW)
CT_I_02	25	20	1	0.115	0.700
CT_I_03	50	20	1	0.190	1.100
CT_I_04	100	20	1	0.320	1.750
CT_I_05	250	20	1	0.650	3.250
CT_C_04	100	20	1	0.320	1.750
CT_C_05	250	20	1	0.650	3.250
CT_C_06	400	20	1	0.920	4.600
CT_C_07	630	20	1	1.323	6.489
CT_L_05	250	20	1	0.650	3.250
CT_L_06	400	20	1	0.920	4.600
CT_L_07	630	20	1	1.323	6.489
CT_L_08	1000	20	1	1.700	10.500
CT_S_05	250	20	1	0.650	3.250
CT_S_06	400	20	1	0.920	4.600
CT_S_07	630	20	1	1.323	6.489
CT_L_04	100	20	1	0.320	1.750

Table 11. MV/LV Transformers

3.2 Characterization of the EV scenarios

This section details the data used for the senstivity analysis regarding the different penetration levels and characteristics of EVs.

3.2.1 Expected number of EV

According to Deliverable 3.2, three different EV penetration escenarios have been considered.

SCENARIO	DEFINITION
1	**A sensible estimate of EV uptake that is the most likely of the three Scenarios to occur in reality.** However, the needs of the MERGE project require information on the effects of mass integration of EV on the grid and this Scenario, whilst likely in reality, may not be sufficiently high to assess the future needs of the grid.
2	**Whilst being a more aggressive EV uptake Scenario than is expected to occur in reality, this Scenario is the most appropriate for use in the MERGE project.** It is recommended as the prime focus for the MERGE project partners to use in their studies as it will provide better information on the effects of mass integration of EV on the grid.
3	**A very aggressive EV uptake Scenario**. This could be used as an alternative Scenario by the MERGE project partners if necessary. It is unlikely that these values will be exceeded.

Table 12. Scenarios

Some of the analysis have considered all the scenarios. In other cases, the analysis have been focused in scenario 3, as a cap for EV impact on distribution networks. This is considered an extreme case, with sufficient EV penetration so that the network requires reinforcements, which can be therefore analysed with the large-scale planning tool.

In particular the total number of electric vehicles have been obtained from tables of D3.2 related to the total number of EV per country, for each of the three scenarios, in years 2020 and 2030.

SPAIN Vehicle class / technology		SCENARIO 1 YEAR 2020	SCENARIO 1 YEAR 2030	SCENARIO 2 YEAR 2020	SCENARIO 2 YEAR 2030	SCENARIO 3 YEAR 2020	SCENARIO 3 YEAR 2030
L7e	BEV	2,035	11,762	4,159	25,109	8,490	48,957
M1	BEV	59,756	207,018	133,670	656,359	293,468	2,059,415
	PHEV	59,756	690,060	103,138	1,197,940	146,472	1,540,031
	EREV	4	138,012	7,467	355,330	58,694	708,795
N1	BEV	6,829	23,525	15,275	74,586	33,535	234,024
	PHEV	6,829	78,416	11,786	136,130	16,738	175,003
	EREV	0	15,683	853	40,378	6,707	80,545
N2	BEV	2,656	23,002	5,428	49,103	11,081	95,739
TOTAL		137,865	1,187,478	281,776	2,534,935	575,185	4,942,509

Table 13. Number of EV in Spain per scenario, year, vehicle class and vehicle technology.

GREECE Vehicle class / technology		SCENARIO 1 YEAR 2020	SCENARIO 1 YEAR 2030	SCENARIO 2 YEAR 2020	SCENARIO 2 YEAR 2030	SCENARIO 3 YEAR 2020	SCENARIO 3 YEAR 2030
L7e	BEV	507	2,929	1,037	6,253	2,116	12,192
M1	BEV	14,894	43,264	33,324	137,170	73,150	430,387
	PHEV	14,894	171,849	25,712	298,330	36,510	383,522
	EREV	1	34,370	1,862	88,490	14,630	176,515
N1	BEV	1,702	5,858	3,808	18,575	8,359	58,280
	PHEV	1,702	19,528	2,938	33,901	4,172	43,582
	EREV	0	3,906	213	10,056	1,672	20,059
N2	BEV	662	5,728	1,353	12,228	2,762	23,842
TOTAL		34,362	287,432	70,247	605,003	143,371	1,148,379

Table 14. Number of EV in Greece per scenario, year, vehicle class and vehicle technology.

The number of vehicles for each country, scenario and year has been obtained from Table 13 and Table 14. For each distribution area, the number of EV has been obtained assuming proportionallity with the number of customers, considering 27,971,300 customers in Spain and 7,600,000 customers in Greece. Taking into account the total number of customers in Spain and Greece, the expected penetration of Electric Vehicles in these countries is similar. This simplified scaling does not take into account that EV will more probably be located in urban areas; and therefore this approach may allocate too many EV in rural areas.

In Figure 3 the total number of EV in both counties are represented, showing that the number of EV in 2020 is very low under any of the three scenarios; while the number of EV is much higher in 2030. This table and data has significant influence in subsequent analysis.

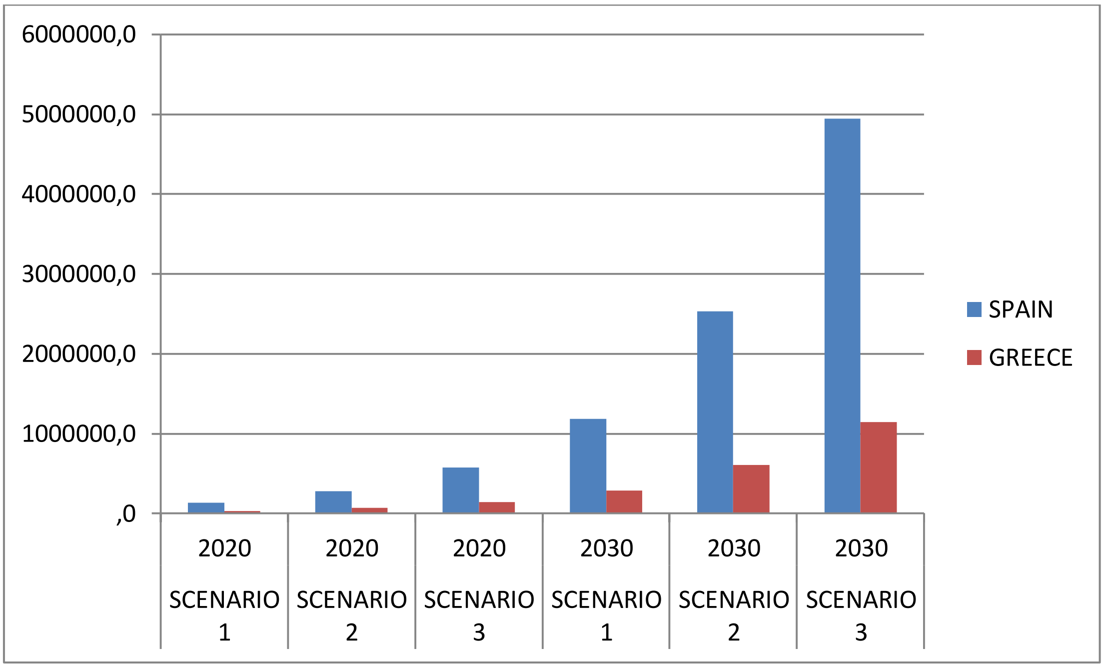


Figure 3. Expected Total Number of EV in Spain and Greece.

3.2.2 EV characterization

The parameters are based on Deliverable D2.1. Charging hours have been calculated using average distance [km/day], energy consumption [Wh/km], the standard charging mode [kW], and considering the limit of the battery size [kWh]. Discretized values of 1 ,2, 3 and 8 hours have been used in simulations.

VECHICLE CLASS	VEHICLE TECHNOLOGY	MODE STANDARD CHARGING RATE (kW)	CHARGING HOURS PER DAY (hours)
L7e	BEV	3	1.02
M1	BEV	3	2.05
	PHEV	3	1.99
	EREV	3	3.23
N1	BEV	3	2.99
	PHEV	3	2.73
	EREV	3	2.99
N2	BEV	10	8.03

Table 15. EV Parameters

The fact of using average distance instead of maximum distance is a conservative hypothesis, that will lead to less reinforcements.

3.2.3 Load and generation profiles

Figure 4 shows the load profile of residential customers. Although it is an average load profile, it has also been condidered for individual coustomers, due to a lack of individual customer profile data. On the other hand, Figure 5 shows the load profile of industrial customers, that has been applied to MV and HV customers. The profiles for residential and industrial customers are based on the data for every type of consumer published by Spanish Energy Comission (CNE) at www.cne.es.

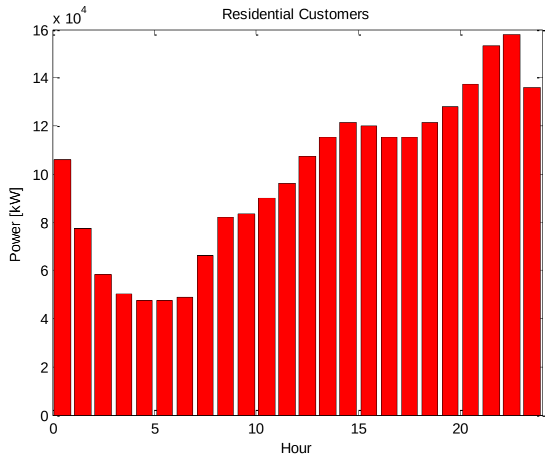


Figure 4. Residential customer profile

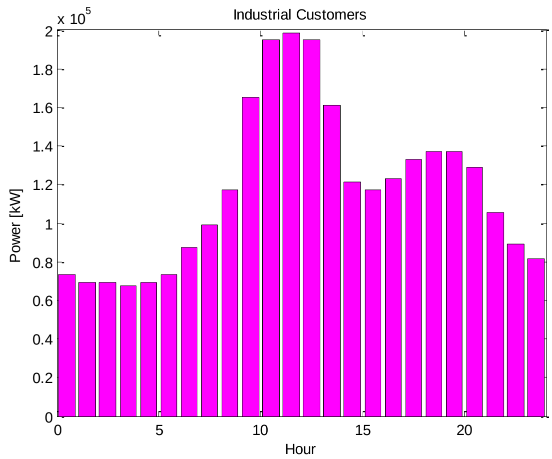


Figure 5. Industrial customer profile

The generation profile of a photovoltaic distributed generator is shown in Figure 6. A standard photovoltaic generation profile has been considered for such technology. For simplification purposes, other distributed generation technologies are modeled with a flat generation profile.

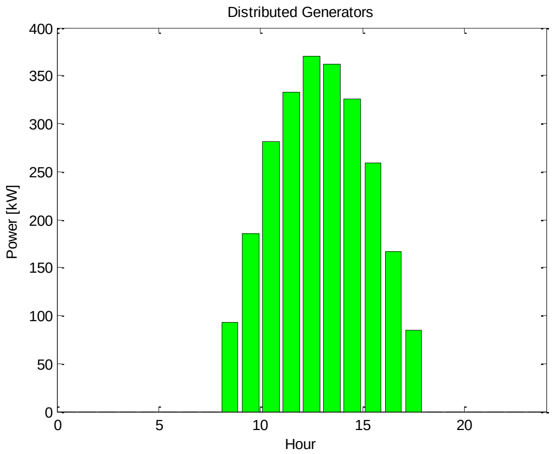


Figure 6. Photovoltaic distributed generation profile

Finally, Figure 7 represents, for each electric vehicle class and technology, the demand profile that has been considered for Multiple tariff policy aiming charging at Valley Hours. It is an extreme scenario in the sense that it considers that there is an hour, in which all electric vehicles are simultaneously charging, and it considers no recharging at all at peak hours.

The fact of using the same profiles for all customers is a simplification which may have significant impact in the results, because with this approach the aggregated net profile is more or less replicated locally, reducing the number of local problems in the distribution grid

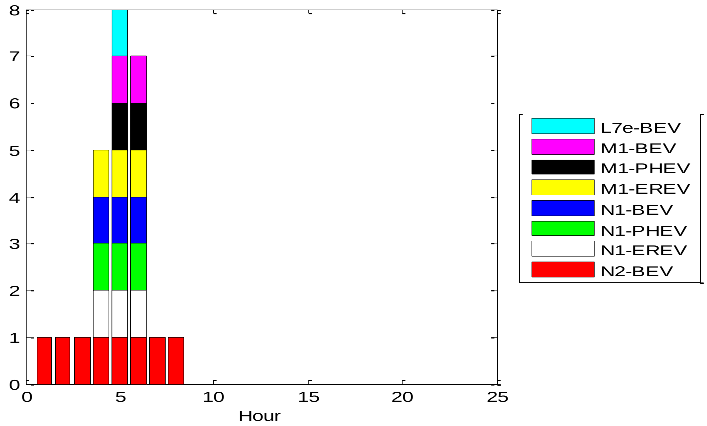


Figure 7. Electric vehicle profile.

3.2.4 EV charging profiles

The analysis of the impact of EV intro the distribution network reinforcements considers three different EV charging schemes: charging at peak hours, charging at valley hours and smart charging.

- **Dumb Charging at peak hours (Peak)**: Electric vehicles of the same type are considered to charge at the same time, during peak hours.

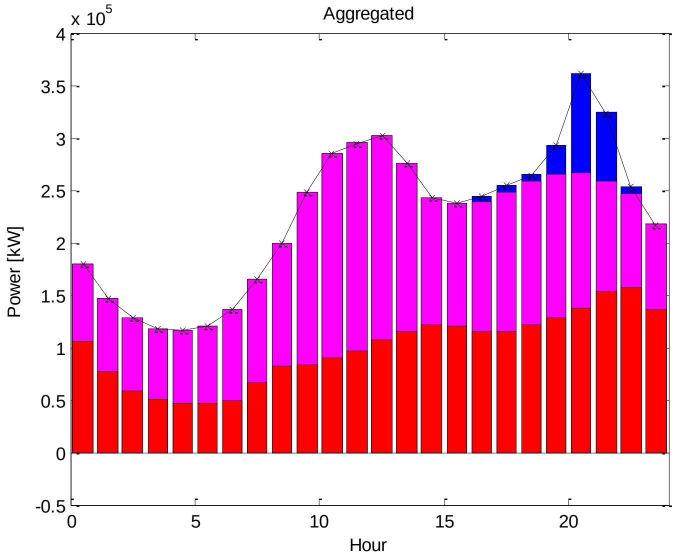


Figure 8. Dumb charging at peak hours

- **Multiple tariff policy aiming charging at Valley Hours (Valley)**: Electric vehicles of the same type are considered to charge at the same time, during off-peak hours. This type of recharging is used to simulate the target of a multiple tariff policy. It could be obtained with new appropriate Multi-Tariff incentive schemes, and with technological solutions such as smart meters and timers in the cars.

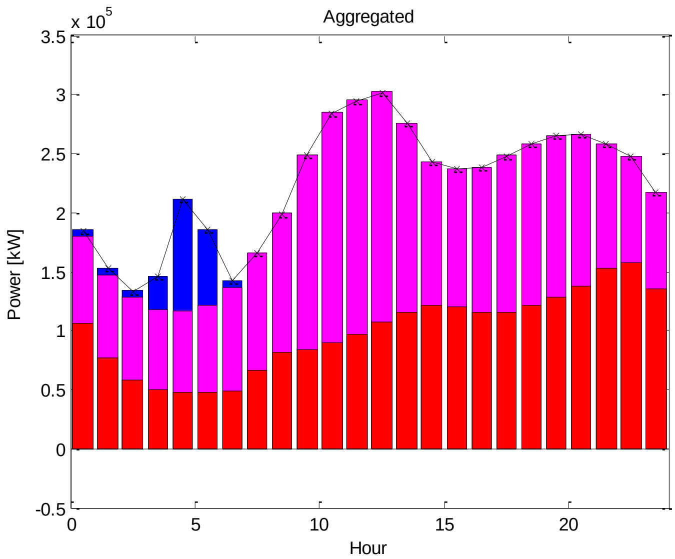


Figure 9. Multiple tariff policy aiming charging at Valley Hours

- **Smart Charging (Smart)**: Electric vehicles are charged selecting the starting charging hour to "fill the valley" of the overall aggregated profile, considering demand and distributed generation. Local issues were not taken into account to design this type of charging, so it only fills the valley from an aggregated point of view. This recharging system is expected to require system controls and communication systems.

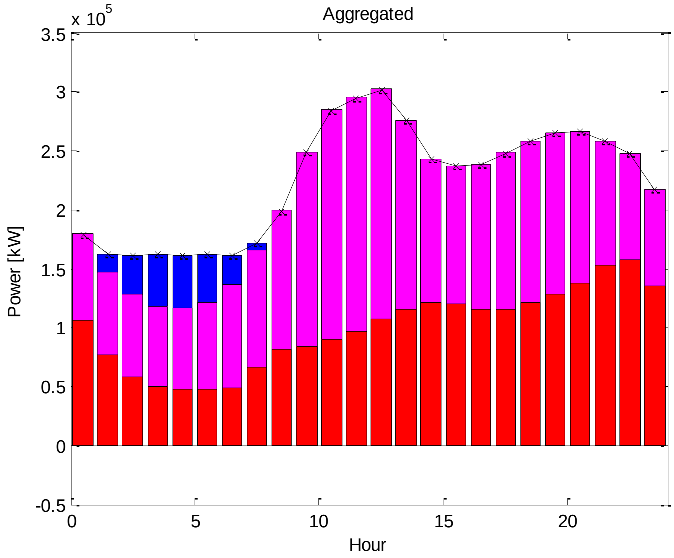


Figure 10. Smart Charging

3.2.5 EV location

In the analysis, two different locations of EVs charging stations have been studied:

- Distributed charging stations, located in the low voltage network. Within this scheme, two additional approaches are studied, considering if EV charging stations are located at the current connection points of the loads or not.
- Concentrated charging stations, located in the medium voltage network, due to the higher charging capacity required.

Electric vehicles have been located in the low voltage network with two approaches:

- **Placement independent of the demand**: In this case EV have been located selecting random locations with the supply points, independently of the demand and of the number of customers of each supply point. In Figure 11 it is shown that in this case the demand of the EV is more or less uniform through every node, independently of their demand. This is not expected to happen, but this case may be helpful to indicate what happens when the aggregated profiles are not replicated locally, reproducing the effect of local issues appearing in the distribution grid.

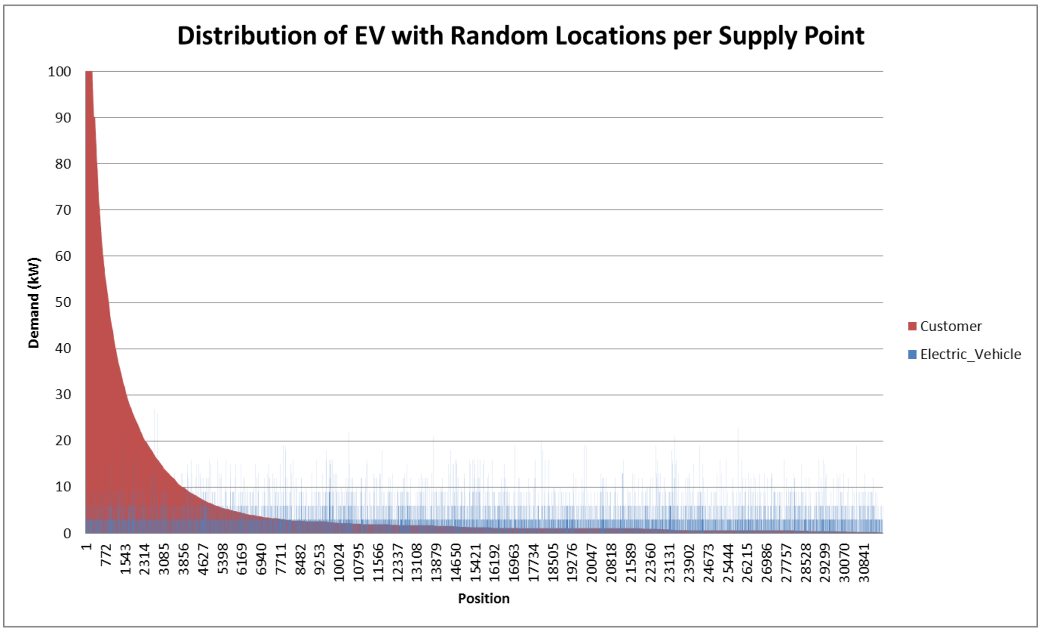


Figure 11. EV placement independent on the demand

- **Placement dependent on the demand**: In this case EV have been located selecting random locations with customers. In this case more electric vehicles are expected to be located in supply points with many customers. This is more likely to occur in reality. In Figure 12 it is shown that in this case the demand of the EV is more correlated with the demand of the customers.

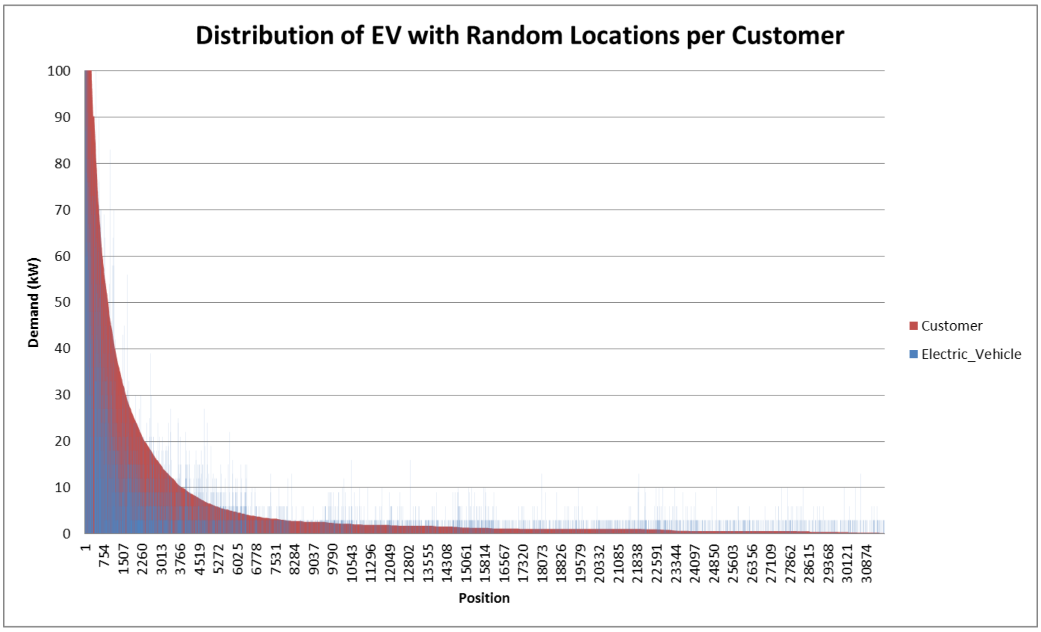


Figure 12. EV placement dependent on the demand

4 ANALYSIS OF THE RESULTS

This section presents the results for the analysis of the impact of EV penetration into distribution networks reinforcements. First, the resulting reference networks of the different distribution areas are presented. Then, the results of four sensitivity analysis of EV penetration are presented:

- EV penetration sensitivity analysis (EVs located in LV and for the Greek and tourist distribution areas).
- Distribution area sensitivity analysis (EVs located in LV and scenario 3 for EV penetration).
- EV charging scheme and location in LV analysis
- EV charging stations location MT vs. LV

4.1 Reference networks

Table 16 summarizes the main figures of the different distribution areas included in the analysis. Number and power of LV & MV customers are an input to the model. In the case of Spain HV/MV substations and MV/LV transformers have been also set as an input. The lenght of the network feeders is a result of the RNM.

The distribution areas cover large zones. The Tourist area is the largest area in terms of customers, networks lenghts and MV/LV transformers, with about 170,000 customers and about 1GW of installed power. Both the tourist and the rural area have a significant contracted power of MV customers. All the other areas, represent cities, and they predominantly have LV customers. The Big City Old Network Area is significantly smaller than the others, therefore it is considered to be less representative.

	NUMBER OF CUSTOMERS		POWER OF CUSTOMERS (kW)		LV NETWORK	MV NETWORK	MV/LV TRANSF.	HV/MV SUBS.
	LV	MV	LV	MV	km	km	NUMBER	NUMBER
Tourist	154,984	15,171	816,663	204,538	1,058	600	1,089	7
Rural	25,637	921	120,987	41,293	378	567	267	3
New City	106,978	197	564,913	3,133	678	780	838	13
Big City Old Network	8,173	212	53,785	1,638	31	60	93	3
Big City New Network	34,567	355	227,004	4,958	313	285	412	2
Greek City	38,737	66	179,838	5,450	246	227	318	1

Table 16. Distribution areas overview

In the following the resulting reference networks of the different distribution areas considered are graphically presented.

The resulting network of the distribution area in Katerini is an urban network, which follows a certain street map, because of the customers have been located in the contour of the building blocks. Load in the area is 180MW, supplied throug 320 medium to low voltage transformation centers.

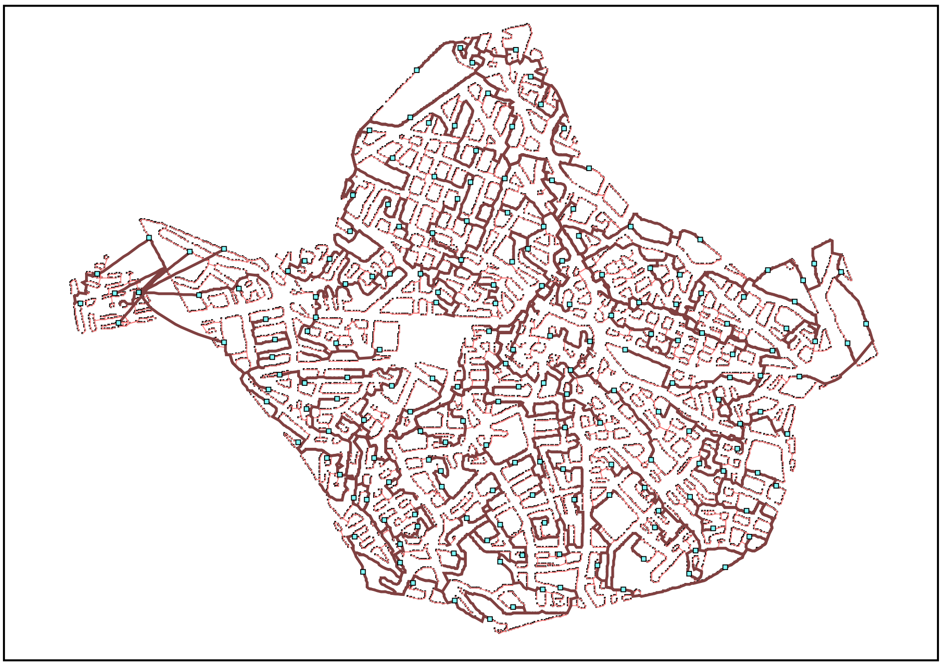


Figure 13. Greek City distribution network.

The Tourist Area is a large 42km^2 coastline, that covers an area of about 400km^2. Load is about 1GW, with 170,000 customers and 353 distributed generators. A zoom-in in a municipality is also shown inFigure 14.

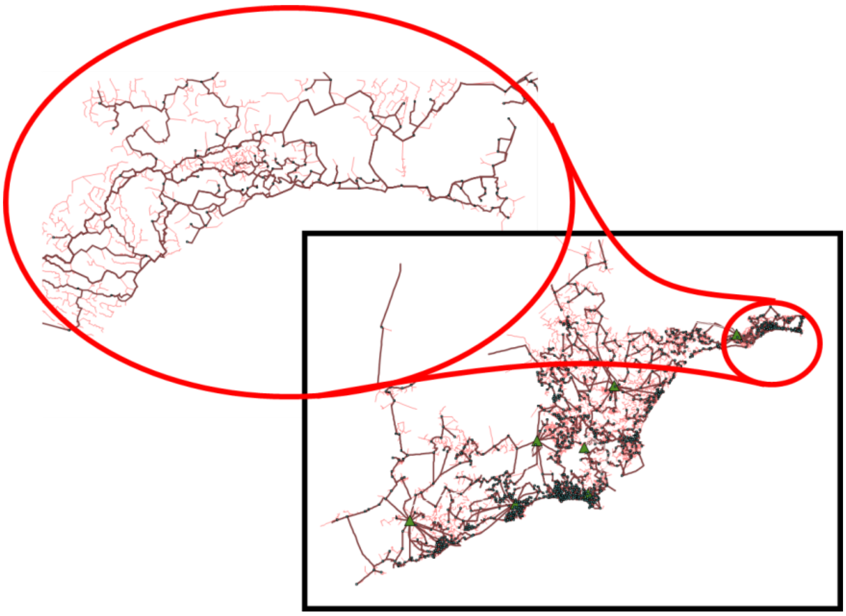


Figure 14. Tourist Area distribution network.

The Rural Area the network is predominantly MV, with longer lines than the other urban areas. Demand is scattered, with small settlements, which are located far each other. Total load is about 180 MW with over 160,000 consumers.

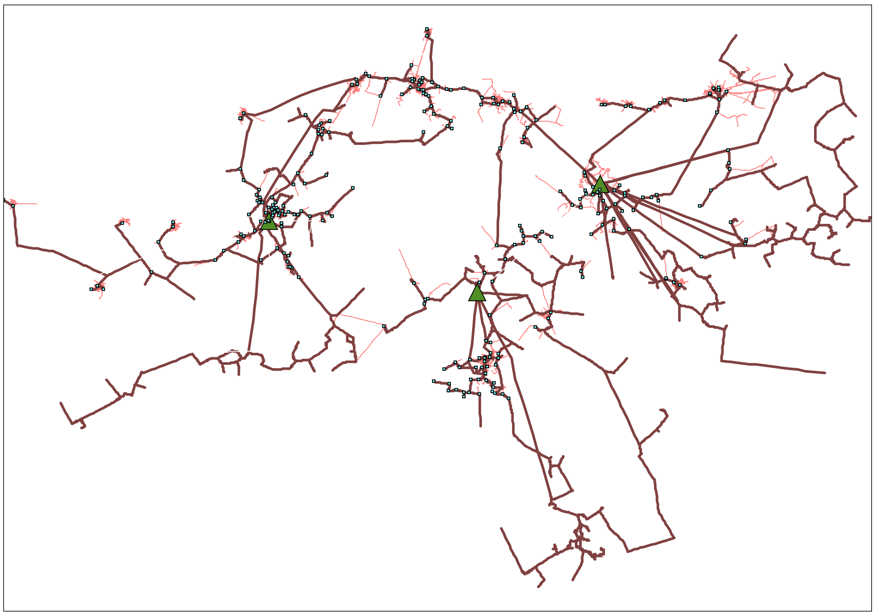


Figure 15. Rural distribution network.

The new city distribution network and its surroundings are shown in Figure 16. Cummulated load is 500MW. The resulting network is similar to that of the tourist area, but with a higher degree of urban areas.

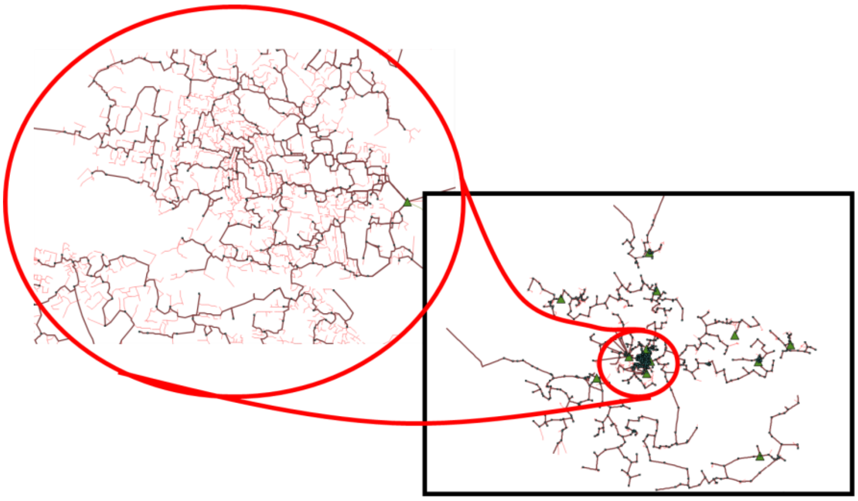


Figure 16. New City distribution network.

As shown in Figure 17 the big-city old network area is a small zone, with only a few customers, which is not considered very representative for a large-scale planning model.

Figure 17. Big City Old Network distribution network.

In Figure 18 it is shown the Big city New Network area, with medium size settlements. Compared with the previous Old Network is four times larger in demand and network lenght.

Figure 18. Big City New Network distribution network.

4.2 Incremental analysis

This section presents the results of EV impact on distribution network reinforcements under different network scenarios and EV charging schemes. These results are the basis for the main conclusions on efficient strategies for EV charging.

As an example, Figure 19 shows a zoom-in of an example of reinforcing the initial network (obtained in the previous section). In this case the initial network and MV/LV transformers are presented in red; while reinforcements are in blue. Lines represent MV and LV network, and thicker lines represent MV electrical lines. MV/LV transformers are represented by circles.

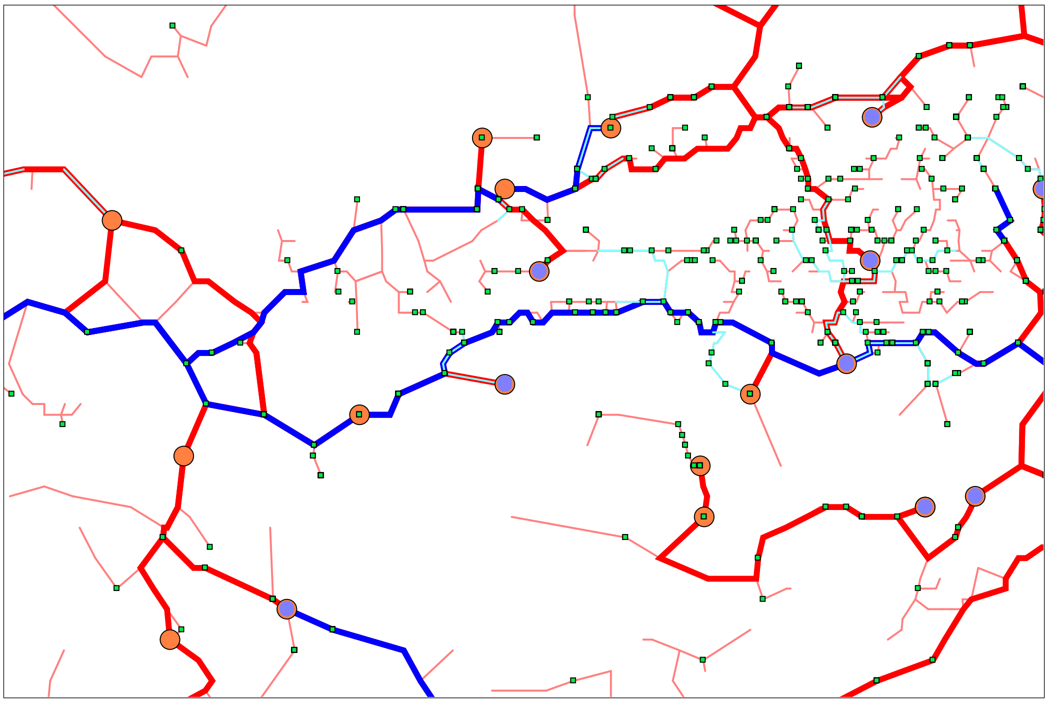


Figure 19. Reinforcement example

In this case the aggregated costs of all the reinforcements are presented, distinguishing three main concepts: LV feeders, MV/LV transformers and MV feeders.

Results of investments in Euros would have been very dependent on the size of each network. Therefore, in order to obtain more general conclusions, the replacement cost of the initial network and the cost of the reinforcements have been combined in order to express the reinforcements as a percentage. This allows comparing the results in different distribution areas. For example in Figure 20 the cost of the LV feeders reinforced in the Greek city in a given simulation have been referred to the replacement cost of the LV feeders in the initial network of the Greek City, and expressed as percentage. In this concrete case, this means that, in the Greek City with dumb recharging at peak time at year 2030 under scenario 3, LV Feeders would have to be reinforced increasing the replacement cost of the LV feeders by over 15%. This result can be directly compared with the results in the Tourist Area in Figure 21, which is about 10%.

4.2.1 EV penetration sensitivity analysis

The three different EV penetration scenarios, associated to expected number of EVs in the years 2020 to 2030 are analyzed, for the Greek and Spanish Tourist distribution areas. Results include the reinforcements needed in these distribution networks, which include the following:

- **Reinforcements in the low voltage networks**, due to the need of higher cross-section and ampacity, and hence higher costs. Then, a conductor is selected, within the previously defined catalogue.

- **Reinforcements in the low voltage to medium voltage transformer**, as there is a need of a higher transformation capacity. It is important to indicate that there are few typical rated capacities available, e.g. 250 kVA, 400 kVA, 630 kVA, etc.

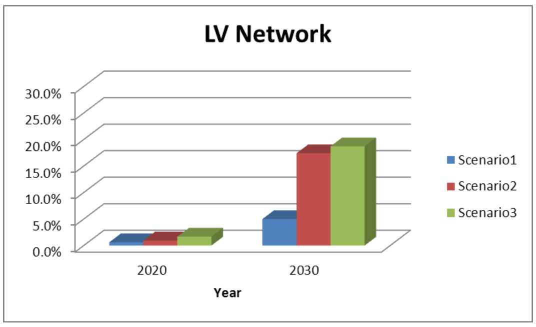
- **Reinforcements in the medium voltage network**, due to the need of higher cross-section and ampacity, and hence higher costs. Then, a conductor is selected, within the previously defined catalogue.

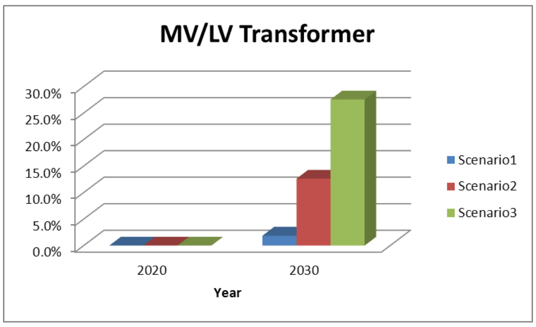
The main assumptions of this analysis are that the recharging of EVs takes place at peak time, and recharging stations are located in the LV network close to the corresponding customer connection points.

EV penetration in the Greek City distribution area

From the results presented in the following figure, we can observe that there are not significant reinforcements in year 2020 under any of the three EV penetration scenarios. This figure presents the ratio between the reinforcement costs due to EV penetration scenarios and the costs of the reference network (obtained in the previous section). The higher reinforcements are required in the MV/LV transformers, while the lower reinforcements are required in the MV feeders.

Recharging at peak time expected reinforcements are very high, up to 25% of the cost of the existing elements, for HV/MV transformers, in Scenario3, year 2030.





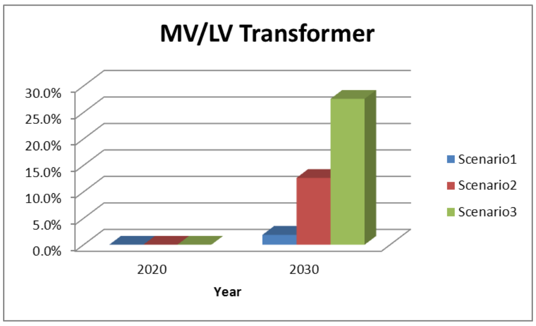


Figure 20. Greek city. Recharging at peak time. EV placement dependent on the demand.

EV penetration in the Spanish tourist distribution area

As it occurred with the Greek distribution area, there are not significant reinforcements in year 2020 under any of the three scenarios in the Spanish tourist area. The higher reinforcements are required in the MV/LV transformers, but in this case reinforcements in LV & MV feeders are more similar.

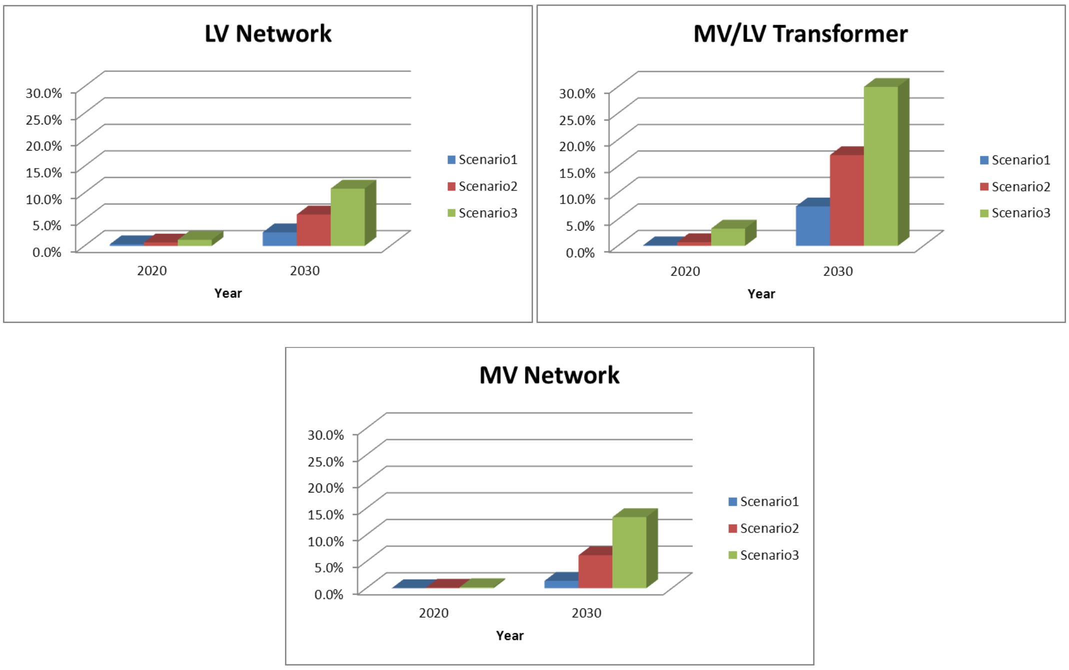


Figure 21. Tourist Area. Recharging at peak time. EV placement dependent on the demand.

Next figure presents the cost of the reinforcements divided by the number of EV considered, in order to obtain some indication on the cost required per EV. These results are directly influenced by the standard equipment costs that have been considered. The results in this section seem quite high, which may be explained by the fact of considering recharging at peak time.

For LV feeders, the cost per EV connection is more or less constant, at about 275 €/EV. However for MV/LV transformers and MV feeders, almost no reinforcements are required when the number of EV is low. As the number of EV increases, the cost per EV also increases, reaching also a constant value in the case of MV/LV transformers at about 390 €/EV.

Comparing Figure 21 and Figure 22, the higher values at year 2020 of the LV Feeders in [Euros/EV] than as percentage are easily explained because there are very few expected electric vehicles in 2020. Therefore the total increase of the replacement cost of LV feeders in [%] is very low because very few feeders have to be reinforced at 2020. On the contrary, in these simulations, the total cost of the LV feeder reinforcements divided by the number of electric vehicles is more or less constant independently of the year (and number of electric vehicles), as Figure 22 shows.

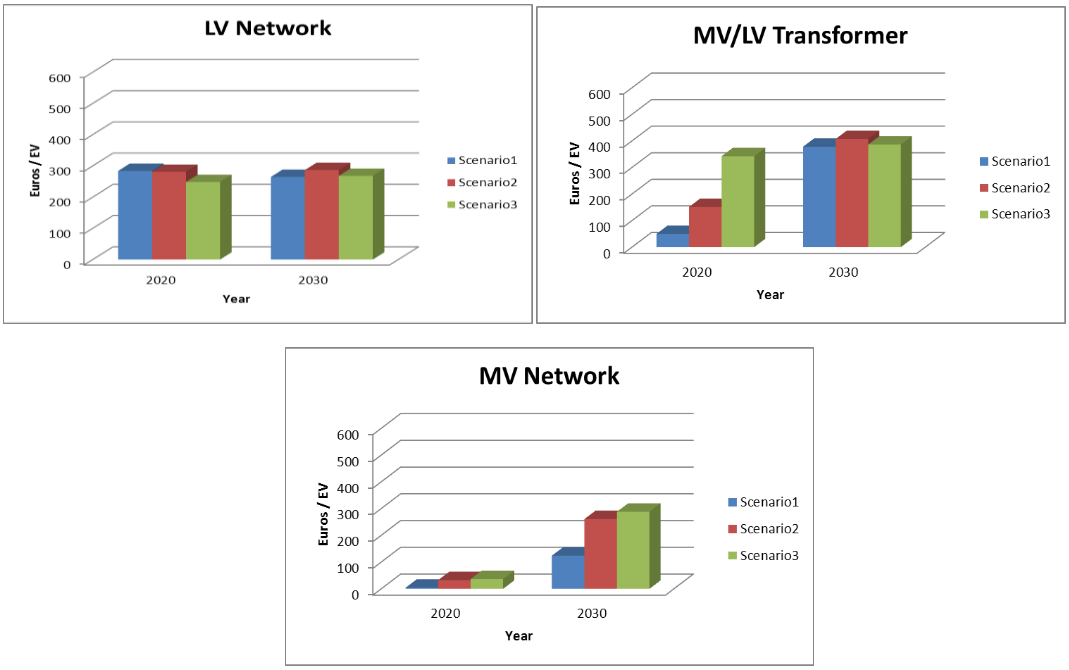


Figure 22. Tourist Area. Recharging at peak time. EV placement dependent on the demand.

4.2.2 Distribution area sensitivity analysis

The impact of EV charging in six different distribution areas (including urban and rural networks) is presented. For this sensitivity analysis the following assumptions are considered: scenario 3 corresponding to the expected EV penetration in the year 2030, recharging takes place at peak time and EV charging connections are placed close to the current load points.

In the urban areas reinforcements in MV/LV transformers are generally higher than in feeders. A load increase in these areas generally does not result in under voltages, but to increase the capacity of the transformer, which was designed for a certain use factor. Reinforcement costs are in the range of 20% in the old network area to 30% in the tourist area.

Moreover, in urban areas, reinforcement costs in MV feeders are typically higher to those in LV networks. Increasing the peak load in these areas needs both additional transformation capacity and higher a ampacity of the upstream network.

However in rural areas, undervoltage limit becomes a common constraint resulting from a load increase. Then, more reinforcements are needed in MV and LV feeders, which are also longer than in urban areas.

Finally, the higher reinforcements in the rural area are conditioned by having considered the number of EV proportional to the number of customers independently of the type of distribution area. This means disregarding the different probabilities associated to the appearing of an EV in each type of area (rural, semi-urban, urban), that would have led to consider less EV in the rural area; and therefore to less reinforcements.

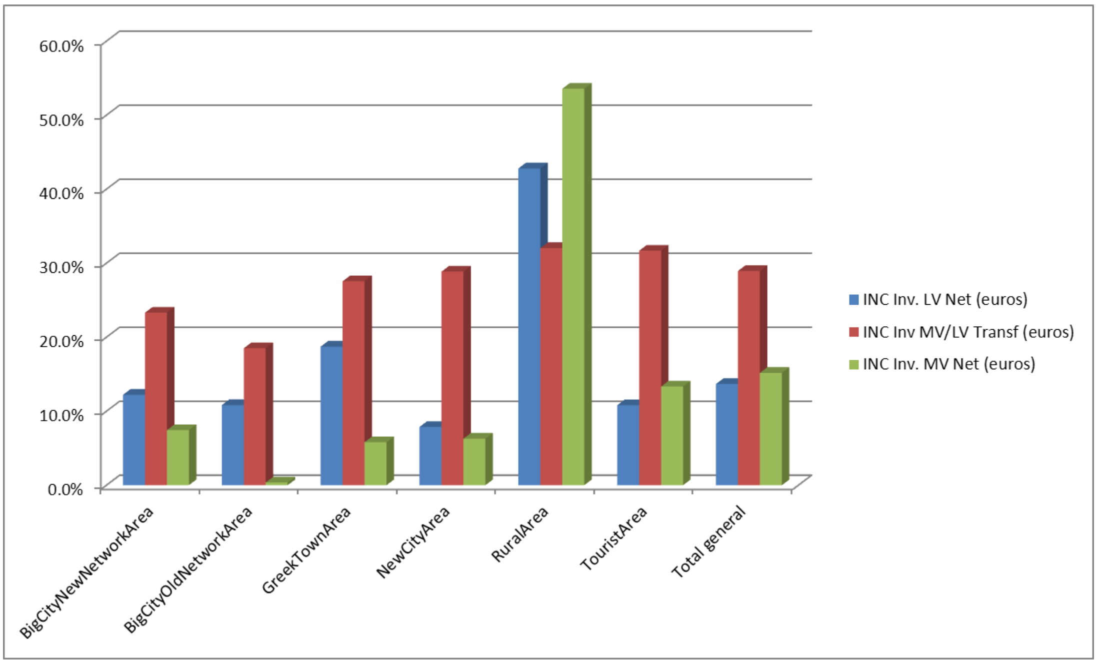


Figure 23. Distribution areas. MV/LV feeders and MV/LV transformers percent results. Scenario 3. Year 2030. Recharging at peak time. EV placement dependent of the demand.

4.2.3 EV charging scheme and location in LV analysis

Results from three different charging strategies are presented, for the scenario 3 and year 2030 have been considered. In addition, the EV charging stations can be located in the close to the already settled consumer connection points or in other locations.

EV placement independent of the demand

Next figures show the incremental costs for the different distribution areas and charging strategies if the EV loads are located randomly in the network.

The six distribution areas show similar tendencies. Dumb charging at peak hours increases the peak demand in the network, and then requires the highest reinforcement costs. These costs are in the range of 10% (in the big city old network case) up to 45% (in the new city and rural areas) for the LV network. Under this strategy the needs in transformers are more limited, from 25% up to 35%.

If a multiple tariff policy is defined, that incentivizes charging at valley hours, there is a significant increase in the consumption during this period, however lower that the daily peak. Then, the reinforcements are much lower than dumb charging. For three areas there are nearly no reinforcements needed, both in the LV network and the transformers. However, other areas need some reinforcements (rural, new city and tourist areas) lower than 20% in both LV feeders and transformers.

Finally, the use of a smart recharging strategy will reduce the peak demand during the valley period, hence the costs can be even further reduced in some distribution areas. This is the case of the new city and tourist areas, both in the needs of LV network reinforcements and capacity needs of the transformers.

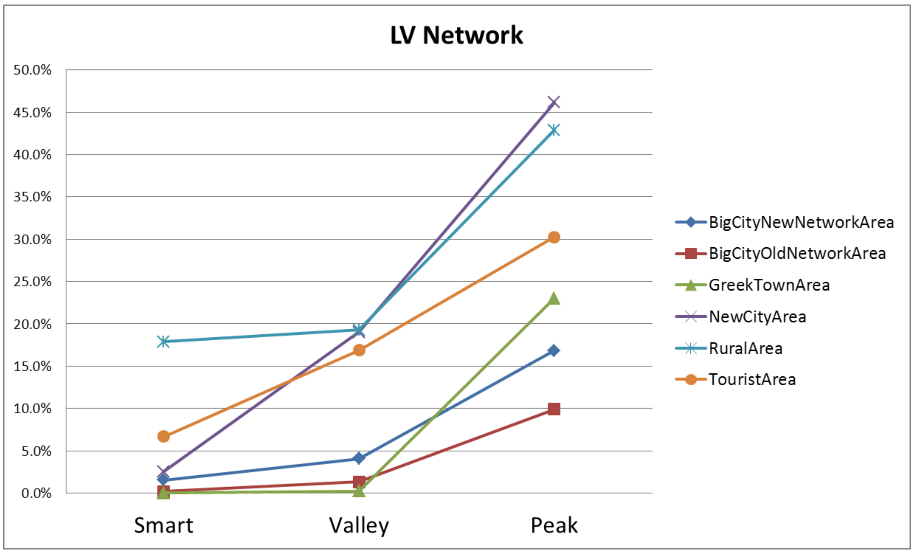


Figure 24. Distribution areas. LV feeders percent results per scenario and year. Scenario 3. Year 2030. EV placement independent of the demand.

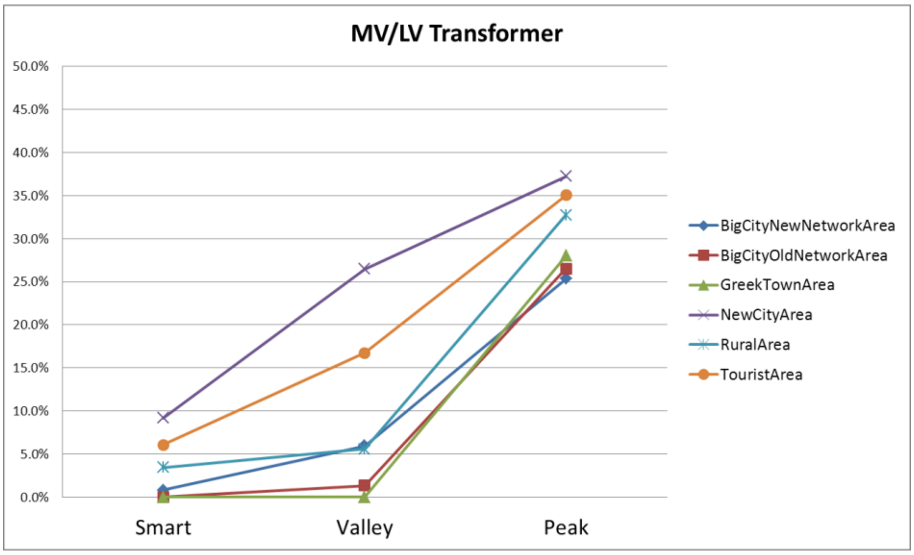


Figure 25. Distribution areas. MV/LV transformer percent results per scenario and year. Scenario 3. Year 2030. EV placement independent of the demand.

EV placement dependent of the demand.

A second analysis considers that EV charging stations are located in the some places as the existing customers.

Again dumb recharging at peak time is always the most costly solution, which requires the highest reinforcements. The rural area has similar LV network needs as the previous case, nearly 45%. However the other distribution areas have lower needs than in the case of random location of the EV charging in the LV, always below 20%.

In this scenario, multiple tariff policy aiming charging at Valley Hours decreases the costs to near zero. This could be applied to all distribution areas analyzed, expect for the rural area where reinforcement costs are still relevant, 20% for LV feeders and 5% for transformers.

Finally, the cost reduction achieved under a Smart Recharging scheme is quite similar to that of a multiple tariff scheme. A multiple tariff policy aiming charging at Valley Hours can easily be obtained with new appropriate Multi-Tariff schemes, and simple technological solutions such as timers in the cars. According to the results presented within the MERGE project, Smart Charging requires the development of a Smart Metering infrastructure, which if properly adjusted, will allow the easy development of such approach without large extra costs. Then a multi-tariff scheme is a sufficient option for EV charging, if the charging points are close to the corresponding consumers.

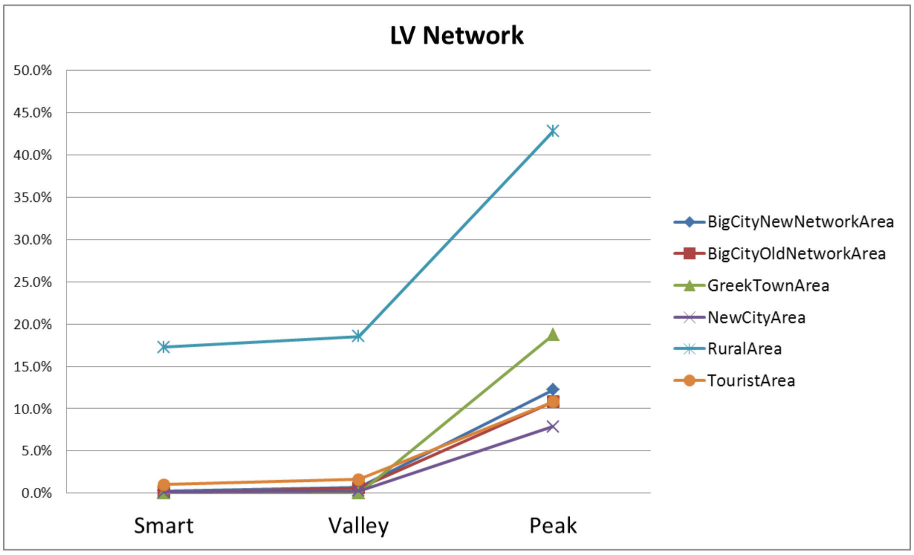


Figure 26. Distribution areas. LV feeders percent results per scenario and year. Scenario 3. Year 2030. EV placement dependent of the demand.

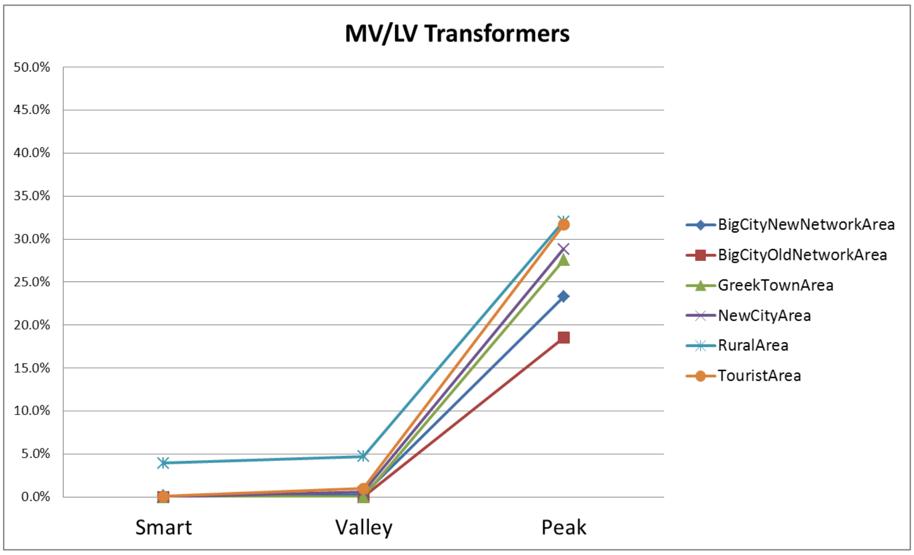


Figure 27. Distribution areas. MV/LV transformer percent results per scenario and year. Scenario 3. Year 2030. EV placement dependent of the demand.

4.2.4 EV charging stations location MT vs. LV

In this section a comparative analysis of EV charging in LV and MV networks is presented. First, reinforcements required if EVs are aggregated in the MV network are calculated. Then, these results are compared with the previous results where EVs were connected at the LV network.

Charging stations located in the MV can charge up to 30 EVs. The scenarios analyzed consider the higher EV penetration, associated to scenario 3 in 2030. The results presented in the following only shows reinforcements required in the MV feeders, as neither LV feeders nor transformers are affected by the higher load in the MV network. In addition, two possible locations of charging stations have been considered:

- **New connections**: recharging areas are located in new medium voltage EV supply points, not necessarily in the location of existing MV supply points.
- **Existing connections**: recharging areas are located in the same location than existing MV/LV transformers.

In Figure 28 the percent incremental cost of MV feeders is shown when selecting new locations for the MV supply points. In this case there is a connection cost depending basically on the coordinates of the new locations and the distances to the existing MV network. This additional cost is more or less constant, and independent of the EV recharging profiles. Dumb recharging of EVs at peak time would require slightly higher costs. Incremental costs are in the range of 15% up to 25%, corresponding to the Greek and Spanish tourist distribution areas, respectively.

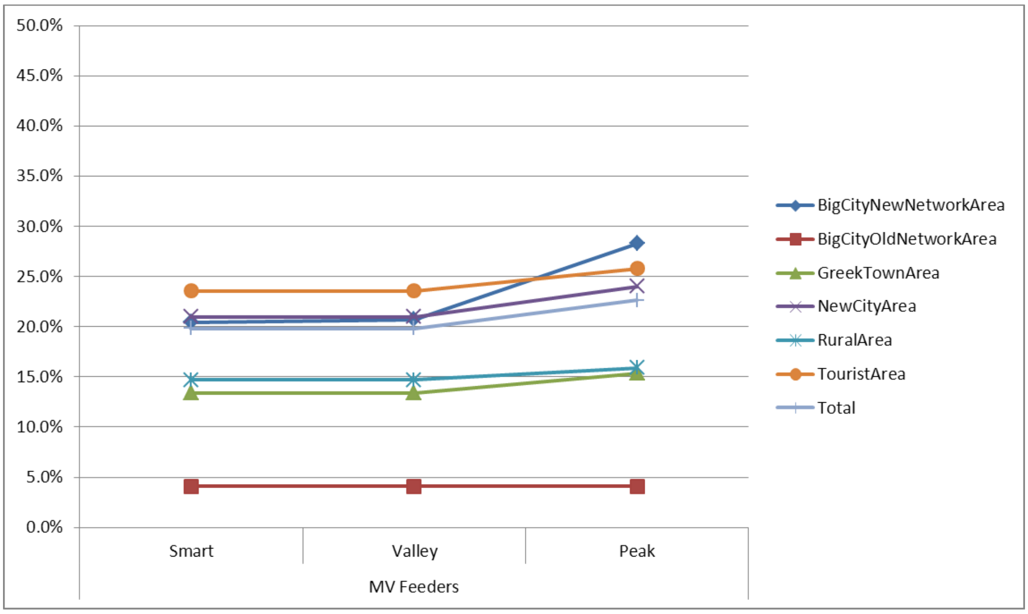


Figure 28. Distribution areas. MV feeders percent results per scenario and year. EV recharging in new MV supply points.

In Figure 29 the percent incremental cost of MV feeders is shown when selecting new locations from existing MV supply points or MV/LV transformers. In this case the reinforcements are lower, except for the new city distribution area. Network updates are quite dependent on the EV charging strategy. Smart Charging leads to near zero reinforcements, while dumb charging at peak hours leads to the maximum level of reinforcements. Depending on the distribution area, in some cases mmultiple tariff policy (charging at Valley Hours) reduces reinforcements near to zero; while in other cases only smart charging is able to achieve such reduction.

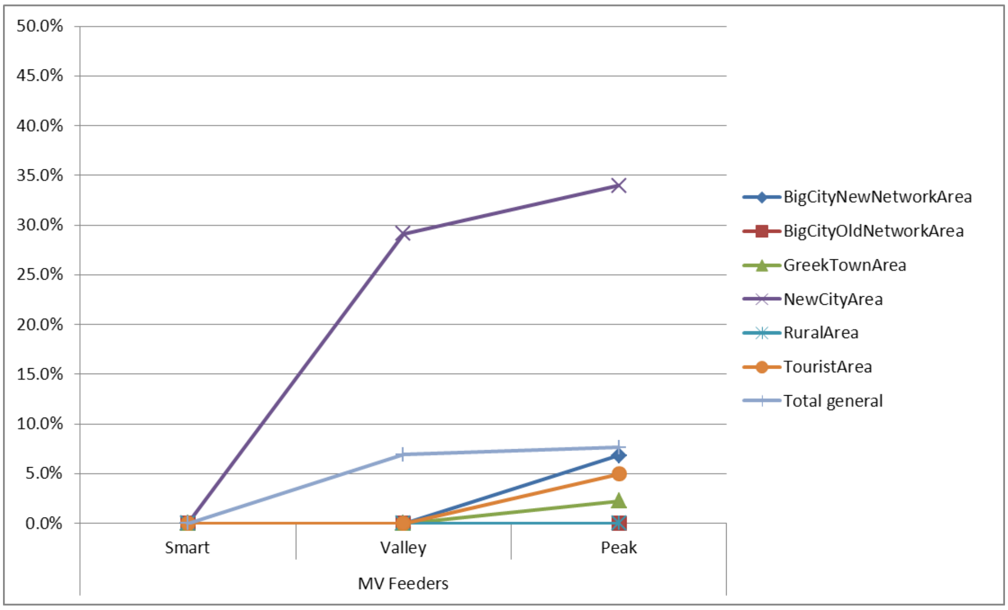


Figure 29. Distribution areas. MV feeders percent results per scenario and year. EV recharging in existing MV supply points.

In the following figures the total investment costs (including those of LV and MV networks and LV/MV transformers) are compared when locating the EV in low voltage and in medium voltage. For EV in LV, locations have been selected from LV customers. For MV EV supply points in new MV locations, coordinates have been selected from LV customers. For MV EV supply points in old MV locations, coordinates have been selected from MV/LV transformers.

For dumb charging at peak time it is always less expensive the aggregated recharging directly at the MV network. This difference is even higher if the aggregated charging points are deployed in existing MV connections.

If MV charging stations are not directly located in the existing MV network, there is an additional fixed cost of new MV feeders, which is higher than the required investment cost with LV recharging points at home (Figure 30). Then, distributed EV charging, either with Smart Charging or with Multiple tariff policy aiming charging at Valley Hours, require less investment costs than connections to new MV supply points

On the other hand, if the new charging stations are placed in existing MV/LV substations (which would be the expected future, as it corresponds to parking areas in railyway/bus stations or commercial areas), the required investments are lower than EV charging in LV supply points. Moreover, there is no need of reinforcements with a Smart charging strategy in aggregated stations connected to the MV, for any of the distribution areas studied.

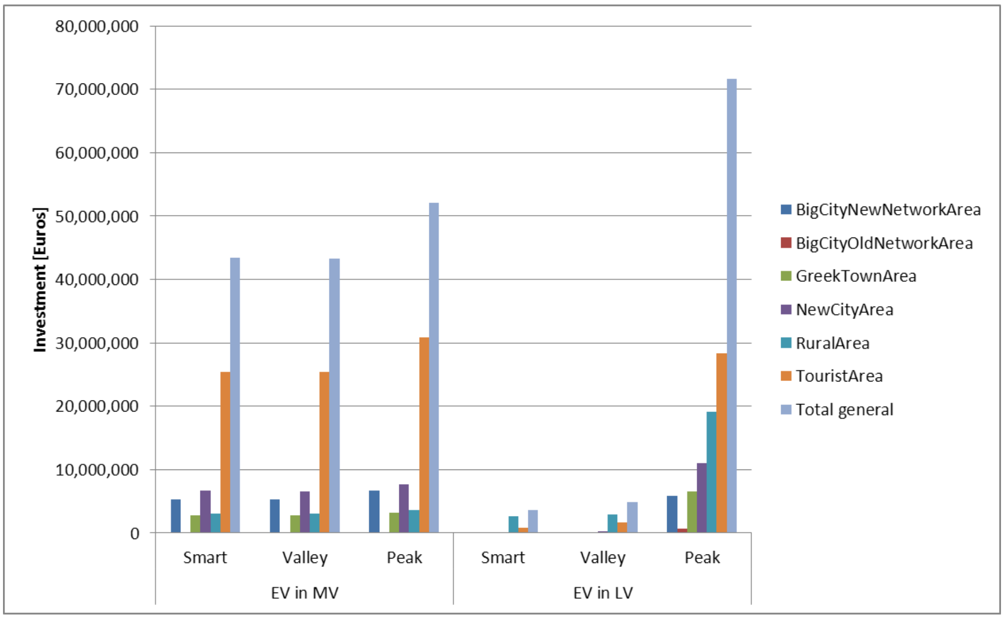


Figure 30. Distribution areas. Total investement cost. EV located in LV versus EV located in new MV. For MV new MV supply points have been considered.

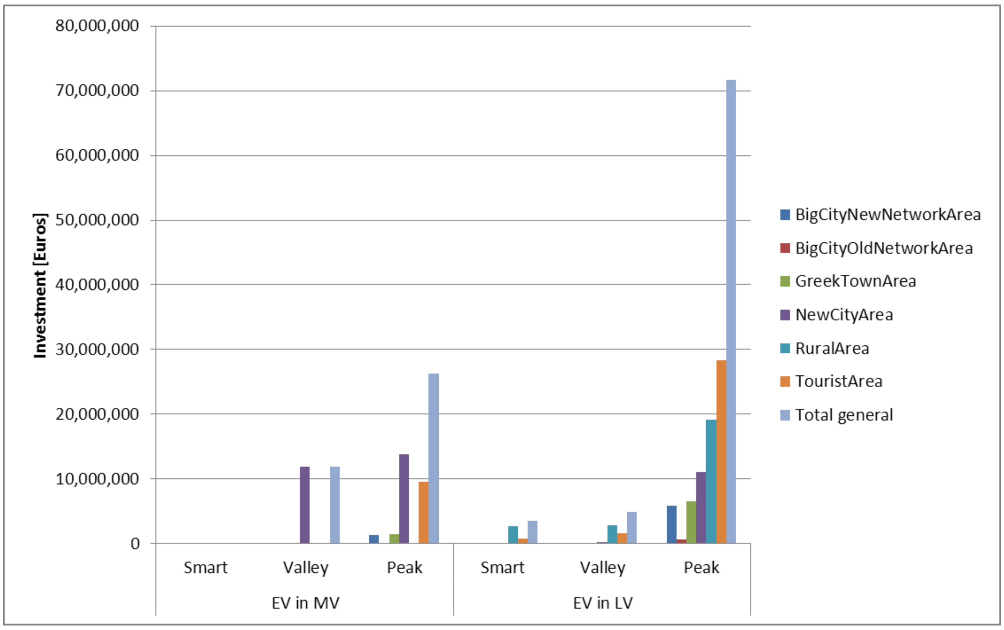


Figure 31. Distribution areas. Total investement cost. EV located in LV versus EV located in existing MV. For MV old MV/LV transformer coordinates have been considered.

5 CONCLUSIONS

Investments are not expected to be very significant in year 2020, under any of the three scenarios of EV penetration, as the forecast number of EV for that year is low. However, in year 2030 the required reinforcements may be quite high, especially if there are no strategies to EV charge, and then EVs are charged at peak hours. Therefore actions should focus on the reinforcements required for year 2030, and regulation should discourage dumb charging at peak hours.

In the urban areas more reinforcements are expected in MV/LV transformers than in feeders, because of a capacity issue, being the current limits the relevant constraint. However in the rural areas more reinforcements are required in feeders, in order to ensure the voltage limits. Therefore, capacity issues are expected in urban areas, while voltage issues are expected in rural areas.

The six distribution areas analyzed show similar tendencies. Dumb charging at Peak Hours is always the most costly solution, requiring high reinforcements. Multiple tariff policy aiming charging at Valley Hours always decreases significantly the reinforcement costs. And, in some cases, Smart Charging can decrease the costs even further. In other cases multiple tariff policy, aiming charging at Valley Hours, may be enough to almost eliminate the need of reinforcements. These results are dependent on the simulation assumptions; for example the use of average profiles for single customers, may have lowered the need of reinforcements due to local problems in the distribution grid.

Generally, aggregated recharging in the medium voltage network is less costly, except when the new medium voltage recharging points are located far from the existing MV network, which would lead to a fixed cost independently of the EV profile. In this case, charging at LV would be a cheaper approach. Therefore, if aggregated MV charging points are deployed, they should be located near the existing MV network in order to diminish the connection cost.

Multiple tariff policy aiming charging at Valley Hours can easily be obtained with new Multi-Tariff schemes, and simple technological solutions. On the other hand, smart charging would require the development of a Smart Metering infrastructure, which if properly adjusted, will allow the easy development of such approach without large extra costs, according to the results presented within the MERGE project. For Multiple tariff policy aiming charging at Valley Hours, from the point of view of technology, the EV should have a simple timer, to allow customers select the starting or finishing charging hour. At least, new Multi-Tariff schemes should also be established to encourage customers to recharge at valley hours. With a simple dual-tariff scheme, probably most customers would simultaneously start charging at the start of the valley tariff. Therefore, a somewhat more complex multi-tariff scheme should be established so that customer recharging is more spread all along the valley hours.