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Optimal allocation of electric vehicle charging infrastructure in cities and regions

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Abstract

A geospatial analysis of electric-vehicle charging infrastructure allocation within a city and a region, based on open source GIS tools, is described. A methodology was developed to provide optimal locations of electric vehicle infrastructure (charging stations) within a spatially extended region. Two different cases were identified: placement in a city network (urban road network) and in a regional or national network (rural roads and highways). For a city and a regional network, the methodology identifies high-potential areas for the installation of charging station. In contrast, for a highway network the methodology provides explicitly the suggested locations: the charging stations should preferably be placed in already built areas, gas stations or rest areas, to minimize additional investment costs. A pilot study was made for the city of Bolzano/Bozen (city road network) and the province of Alto Adige/Südtirol (rural and highway network). The municipality and the province gave positive feedback on the suggested locations.

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Acknowledgements

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Executive summary

Policy context

Road transport, a key component of economic development and human welfare, plays a growing role in world energy use and emissions of greenhouse gases. In 2010, globally, the transport sector was responsible for approximately 23% of total energy-related carbon dioxide emissions, a potent greenhouse gas. Greenhouse gas (GHG) emissions from the transport sector have more than doubled since 1970, 80% of this increase coming from road vehicles. In the European Union, road transport contributes one-fifth of EU’s total emissions of carbon dioxide. Emissions in 2012, even though they fell by 3.3%, were still 20.5% higher than in 1990. Light-duty vehicles, cars and vans, produce approximately 15% of the EU’s emissions of carbon dioxide.

Transport in Europe is 94 % dependent on oil, 84 % of it imported, leading to a financial cost of EUR 1 billion per day and significant dependence on importing oil with the consequent threat to the EU’s security of energy supply.

Emissions from road transport influence air quality in cities. Numerous epidemiological and toxicological studies have associated urban air quality and air pollution, including particulate matter, with adverse health effects.

Given the negative impact of fossil fuels on the environment, public health, and energy security policy makers support the replacement of fossil fuels by more sustainable alternatives.

The European Commission regards alternative fuels an important option to sustainable mobility in Europe. The Clean Power for Transport package, adopted in 2013, aims to foster the development of a single market for alternative fuels for transport in Europe. It contains a Communication laying out a comprehensive European alternative fuels strategy [COM(2013)17] for the long-term substitution of oil as an energy source in all modes of transport. The Directive on the deployment of alternative fuels infrastructure (2014/94/EU) requires Member States to develop national policy frameworks for the market development of alternative fuels and their infrastructure, among other elements. The study summarized in this report presents a GIS (Geographic Information System) methodology, based on open source tools that may assist national authorities to allocate charging stations for electric vehicles (EVs) in urban environments, rural road networks, and highways.

Key conclusions

The aim of the proposed methodology is to provide optimal locations of EV infrastructure (charging stations) within a spatially extended region. Two different cases were identified: placement in a city network (urban road network) and placement in a regional or national network (rural roads and highways). For a city and a regional network, the methodology identifies high-potential areas for the installation of charging stations. In contrast, for a highway network the methodology provides explicitly the suggested locations: the charging stations should preferably be placed in already built areas, gas stations or rest areas, to minimize additional investment costs.

A pilot study was made for the city of Bolzano/Bozen (city road network) and the province of Alto Adige/Südtirol (rural and highway network). The results of the study were highly appreciated by the municipality and the province.

Main findings

Particular characteristics of the methodology are its versatility and ease of use. The methodology can be easily implemented by local or regional authorities as it relies mainly on data readily available to them.

As in many previous studies, the critical issue is data availability. Local authorities and network operators have to assist in the collection of required data that are difficult to find from other sources. Typical information required is residential data, parking places, electricity network, and already installed charging points.

The methodology described in the report can also be used to support the implementation of the Directive on the Deployment of Alternative Fuels Infrastructure, thereby assisting Member States to enhance deployment of EVs and their recharge infrastructure. Regarding the analysis of the highway network, the methodology could provide additional input in studies that analyze the inter-connection of highway corridors across member states throughout Europe.

Related and future JRC work

A future development could be the application of the methodology to other cities to investigate the effect of different layers or weighting factors on the allocation map. Examples could be cities of different sizes (spatial extent and population), located in different countries (Gross Domestic Product, transport demand and options, climate conditions).

1. Introduction

Emissions from the road transport sector are responsible for most of the air quality problems in cities across the European Union (see, for example, Ntziachristos et al., 2009). The European Commission vigorously supports sustainable-mobility initiatives and smart-cities projects that can lead to road-transport decarbonisation or mitigation of urban air pollution. They are among the pillars of the Europe 2020 strategy (EC, 2015a). One of the key aspects of these initiatives is the decarbonisation of road transport with the further deployment of electric vehicles (EVs) across Europe (EC, 2015b). Whereas financial incentives are a basic factor for EV deployment in the EU member states, the other important issue is the existence of an appropriate, publicly accessible charging infrastructure (Thiel et al., 2015).

The objective of this report is to provide a methodology to determine the optimal areas to allocate EV charging infrastructure at a city or regional and national level. Two different, but complementary, approaches are proposed depending on the spatial scale of the area of study. The first approach is appropriate at city level, and the second at regional or national level. Various previous studies have addressed the issue of allocation of EV infrastructure. Some studies take into consideration driving patterns of conventional vehicles (De Gennaro et al., 2014, 2015; Paffumi et al., 2014), others origin-destination matrixes (Bauche et al, 2014, Efthymiou et al., 2015), or flow refueling optimization (Cruz-Zambrano et al., 2013; Kuby et al., 2009). Some analyses are based on proprietary commercial GIS software, e.g., ArcGIS (Lindblad, 2012). The methodology described in this document is based on the hypothesis that EV drivers in urban areas will be an integral part of a smart city and their re-charging needs can be accommodated within a smart urban planning approach. Hence, the methodology tries to solve the problem of optimal allocation of the recharging infrastructure within an urban planning approach. As such, it is based on geospatial data that can be provided by local or national authorities or obtained from online sources like OpenStreetMap (OSM, 2015). Furthermore, it can be applied using open source GIS tools like QGIS (QGIS, 2015). In fact, all the maps presented herein were created with open source GIS tools. The maps were overlaid on Google Streets or Google Satellite layers using the Openlayers plugin of QGIS, but any similar layer-software may be used (OpenStreetMap, Bing Maps, etc.).

Various electro-mobility projects in Europe were studied to develop the proposed methodology. The Green eMotion (Corchero et al., 2015) and Zem2All (Zem2All, 2015) projects were analyzed, along with proposed or implemented action plans on EV charging infrastructure deployment in cities and regions around the world (TfL, 2010; AUE, 2012; C2ES 2012; Forbes et al., 2012; TS, 2013). The feedback of relevant stakeholders expressed in various electro-mobility forums was taken into consideration (MoTraSim, 2014; UITP, 2015; POLIS, 2015). The methodology also considers the requirements incorporated in the Directive on the Deployment of Alternative Fuels Infrastructure (EU, 2014): thus, it can guide member states in their elaboration of national policy frameworks as required by the Directive.

The city level approach was successfully applied to the city of Bolzano/Bozen (Italy) and the regional (or national) level approach to the province of Alto Adige/Südtirol (Italy).[1] These studies were performed in collaboration with the European Academy of Bozen/Bolzano (EURAC). The steps of the implementation along with the resulting allocation maps are presented and commented upon.

[1] Henceforth, for compactness we shall refer to the city and region as Bolzano and Alto Adige, respectively.

2. City level

The approach at city level is based on a set of collected geospatial data that are edited to be transformed into raster layers. Based on different weighting factors and using map algebra a map is created with cells of size 100x100 m (Figure 1). This calculated map indicates the optimal city areas where EV charging infrastructure (i.e., charging stations) could be placed according to specific scoring levels (which, of course, depend on the weighting factors). Local authorities along with the electricity distribution system operator (DSO) can agree on the exact location of the charging stations within the high-score areas. The final location should take into account space limitations and the maximum acceptable distance from the electricity network. Space limitations could also include the width and installations present in road pavements. For example, in the city of Oslo, space limitations were imposed by the municipality pavement cleaning service, and by citizen complaints about the bright light emitted by some chargers placed close to the windows of their ground-floor apartments (AUE, 2012). The analysis at city level is based on an urban planning spatial analysis approach similar to the process used to define the optimal areas to allocate land for waste incineration (CUOSG, 2015a) or emergency shelters (CUOSG, 2015b).

In this section, the required input data are presented along with the methodology. The developed methodology is applied to the city of Bolzano in the last subsection. The required input data may vary depending on the scope of the study and the examined area: for example, layers could be added or removed according to the needs of the study.

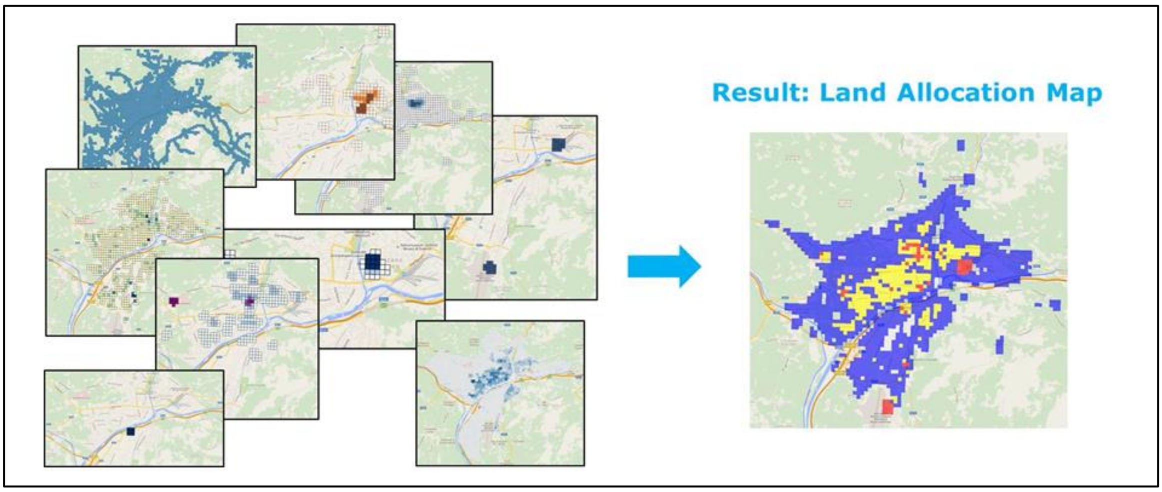

Figure 1. Land allocation map obtained via map algebra and weighting factors on raster layers.

2.1 Input data

2.1.1 Residential statistics

Residential statistics refer to statistical data on the number of people (and possibly their characteristics such as age, employment status, etc.) who live within the examined area. These data are used to locate public charging stations that are within close proximity to highly populated areas. The aim is to provide charging stations to be used mostly at night by drivers who do not have access to private plugs (as those in private garages). The residential statistics data can also be expressed as population density maps. They should be collected at as high spatial resolution as possible.

Suggested format:

Polygon shapefile (*ESRI format*) or raster file (*TIF format*).

Possible source:

- Local authorities (*Municipality, Province, Region*),
- National or governmental agencies (*National Statistical Service, National Land Survey and Registry*).

2.1.2 Parking areas

This category of data includes:

- suitable parking areas alongside roads,
- garages,
- Open parking areas.

Most possibly, they can be found on urban-planning or land-use maps. Parking operators could also provide data on their parking area (Figure 2). It would be very useful if the data included information on the capacity of the parking area (e.g., maximum number of vehicles).

Suggested format:

Polygon (or point, if not available) shapefile (*ESRI format*).

Possible source:

- Local authorities (*Municipality, Province, Region*),
- National or governmental agencies (*National Transport Agency, National Land Survey and Registry*),
- Parking companies.

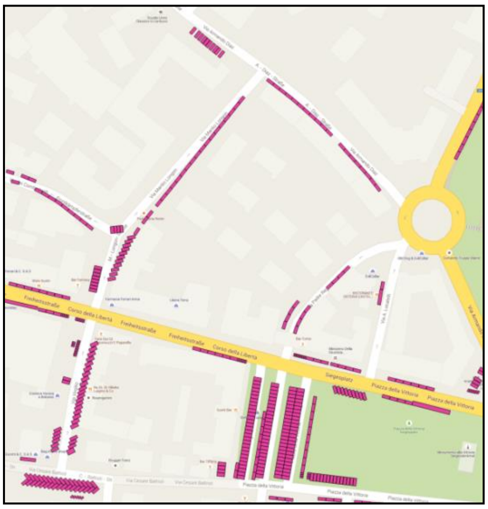

Figure 2. Parking areas.

2.1.3 Electic power distribution network

These data are used to map the electric power grid to which charging stations would connect. The aim is to minimize investment by using the available grid coverage. The data are usually available from the DSO. A detailed data file (with the capacity and characteristics of the grid segments) will render easier the identification of the capacity limits of each area. Various electricity networks are shown in Figure 3. For this study, only the city and rural networks are needed.

Suggested format:

Polyline shapefile (*ESRI format*).

Possible source:

- Electricity distribution companies (DSO),
- Local authorities (*Municipality, Province, Region*),
- National or governmental agencies.

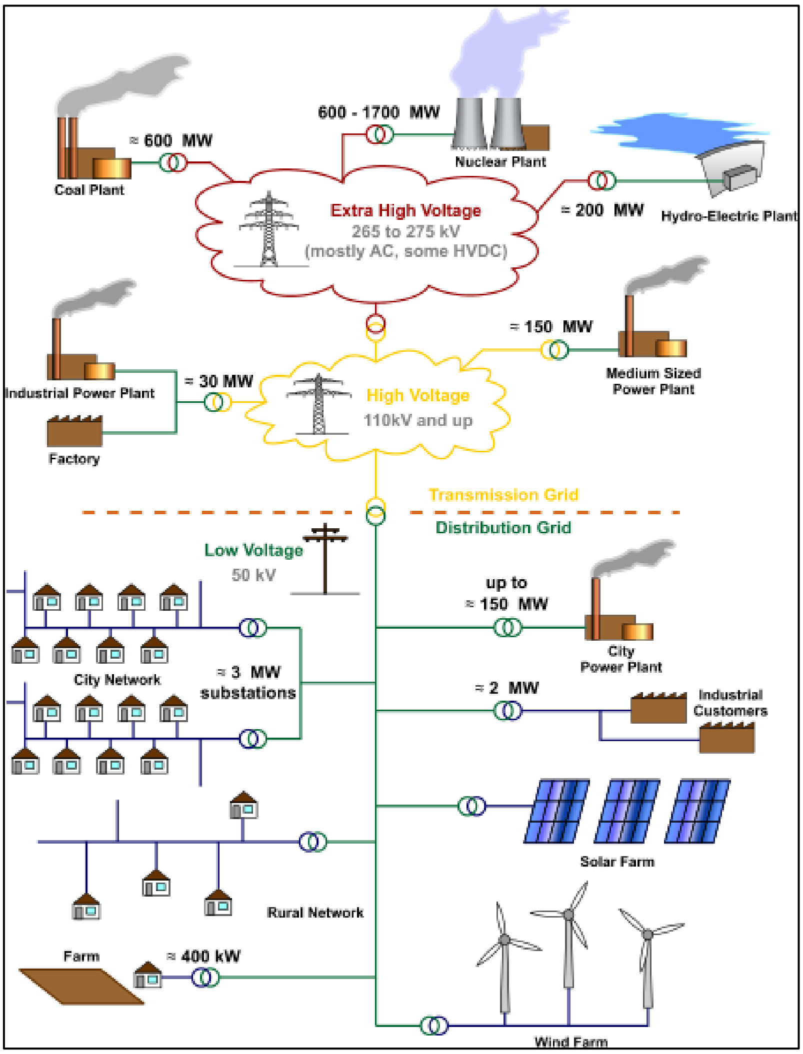

Figure 3. Schematic representation of electricity networks (MBizon, 2010).

2.1.4 Public transport stations

Following the Directive on the Deployment of Alternative Fuels Infrastructure (EU, 2014), and to support co-modality in transport, the installation of charging stations close to public transport stations is recommended. The public transport stations include airports, ports, train, and bus stations.

Suggested format:

Polyline or point shapefile (*ESRI format*).

Possible source:

- Local authorities (*Municipality, Province, Region*),
- National or governmental agencies,
- OpenStreetMaps.

2.1.5 Public access building

They refer to buildings accessible to the public such as hospitals, museums, theatres, and universities.

Suggested format:

Polyline or point shapefile (*ESRI format*).

Possible source:

- Local authorities (*Municipality, Province, Region*),
- National or governmental agencies,
- OpenStreetMaps.

2.1.6 Shopping and food areas

They refer to places like single shops and stores, malls, restaurants, and bars in the city.

Suggested format:

Polyline or point shapefile (*ESRI format*).

Possible source:

- Local authorities (*Municipality, Province, Region*),
- National or governmental agencies ,
- Online sources (*OpenStreetMaps, Foursquare etc.*).

2.2 Methodology

After collecting the necessary geospatial data, a number of steps follow:

2.2.1 Creation of the base vector grid

Use the layer with the largest spatial extent to create a vector grid[2] of 100x100m with a GIS tool. This grid becomes the base to spatially join all other layers (i.e., to create a join between two sets of geospatial data), and to create the relevant vector grid layers. Figure 4 presents the creation of the vector grid from the residential statistics polygon layer of Bolzano: the software QGIS and the "Vector Grid" form were used.

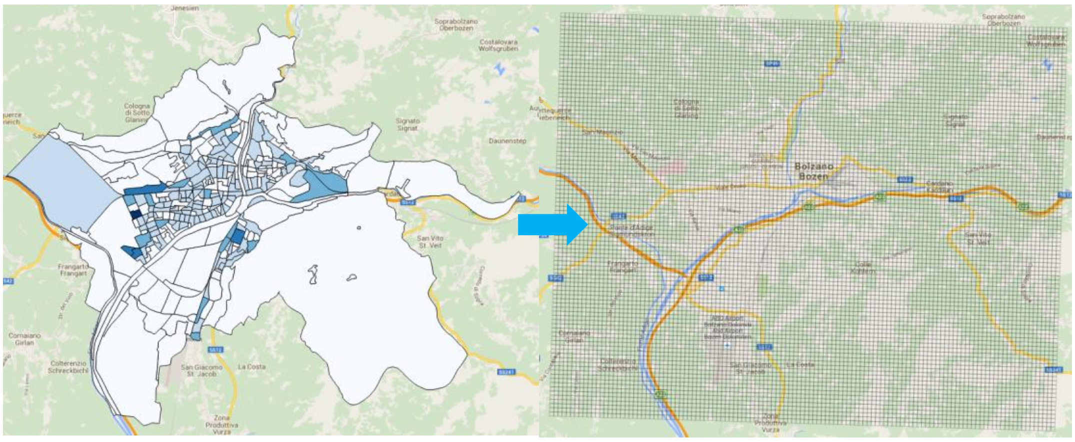

Figure 4. Creation of the base vector grid.

2.2.2 Bufering

Create buffer zones for the other input layers. The buffer zones indicate an effective area around either a point of interest (POI) or a network. The buffering process requires that a characteristic length be chosen: this choice depends on the needs of the study. We chose the maximum distance between the electricity network and a charging station to be approximately 50m, since at larger distances the connection to the grid may be difficult, or expensive, or it might require additional installation time. Figure 5 presents this buffering using the 'Create Buffers' form of the MMQGIS plug-in of QGIS.

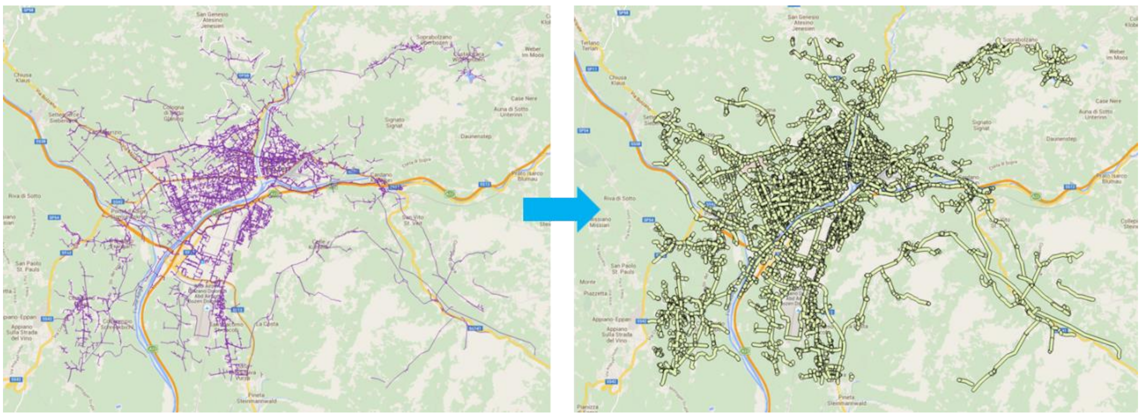

Figure 5. Creation of the buffer.

[2] The vector grid is similar to a raster layer, but it contains vector information. We use a vector grid to perform operations on vector data layers. In the end, we rasterize them to apply the weighting factors on them.

For POI a 100m is suggested as explained in Section 2.2.3: the choice is related to the spatial join of the vector grid. An example of buffering of a point layer that includes public access buildings (theatres, museums, cinemas, and sightseeing) is presented in Figure 6. An example of buffering of a polygon layer of public transport stations (airport, train and bus stations) is presented in Figure 7.

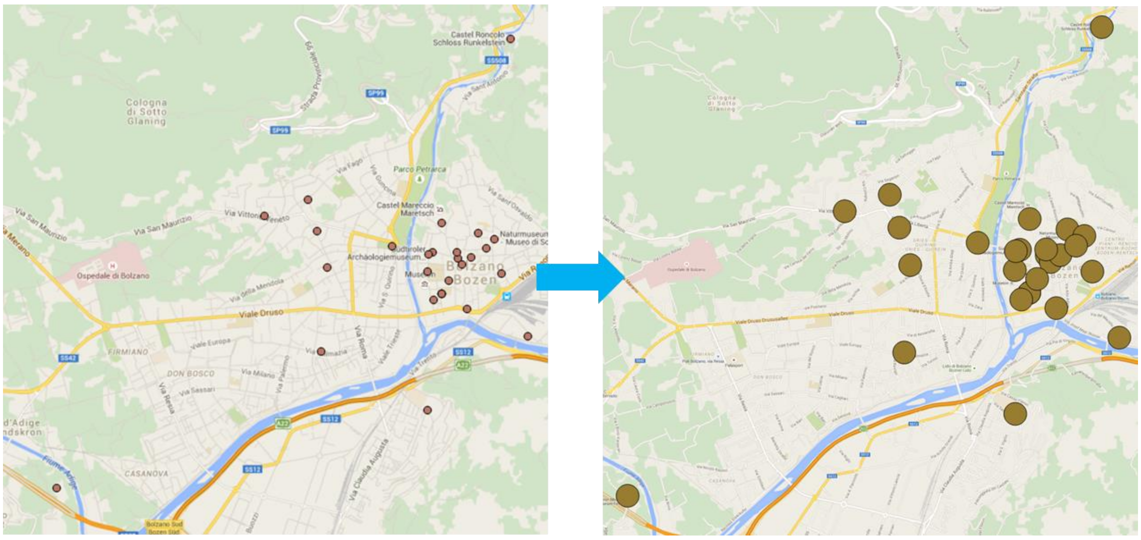

Figure 6. Buffering of a point layer (theatres, museums, cinemas and sightseeing).

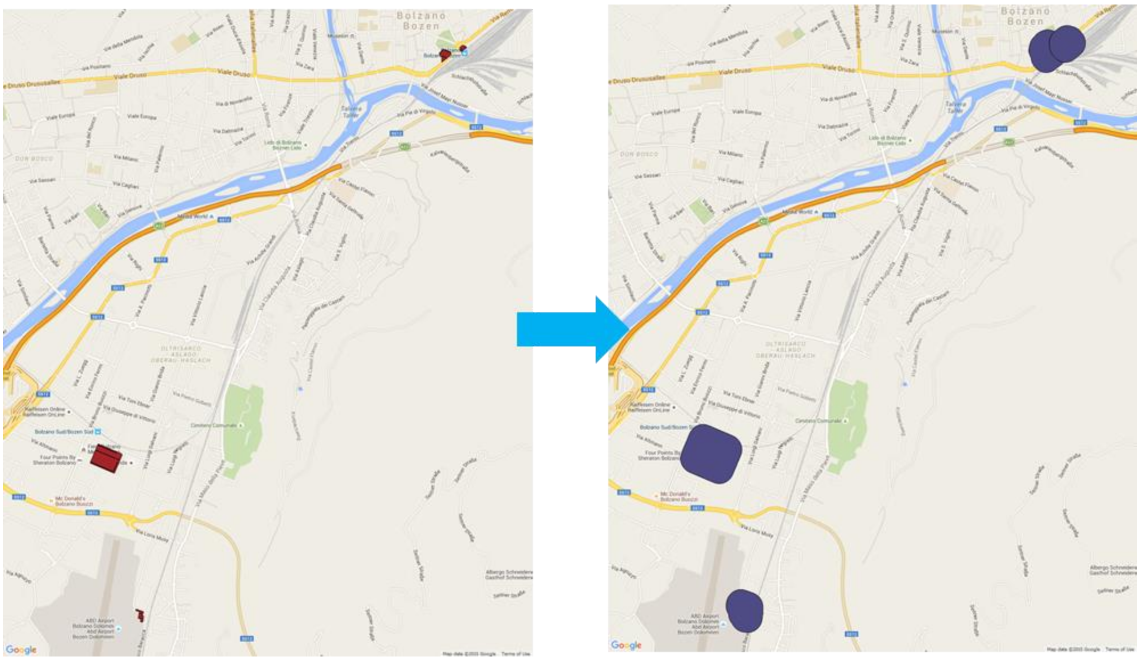

Figure 7. Buffering of a polygon layer (public transport stations).

2.2.3 Spatial join of buffered layers with the vector grid

Initially, the residential statistics polygon layer is spatially joined with the vector grid to create the population density map. The proportional sum of the polygons is added to the grid cells (Figure 8).

Then, all the buffered layers are spatially joined with the vector grid. In this way, all layers are converted into vector grid layers with the same format and extension. For the electricity network, if the buffered layer intersects cells of the grid the cell is assigned a value of 1, otherwise it is assigned a 0. The results obtained using the 'Spatial Join' form of the MMQGIS plugin are presented in Figure 9.

For the rest of the layers the number of features intersecting a cell are counted, and the number is added to the value of the cell. The same plugin, as used for the electricity network, is used. The result of spatially joining the layer for the theatres, museums, cinemas, and sightseeing layer with the vector grid is presented in Figure 10. Only for the public transport stations the separate features are not summed-up, but the cells that intersect them take a value equal with 1. This choice is made because all public transport stations should have the same importance irrespective of their proximity. The result of the spatial join with the rest of the layers is presented in Figure 11.

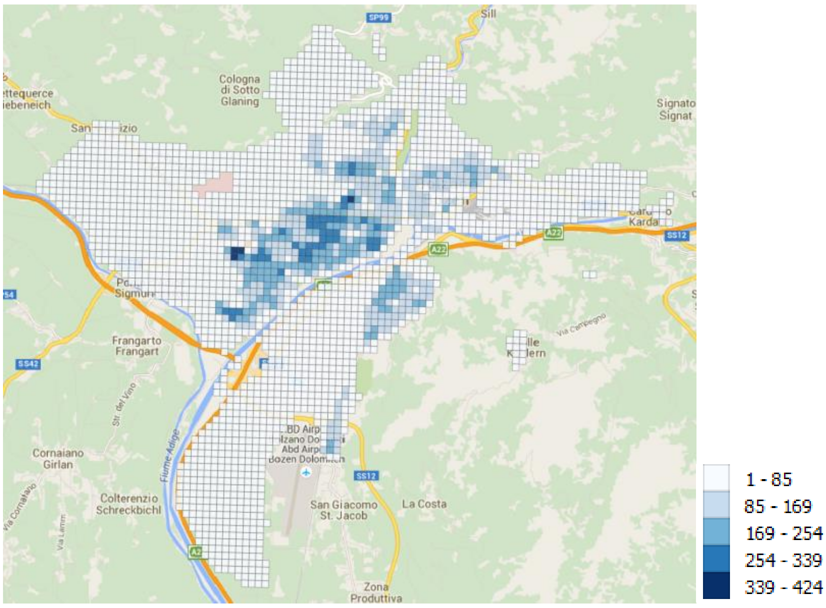

Figure 8. Population density (legend: number of residents/cell).

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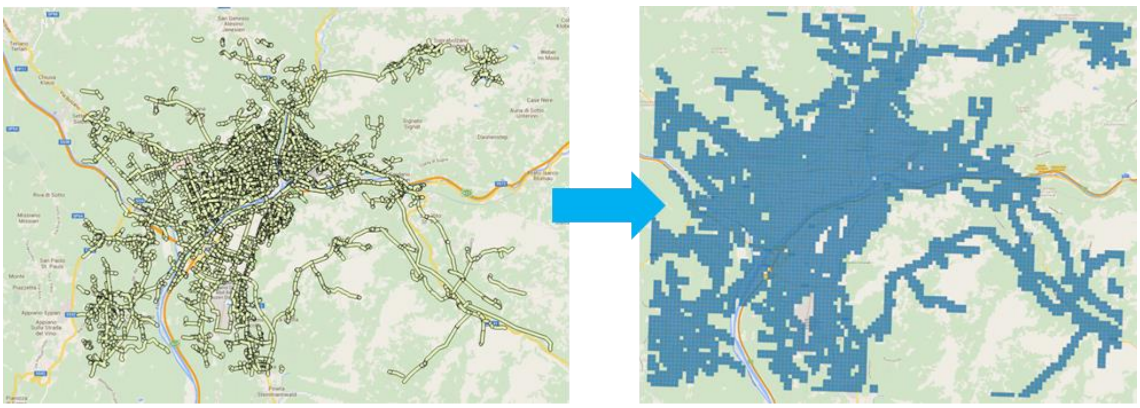


Figure 9. Spatial join of the electricity network with the vector grid.

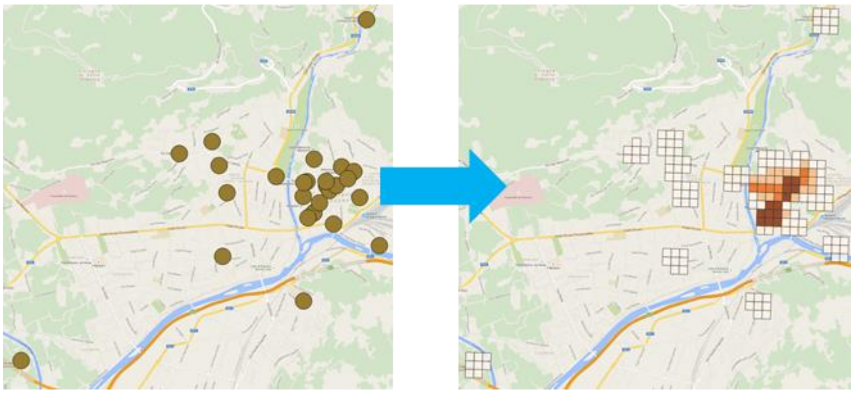


Figure 10. Spatial join of the theatres, museums, cinemas and sightseeing layer with the vector grid.

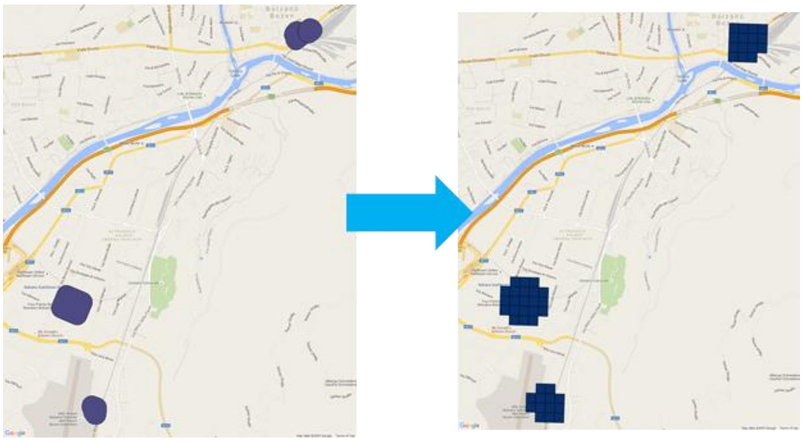


Figure 11. Spatial join of the public transport stations layer with the vector grid.

Further examples of spatially joining buffered layers (parking space, health centres, university locations, stores, restaurants, and malls) with the vector grid are presented in Appendix I.

We conclude by justifying our choice of a 100m buffering of POI, as used in Section 2.2.2. We consider that an acceptable walking distance between a charging station and POI should be less than 300m. Simple geometric considerations (see Figure 12) show that a 100m radius of buffering coupled to a spatial join with 100x100m cells leads to a maximum Euclidean distance between the centre of the POI and the furthest corner of an intersecting cell smaller than 300m.

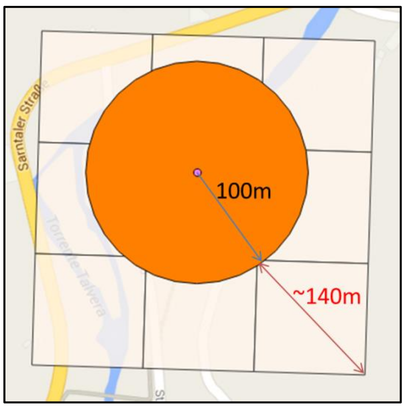


Figure 12. Maximum distance between the centre of the POI and the furthest corner of an intersecting cell.

2.2.4 Scaling and rastering

The outcome of the previous step is a group of vector grid layers with cells to which maximum and minimum values have been assigned or calculated. First a scaling is applied and the results are presented in an additional column (appropriately called 'SCORE') that is added in the feature database. Equation 1 is applied on each cell of all layers.

Equation 1

*SCORE(i) =value (i) * 10 / max*

where:
i = number of cell
value(i) = the value of the ith cell
max = the maximum value of all cells of the layer

The scaling is applied to normalize cell scores between 0 and 10. Lastly, all layers are rasterized based on the 'SCORE' column values.

2.2.5 Map algebra on raster layers

The result of the previous step is a group of raster layers. At this point a weighting factor is applied on each layer based on its importance or usability. Equation 2 can, then, be used with the 'Raster calculator' of QGIS to create a land allocation map with each cell having a different score (Figure 1).

Equation 2

$Raster\_electricity\_network * (Raster\_file_1 * Factor_1 + Raster\_file_2 * Factor_2 \ldots)$

It is important to note that Equation (2) places emphasis on the electricity network, in that it provides an overall multiplication factor[3]. This choice reflects the importance of the existing electricity grid lay-out, and our assumption that no significant modification of the power grid lay-out should be required in planning the allocation of charging stations in a city.

[3] As explained in Section 2.2.3 we chose the *Raster_electricity_network* to be a binary variable [0,1], making the presence of power lines a necessary condition for the consideration of the respective grid cell. Obviously, users of the methodology could deviate from this choice depending on how much emphasis they want to place on the presence of power lines.

2.3 Test case: City of Bolzano

The municipality of Bolzano and the electricity DSO Alperia Srl (the company formed by the merger of SEL and AEW that became operational in January 2016 in Alto Adige) gathered and provided us (through EURAC) the required input data to apply the proposed methodology to the city of Bolzano. Various weighting factors (as described in Section 2.2.5) were tested: the final set of factors is presented in Figure 13. These factors are also based on the number of visitors expected in the various locations. It is apparent that the weighting factors can be changed according to the needs of the study, or if additional information is obtained. For example, if residential areas are considered of higher importance than shopping areas, then the population density weight should increase and the shopping/food areas weight should decrease accordingly.

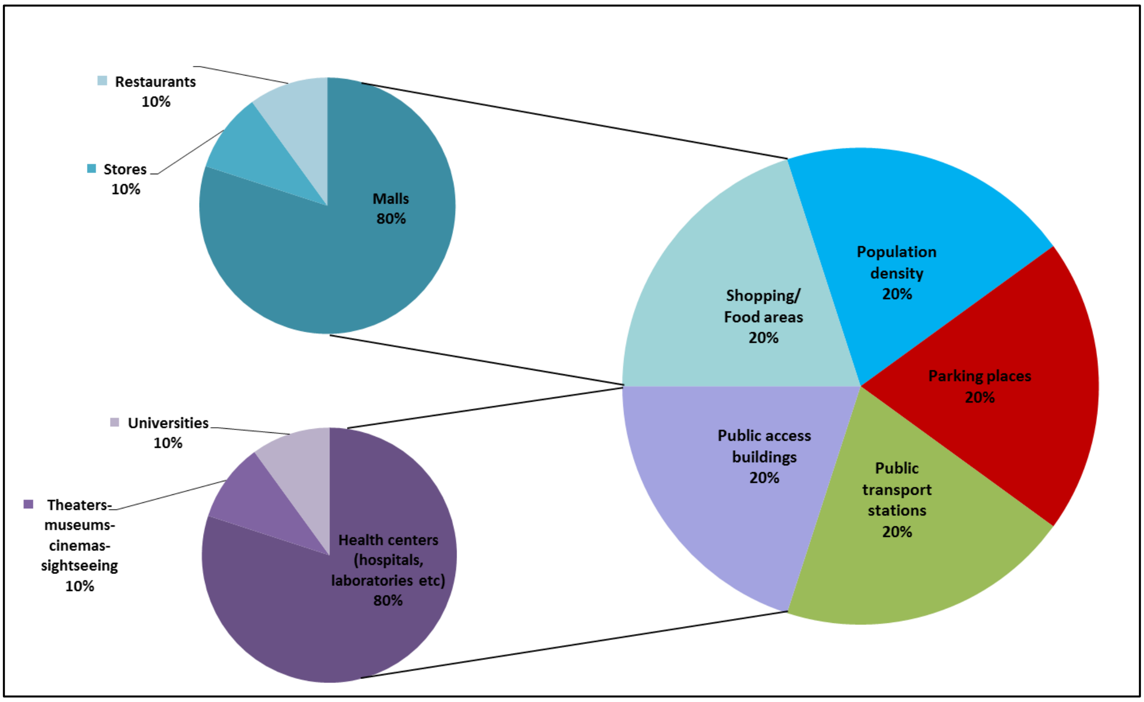


Figure 13. Weighting factors of all raster layers.

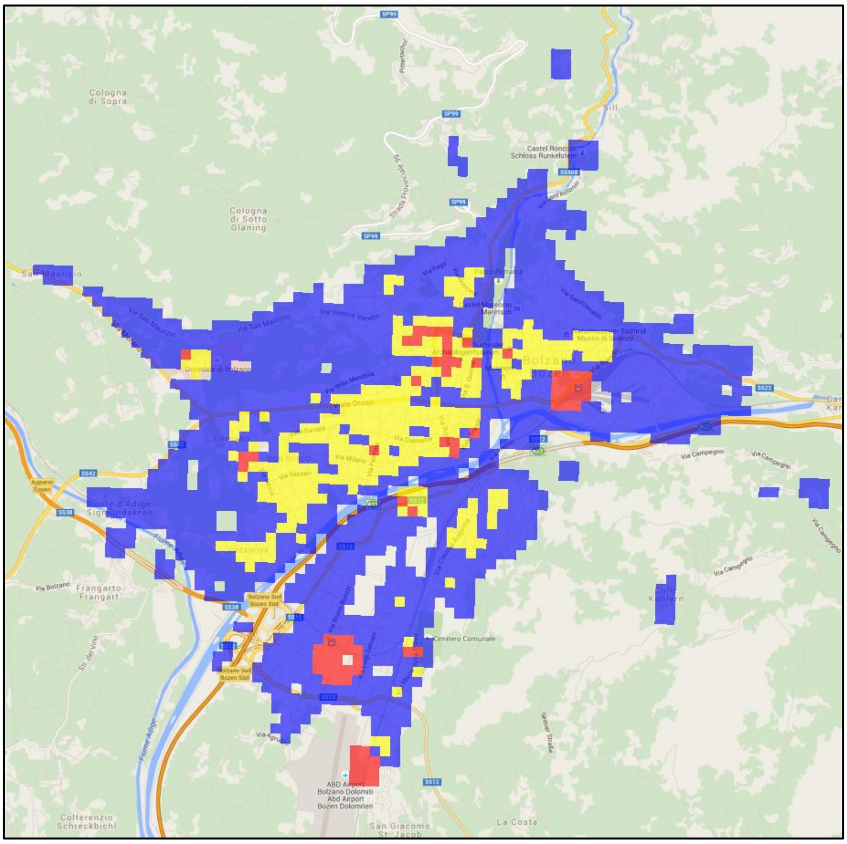
The allocation map based on the factors summarized in Figure 13 is presented in Figure 14. The same map overlaid on a satellite view can be seen on Figure 15. The cells are coloured according to the following colour code:

- **Red**: areas with high score,
- **Yellow**: areas with medium score,
- **Blue**: areas with low score.

Normal chargers can be placed on the Red and Yellow areas, whereas fast chargers can be placed at:

- gas stations,
- public transport stations, and
- parking places that allow limited-time parking (they usually are close to the city centre and pedestrian zones) included inside the Red areas.

In Figures 14 and 15, the red zones are parking areas near the train and bus stations, airport, university, exhibition centre, shopping mall, hospital, and cemetery. The large yellow zones with smaller red areas coincide with parking areas in densely populated districts, as well as near the city centre with its many shops and the pedestrian zone. The "empty" cells are either outside city limits or without power lines.



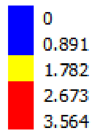
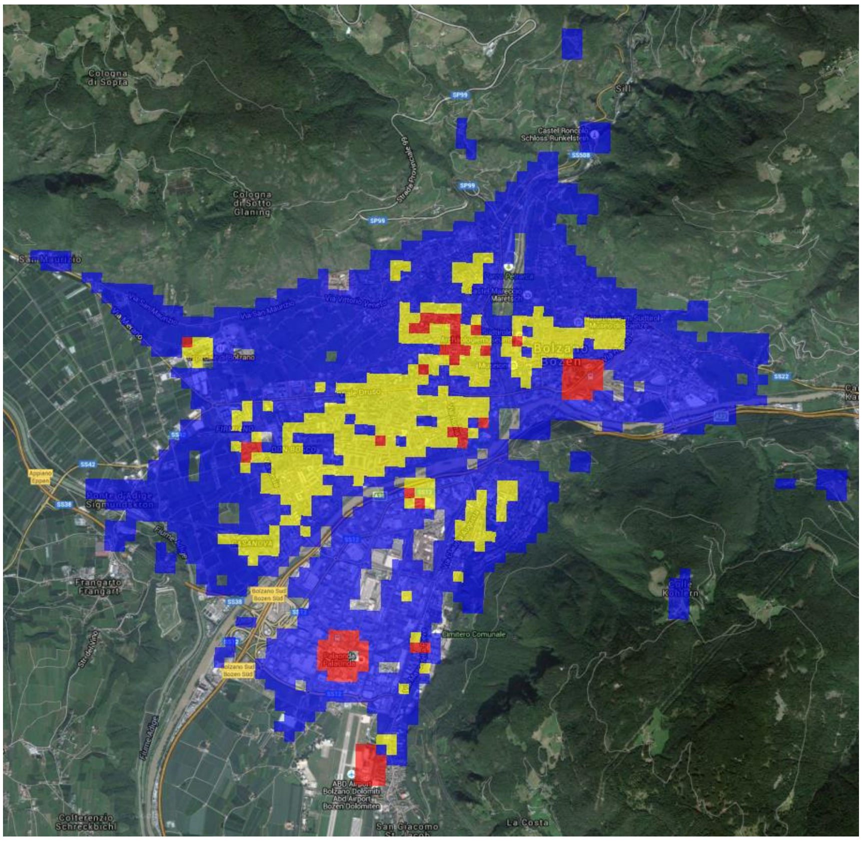


Figure 14. Land allocation map of the city level analysis for Bolzano (legend: score/cell).



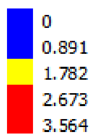


Figure 15. Land allocation map of the city level analysis for Bolzano overlaid on a satellite view (legend: score/cell).

3. Regional/national level

In this section, the required input data along with the analysis of the optimal allocation of charging infrastructure in the province of Alto Adige (Italy) are presented. The spatial extent of the studied area was based on the road network provided to the JRC by EURAC (Figure 16). The study was divided into two parts. The first focused on the highway (referred to as "autostrada") and the second on the main rural roads (referred to as "provinciale" and "statale"). QGIS was used for the analysis along with the QChainage and MMQGIS open source plugins.

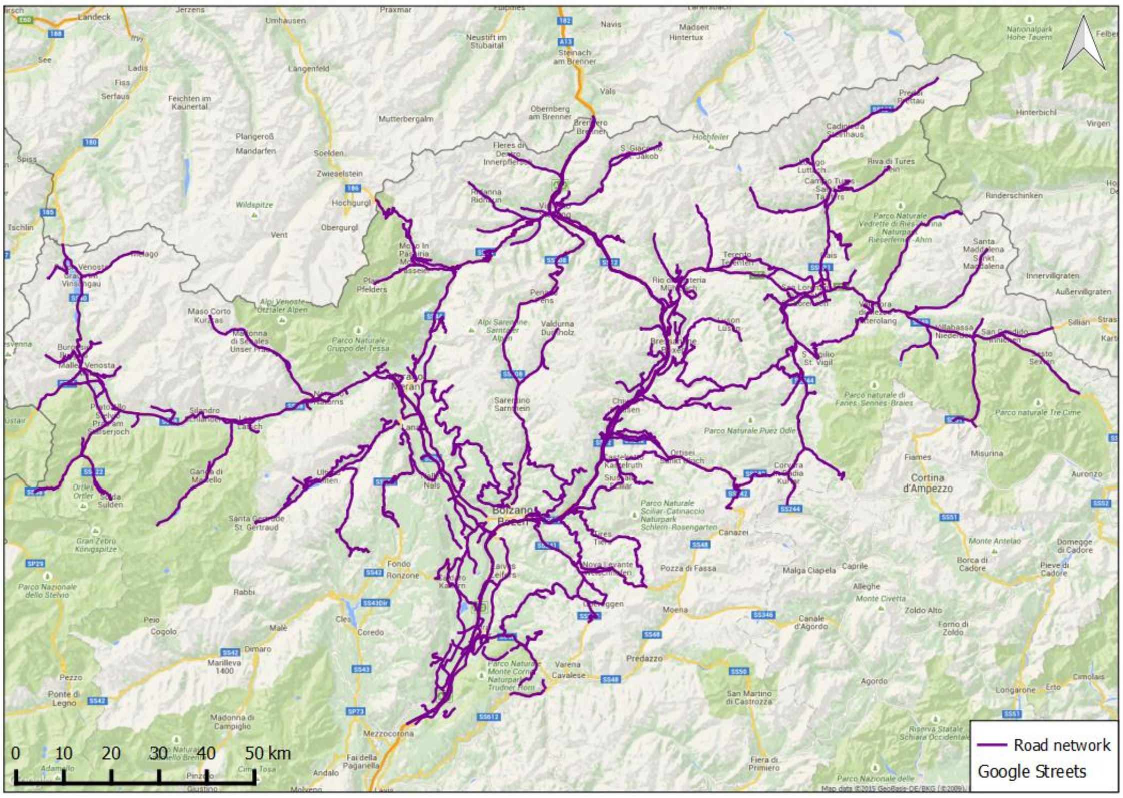


Figure 16. The road network of the Province of Alto-Adige.

3.1 Input data

3.1.1 Road network

These data refer to the road network of the examined area in a geospatial format. The data should also include information on road crossings and the road direction.

Suggested format:

Polyline shapefile (*ESRI format*).

Possible source:

- Local authorities (*Municipality, Province, Region*),
- National or governmental agencies (*National Transport Agency, National Land Survey and Registry*),
- OpenStreetMaps.
-

3.1.2 Service areas

Service areas include gas stations and rest areas along the highways and regional roads. Their location (coordinates) along with the number of vehicles that can park at their parking area would be useful additional information.

Suggested format:

Point shapefile (*ESRI format*).

Possible source:

- Local authorities (*Municipality, Province, Region*),
- National or governmental agencies, road operators
- Companies (e.g., gas station chain companies) that provide this service,

Map content and navigation companies (Google Places API, HERE maps API, Bing Maps API etc.).

3.2 Methodology

The regional/national level analysis aims to allocate EV infrastructure every *x* km, where *x* should be large enough to ensure that no electric vehicle remain without adequate charge on the road (not complete discharge of the usable battery energy). First, the highway network is studied based on the geospatial polyline shapefile with the set of available gas stations and rest areas (as a geospatial point shapefile) along the highway. The suitable and optimal stations or rest areas are selected based on an algorithm that compares all network distances between them. For the rest of the regional network, the geospatial shapefile of the main rural roads is used. It is split in a way that the algorithm predicts an adequate infrastructure for an EV to travel throughout the region without running out battery energy.

3.2.1 Highway network

Charging stations on highways have to be placed in already built areas (rest areas, gas stations, etc.) since the cost and time to construct new areas is high. According to a JRC mobility data analysis, based on both conventional and electric vehicles from various regions (Donati et al., 2015), charging stations placed at a maximum distance of approximately 60km (actual road distance and not Euclidean distance) would provide an adequate infrastructure. We note that a highway charging station serves vehicles travelling towards a specific highway direction since rest and service areas cannot be accessed from both directions. Hence, the distance of 60km refers to each highway direction, the two directions being independent.

3.2.2 Rural-road network

The analysis of the network of rural roads requires a different approach since each suggested charging point location can serve both road directions. In addition, even though the complete road network across the province has to be covered the infrastructure should be placed along the main roads. The charging infrastructure can be installed at either already existing gas stations or public parking areas, or it can be assigned close to the main roads.

3.3 Test case: Province of Alto Adige

3.3.1 Highway network

Create a geospatial file (shapefile) with the highway network in the province. It should include the highway direction: for the case of Alto Adige, the two directions are North and South. Figure 17 presents this shapefile overlaid on Google street maps with a zoomed-in area indicating the two different directions. The process of overlaying required a set of dissolving (i.e., connecting adjacent lines) and splitting (i.e., breaking lines into segments) steps of the initial polyline shapefile[4].

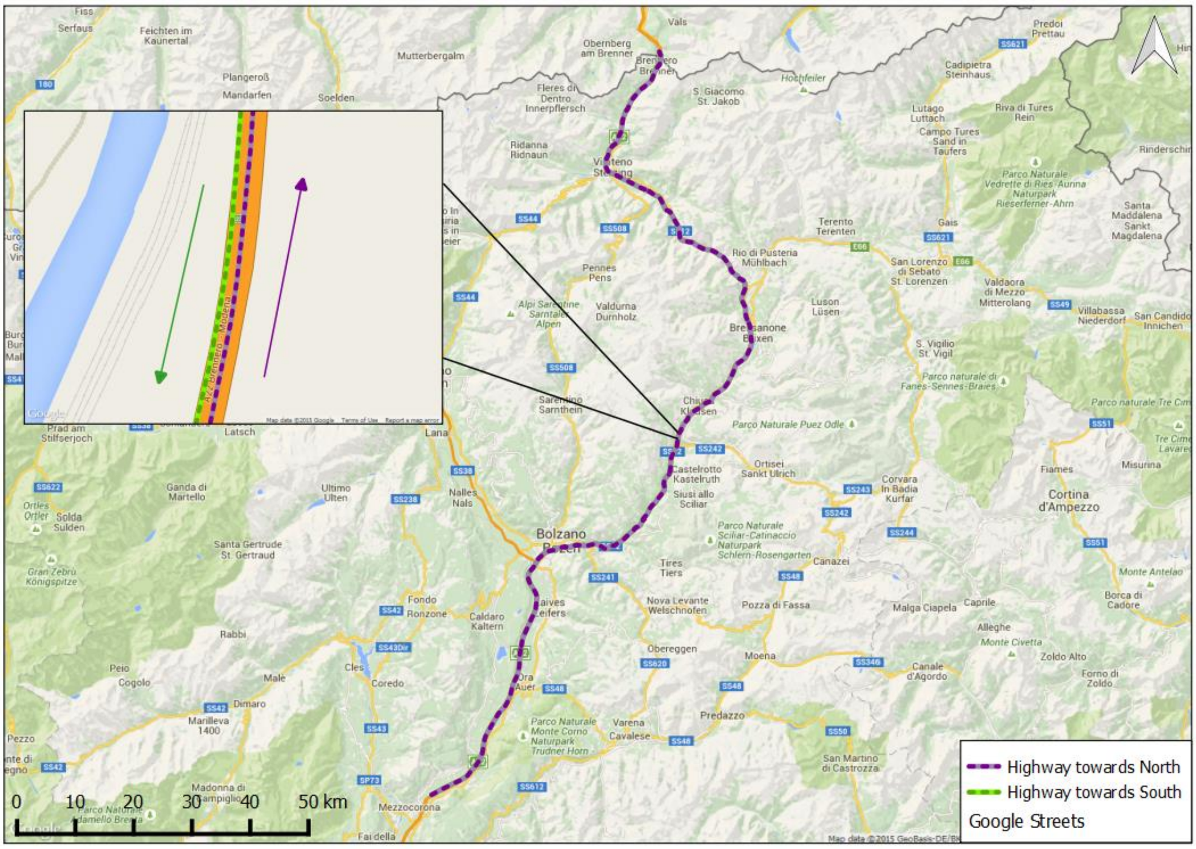


Figure 17. The highway network. Both directions (North, South) are indicated.

The second step is the creation of a shapefile with the location of the gas stations along the highway[5]. Only the gas stations that belong to the highway's rest areas were selected and not those that would require to exit the highway. Figure 18 presents these gas stations: there are four in the direction North and four in the direction South. They are assigned numbers in ascending order according to the highway direction.

Each highway direction has to be split according to the location of the gas stations. The suitable splitting points were determined using the perpendicular of the points to the corresponding polylines. Then, the length of the resulting segments was calculated. Figure 19 presents the distances between the beginning of the highway (chosen to be the border with another province in the South and with another country-Austria-in the

[4] Highway data source: OpenStreetMaps https://www.openstreetmap.org

[5] Gas stations data source: Experian Ltd. 2012

North) and the first gas station, between consecutive gas stations, and between the last gas station and the end of the highway.

The algorithm used to decide which of these stations is appropriate for the installation of charging infrastructure checks first whether the distances between the gas stations are less than 60km (including the distances between the beginning and the end of the highway). Based on these distances, the algorithm determines whether new service areas should be built to host the charging infrastructure. For the case of Alto Adige this is not necessary.

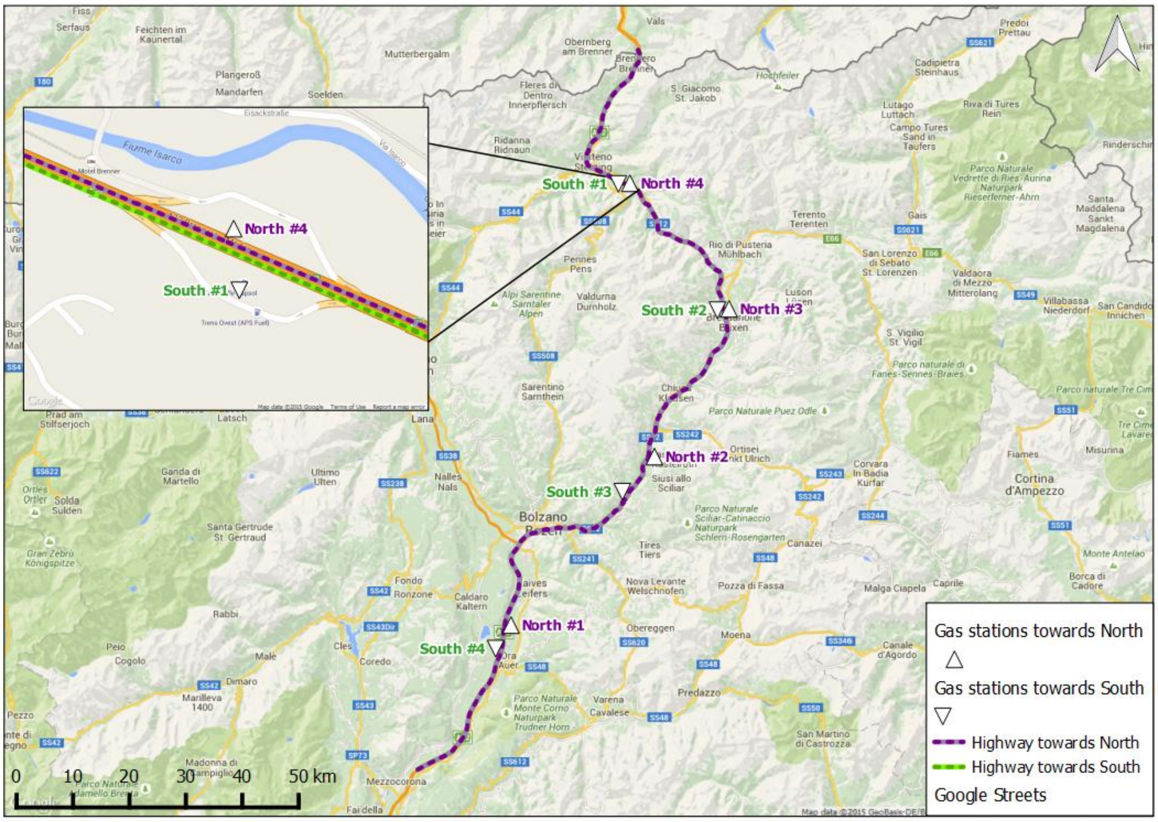


Figure 18. Gas stations located along the highway.

After this step, the algorithm must satisfy an additional condition. Charging infrastructure has to be installed at the first and the last gas stations (within the region), since it is unknown how far (if at all) charging stations are located before and after the examined area. This condition has to be applied to all regions in Europe that plan to install charging infrastructure on highways if the location of the charging stations in neighbouring provinces or states is unknown. The condition guarantees safe and seamless transport of electric vehicles in confining regions and countries. Accordingly, "North #1", North #4", "South #1", and "South #4" are selected suggested areas.

The algorithm continues by checking the distance between consecutive gas stations. An area is characterized as "suggested" every time the limit of 60km from the last "suggested" area is exceeded. For the case of Alto Adige it is considerably simple since there are only two unassigned gas stations per direction. If we consider the direction North the optimal allocation would be "North #2" instead of "North #3" because a smaller travelling distance is calculated . In more detail:

- Choosing "North #2" implies a maximum distance of 44km between charging stations[6].

[6] The total distance between North #2 and #4

- Choosing "North #3" implies a maximum distance of 54km between charging stations[7].

The same approach for direction South suggests that the optimal allocation would be "South #3":

- Choosing "South #2" implies a maximum distance of 57km between charging stations[8].
- Choosing "South #3" implies a maximum distance of 49km between charging stations[9].

Figure 19. Distances between gas stations and the beginning/end of the highway.

The list of suggested gas stations based on the above algorithm is presented in Table 1. The total calculated number is three gas stations towards the North and three towards the South. Figure 20 presents these gas stations geospatially and Figure 21 presents them zoomed-in and overlaid on Google Street maps.

Table 1: Suggested gas stations to install EV charging stations.

Gas station	Close to town	Latitude	Longitude
North #1	VADENA	46.38639	11.294298
North #2	CASTELROTTO	46.57007	11.522907
North #4	CAMPO DI TRENS	46.86872	11.483787
South #1	CAMPO DI TRENS	46.86797	11.484095
South #3	FIE ALLO SCILIAR	46.53162	11.490393
South #4	VADENA	46.36053	11.288427

[7] The total distance between North #1 and #3
[8] The total distance between South #2 and #4
[9] The total distance between South #1 and #3

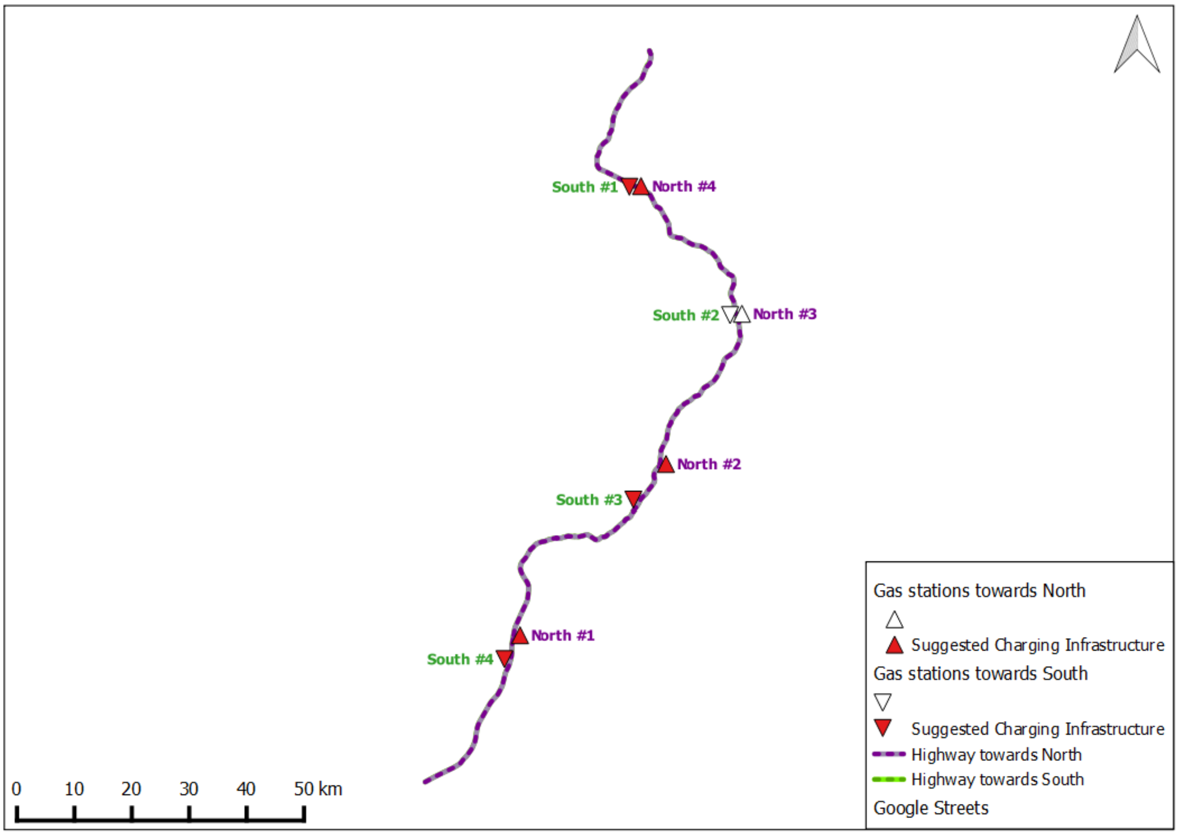


Figure 20. Suggested gas stations to install EV charging stations.

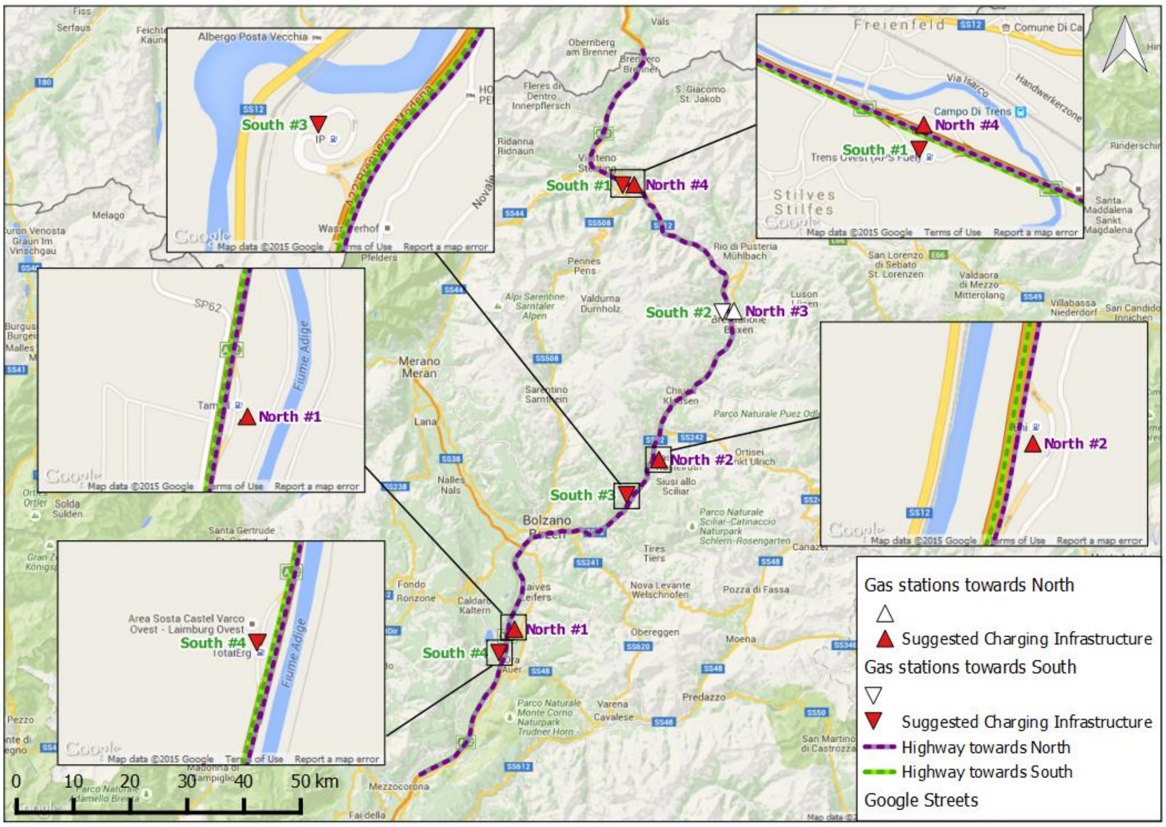


Figure 21. Zoomed-in suggested gas stations to install EV charging stations.

3.3.2 Rural network

The road network provided by EURAC (Figure 16) does not distinguish between main or secondary roads. We decided to keep only the roads that were categorized as "provinciale" (managed by the province) and "statale" (managed by the state). Highways had been removed from the shapefile. All the segments that are smaller than 20 km were removed, and the connected roads were dissolved. The resulting network is presented in Figure 22.

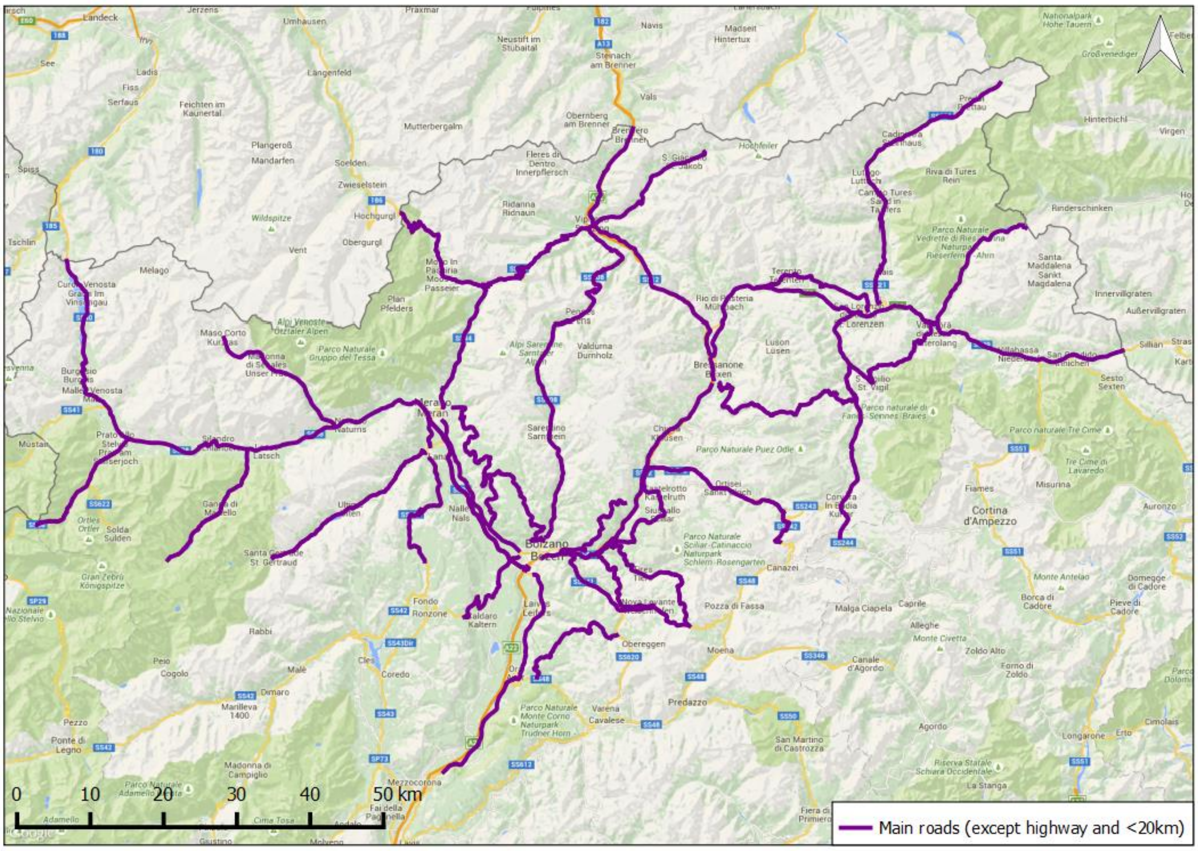


Figure 22. Main roads except highways and road segments less than 20km.

The next step demands the assignment of charging stations on the road network every 30 km. A maximum range of 30 km (half the 60 km used in the highway calculation) was chosen for rural roads since the analysis was based solely on main roads, but the resulting infrastructure should cover also the smaller roads (<20 km). Furthermore, the charging stations would serve both directions: for example, the last charging station before the end of a road should also cover the distance to return to the charging station.

The assignment of charging stations could be made with the QChainage[10] plugin. However, the plugin could not be used directly on the whole network because not all road segments are connected. Therefore, first consecutive road segments were grouped based on their direction and taking the city of Bolzano, the capital of the province, as the centre. This step resulted in four groups: roads heading West, East, North, and South (Figure 23).

[10] https://plugins.qgis.org/plugins/qchainage/

The plugin QChainage was then applied separately for each group splitting the road network every 30 km. The splitting points are presented in Figure 24 by stars. The location of the symbols indicates a suggested location to install a charging station. The stations may be placed in either parking areas and/or gas stations along the roads or in a new area (the choice may be guided by the minimum expenditure). The position has to be decided within a +/- 10km buffer region from the suggested areas. This buffer should be the actual road distance and not the Euclidean distance. Some suggested areas may seem close to each other, but they serve different road segments (Figure 25). The maximum distance of 30 km along with the maximum buffer of 20km add up to a maximum distance of 50km between stations, an acceptable distance, as argued. According to our calculations, the total number of suggested locations to place charging stations on the rural road network ("Strada provinciale" and "statale" , but not highway, "Autostrada") for the Alto Adige province is 36.

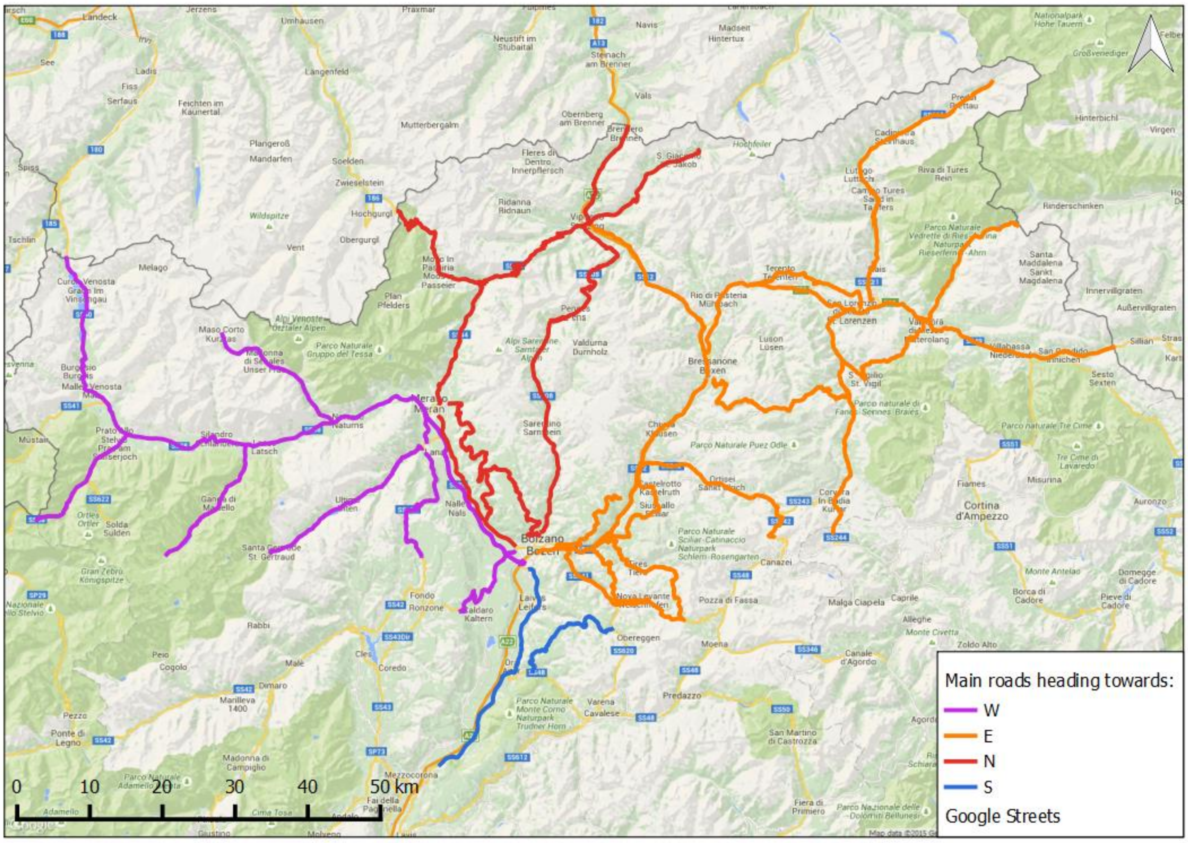


Figure 23. Grouping of road segments based on their direction.

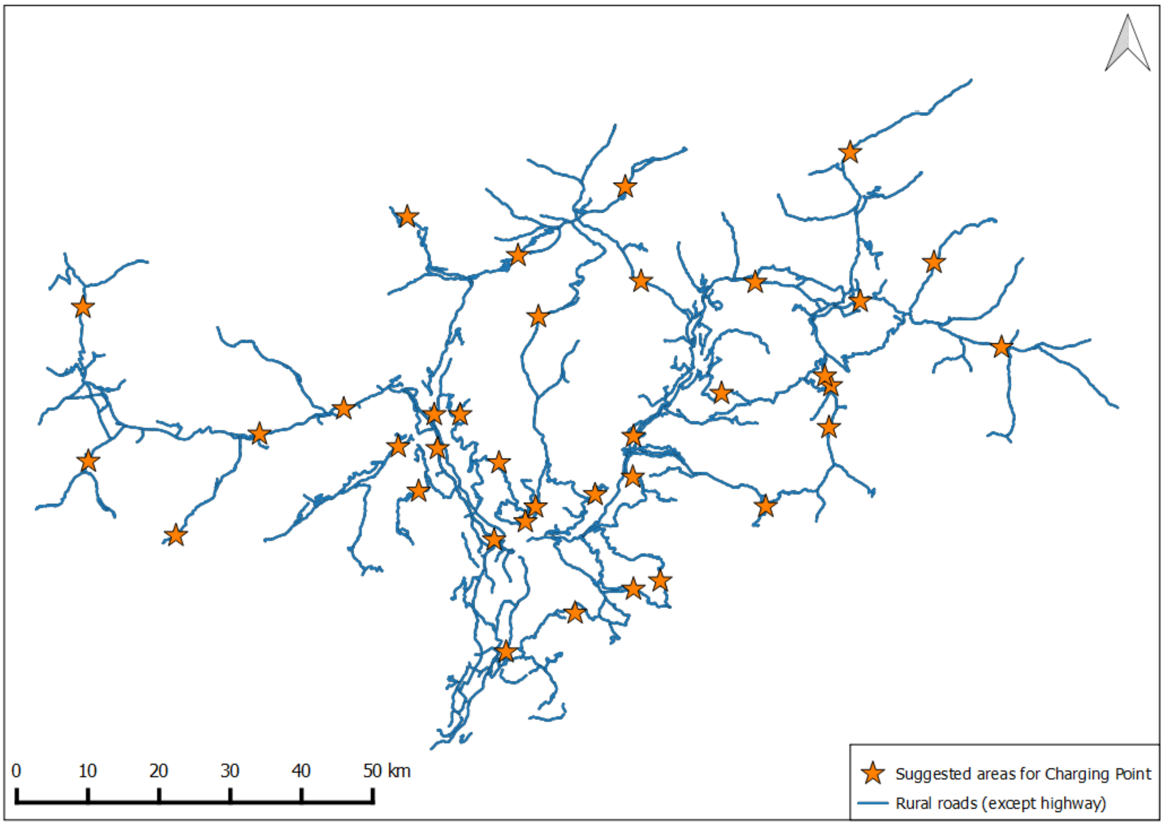


Figure 24. Suggested areas to place charging stations along rural roads.

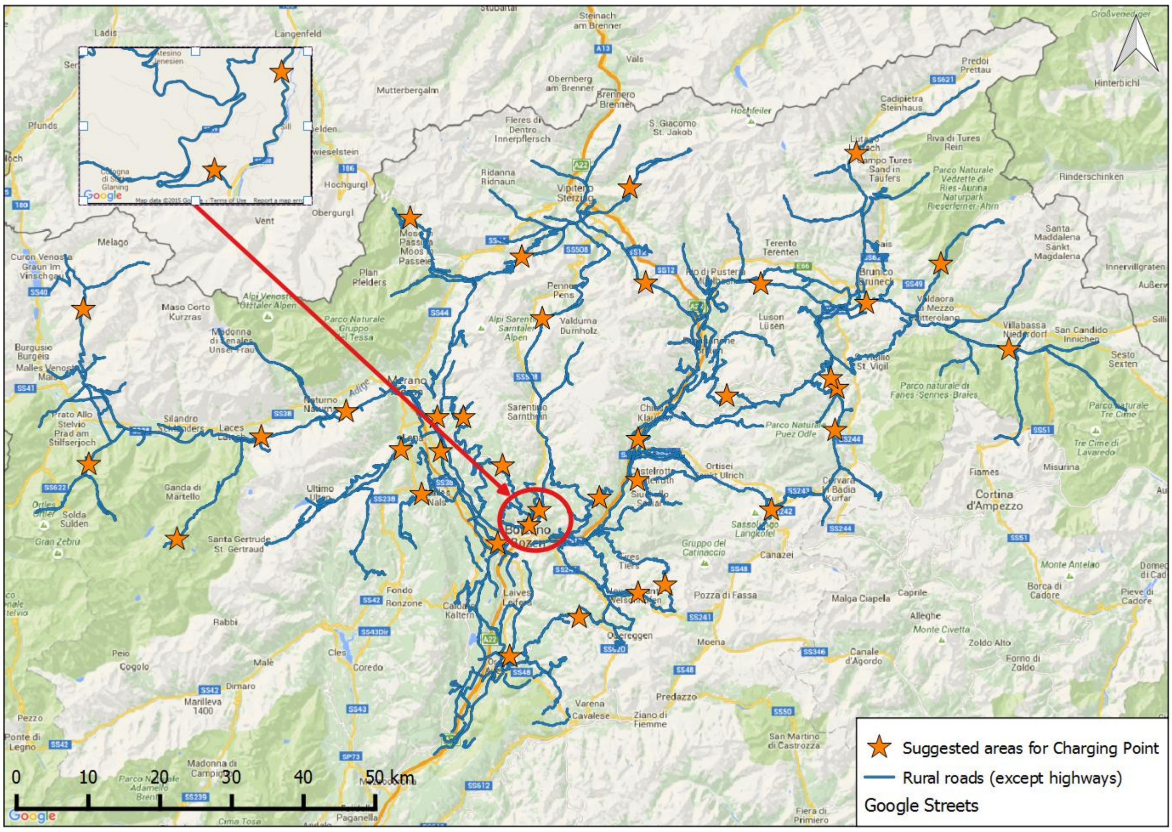


Figure 25. Suggested charging-station locations may appear close to each other, but they serve different road segments.

4. Summary

A geospatial analysis of electric-vehicle charging infrastructure allocation within a city and a region, based on open source GIS tools, is described. A methodology was developed to provide optimal locations of EV infrastructure (charging stations) within a spatially extended region. Two different cases were identified: placement in a city network (urban road network) and placement in a regional or national network (rural roads and highways). For a city and a regional network, the methodology identifies high-potential areas for the installation of charging station. In contrast, for a highway network the methodology provides explicitly the suggested locations: the charging stations should preferably be placed in already built areas, gas stations or rest areas, to minimize additional investment costs. A pilot study was made for the city of Bolzano/Bozen (city road network) and the province of Alto Adige/Südtirol (rural and highway network). The municipality and the province gave positive feedback on the suggested locations.

Particular characteristics of the methodology are its versatility and ease of use. For the city-level analysis, the final raster map can be easily combined with other raster layers to refine the optimal locations. Additional raster layers may be obtained, for example, from other studies or they may arise from specific requirements. If a raster layer specifying areas where it is prohibited to install charging stations, or a layer with areas that are mandatory for installation, is available a new allocation map can be created with little additional effort. The methodology can be easily implemented by local or regional authorities as it relies mainly on data readily available to them.

A further development of our study could be the application of the methodology to other cities so that the effect of different layers or weighting factors on the final allocation map can be investigated. Some examples of areas that could be examined are cities of different sizes (both in spatial extent and population), located in different countries (different Gross Domestic Product, transport demand and options, climate conditions). The approach could be supplemented by including information on existing charging stations and their usage.

Similar to most studies the critical issue is data availability. Local authorities and network operators have to assist in the collection of required data that are difficult to find from other sources like residential data, parking places, electricity network, and already installed charging points.

The methodology described in the report can also be used to support the implementation of the Directive on the Deployment of Alternative Fuels Infrastructure (EU, 2014), thereby assisting member states to enhance deployment of EVs and their recharge infrastructure. Regarding the analysis of the highway network, the methodology could provide additional input in studies that analyze the inter-connection of highway corridors across member states throughout Europe.

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Appendix I

Additional maps that present the spatial joining of buffered layers with the underlying vector grid, as described in Section 2.2.3 are presented:

- Parking places (Figure 26),
- Public access buildings (Figure 27, Figure 28),
- Shopping/food areas (Figure 29, Figure 30, Figure 31).

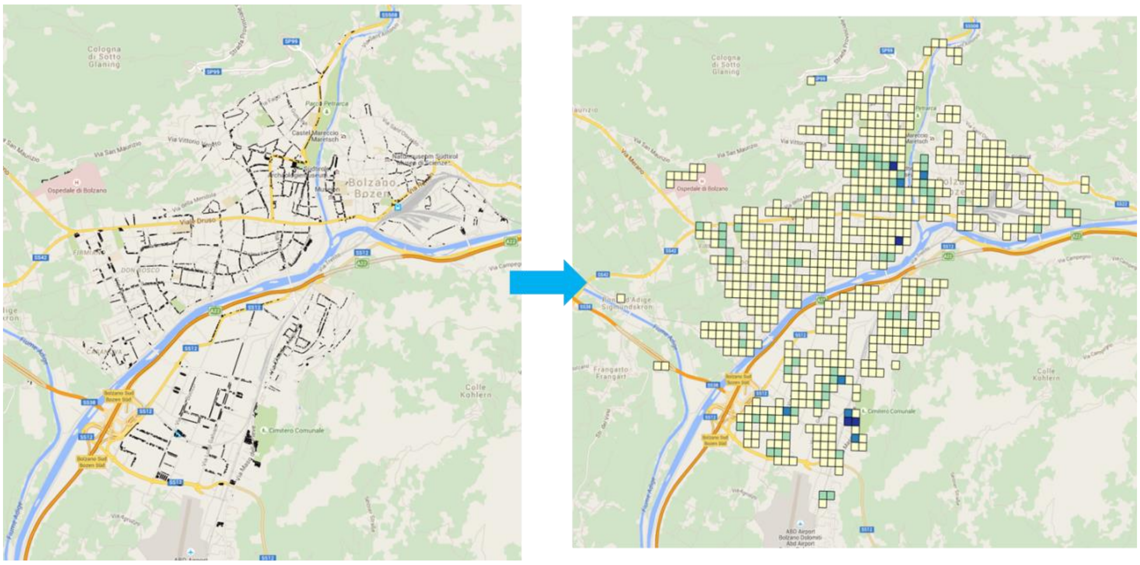

Figure 26. Spatial join with the vector grid: Parking places.

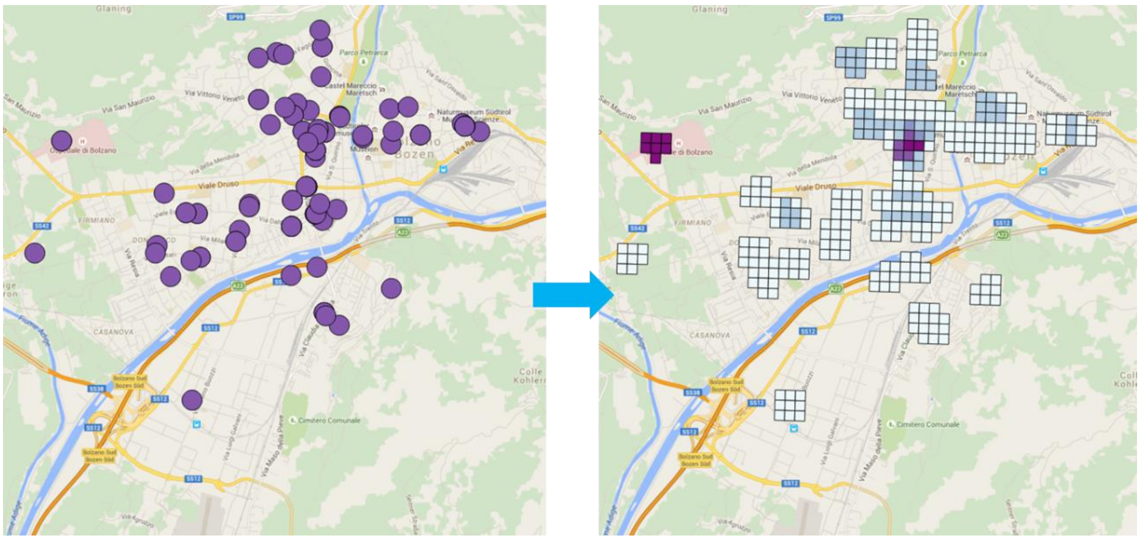

Figure 27. Spatial join with the vector grid: Health centres.

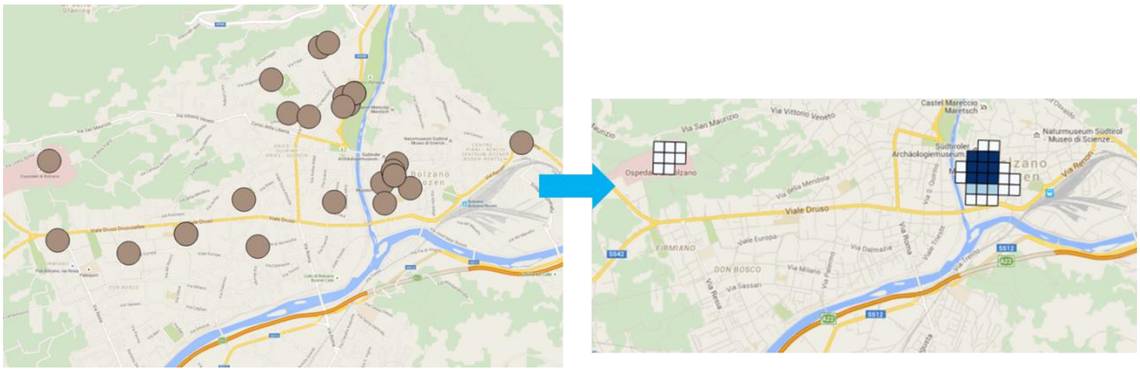

Figure 28. Spatial join with the vector grid: Universities.

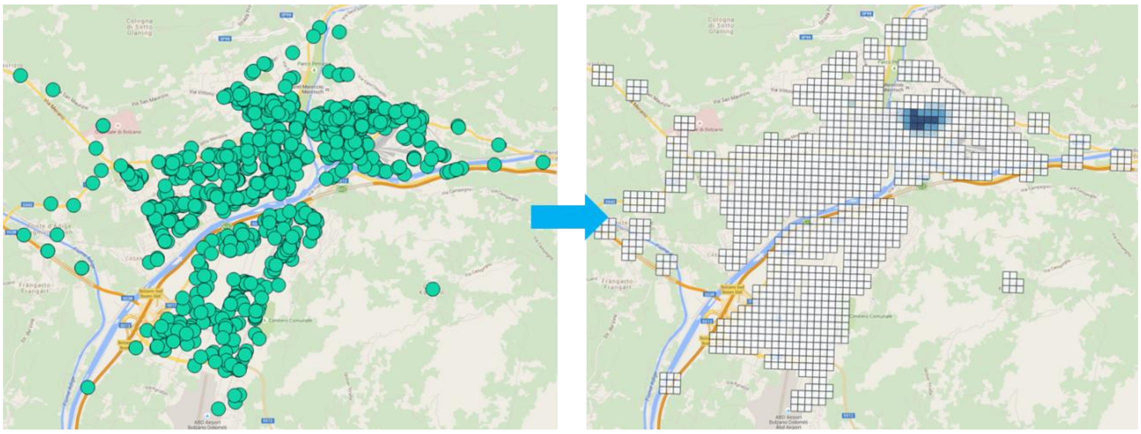

Figure 29. Spatial join with the vector grid: Stores.

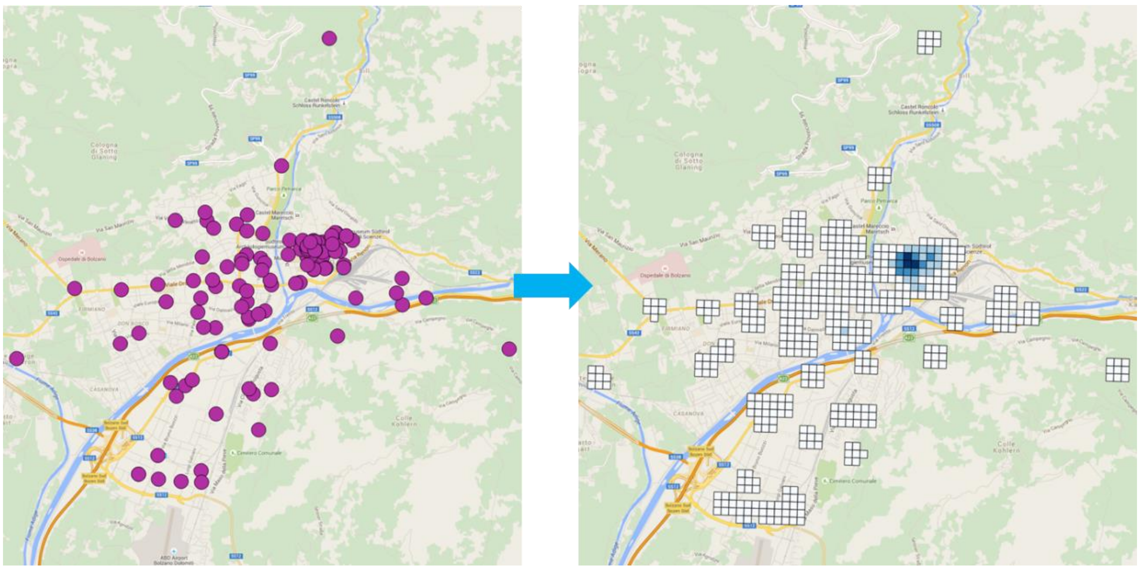

Figure 30. Spatial join with the vector grid: Restaurants.

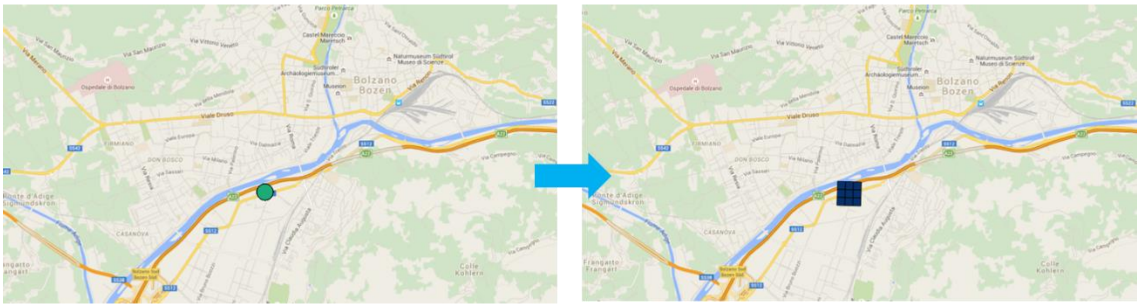

Figure 31. Spatial join with the vector grid: Malls.

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