# SELECTED ASPECTS OF DESIGNING THE INFRASTRUCTURE NETWORK OF REFUELING AND CHARGING POINTS IN URBAN AREAS FOR VEHICLES WITH ALTERNATIVE SOURCES OF POWER

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**Abstract**

Utilization of alternative fuels in transport is promoted in many EU documents and regulations. A document which has an impact on the development of infrastructure for alternative fuels is the Directive 2014/94/EU of the European Parliament and of the Council, which establishes a common framework for measures relating to infrastructure development of alternative fuels in the EU. The research problem, which is described in this paper, concerns the designing of the infrastructure network for alternative fuels in urban areas. Proposed research method and its versatility allows for use it to designing the infrastructure network both EV vehicles charging points and refuelling points for NGV vehicles in urban areas. The results obtained in the simulation experiments suggest the possibility of their use in development of national policy framework for actions in support development of the market of alternative fuels in Poland.

**Keywords:** Alternative sources to power vehicles, alternative fuels market, network of refuelling and charging, PHEV/BEV vehicles, NGV vehicles

## 1. INTRODUCTION

The processes of globalization consisting in economic terms on the free movement of goods and services determine the growth in demand for transport of both cargo and passengers. The continuing high level of transport in road transport in the European Union (EU) and in Poland involve any negative consequences for society. On the one hand, this causes dependence on imported energy and fuels, on the other hand, becomes more and more burden on the environment [3], [4].

Negative trends leading to increased demand for engine fuels and an increase in total atmospheric emissions of pollutants from road transport have led to the adoption by the European Commission (EC) development strategy for the European transport sector up to 2050 in the form of White Paper „Roadmap to a single European transport area: towards a competitive and resource efficient transport system".

The principal objectives of the strategy are to reduce Europe's dependence on imported crude oil, a reduction of 60% of greenhouse gas emissions from the transport sector up to 2050 and the creation of a single European transport area. Implementation of the strategy will force more competition and the creation of an integrated transport network, enabling the combination of different forms of transport. It is assumed that this phenomenon will lead to profound changes in the field of transport technologies in the passenger and freight transport in the range of cities between cities and on long distances. In addition, fundamental changes have occurred in urban transport, which will relate to using vehicles with new construction and technological solutions and alternative power sources. The strategy adopted by the European Commission assumes that up to year 2030 will be withdrawn 50% of vehicles with a traditional combustion engine, and up to 2050 they will be phased out completely [1].

Achieving these objectives requires a number of actions aimed on using a greater range of vehicles powered by alternative power sources and infrastructure development of alternative fuels. A common framework for measures relating to infrastructure development of alternative fuels in the EU sets directive 2014/94/UE [2].

## 2. REQUIREMENTS OF DIRECTIVE 2014/94/EU IN THE FIELD OF ROAD TRANSPORT

Directive 2014/94/UE establishes a common framework for measures relating to infrastructure of alternative fuels development in the EU [2], by setting minimal requirements for the development of infrastructure for alternative fuels both in terms of charging points for electric vehicles as well as points of natural gas as LNG and CNG. These requirements include mainly infrastructure of road transport and waterborne transport.

The Directive also specified principles for a coherent information on vehicles that can be refuelled by alternative fuels introduced on the market or charged in the charging points. The requirement is applicable to all motor vehicles placed on the market after 18th of November 2016.

Another requirement of the Directive is appropriate marking of distributors and providing the information about the prices of alternative fuels in a way enabling comparing them with regard to unit prices. The Directive obliges Member States to create a system of information which would enable access to information concerning the geographical location of refuelling points and charging points in real time.

In terms of providing of natural gas for transport purposes, Member States must ensure that building of a sufficient number of publicly accessible LNG refuelling points allowing heavy goods vehicles powered by LNG ability to move across the EU. This requirement applies to at least existing core network of the TEN-T. Another requirement is to provide by the Member States the appropriate number of publicly available CNG refuelling points to ensure the movement of vehicles powered by CNG in urban / suburban areas and other densely populated areas. Such as for LNG, and also in cases of CNG Member States must ensure an adequate number of publicly available CNG refuelling points, at least in the existing core network of the TEN- T.

In terms of electricity which is needed to power the EV, the Member States should ensure building of a sufficient number of publicly accessible charging points, which would create the opportunity to move to electric vehicles, at least in urban areas (suburban) and other densely populated areas. The Directive does not specify the number of charging points, or the rules of their deployment. The directive indicates only that the number of charging points should be determined taking into account the estimated number of electric vehicles by the end of 2020.

Under the Directive, Member States should create conditions to ensure operators of publicly accessible charging points free buying of electricity from any supplier in the EU. These requirements relate to the electricity market and the rules introduced by European Parliament and Council Directive 2009/72/WE.

## 3. DESIGNING THE NETWORK OF CHARGING AND REFUELING POINTS INFRASTRUCTURE IN URBAN AGGLOMERATIONS

### 3.1. Parameterization of input data

Designing the network of charging and refuelling points infrastructure in urban areas is carried out according to a specific algorithm. Presented in this article authors approach to this problem requires parameterization of input data and determination the order of the implemented measures.

We assume that the set of alternative fuel vehicles classes (EV, CNG, LNG) has the form: $\boldsymbol{P} = \{p: p = \overline{1, P}\}$, moreover a set of types of alternative fuel vehicles (cars, trucks and tractors, and buses) has the form $\boldsymbol{R} = \{r: r = \overline{1, R}\}$. Agglomerations which were analysed form a set in the form: $\boldsymbol{A} = \{a: a = \overline{1, A}\}$. **Table 1** shows the parameterization of data necessary for the algorithm and the rules for their calculation.

**Table 1** Parameterization of data and rules for their calculation

| *The interpretation of the parameter* | *The meaning of the parameter* |
|---|---|
| Participation rate of vehicles in agglomeration $a$ in the total number of vehicles in the country in the base year; | $\alpha(a)=\frac{N(a)}{N}, \quad \forall a \in \boldsymbol{A}$<br>wherein: $N(a)$ is the number of registered vehicles for agglomeration $a$ in base year; $N$ is the number of vehicles in the country in the base year; |
| Number of vehicles class $p$ in agglomeration $a$ in period $t$ (year), for which there is analysis; | $\widehat{N}(a,t)=\widehat{N}(t)\cdot\alpha(a), \quad \forall a \in \boldsymbol{A}$<br>wherein: $\widehat{N}(t)$ is the number of vehicles in period $t$ in country determined on the basis of forecast; |
| Participation rate of vehicles class $p$ in the total number of vehicles in country in period $t$; | $\beta(p,t)=\frac{\widehat{N}(p,t)}{\widehat{N}(t)}, \quad \forall p \in \boldsymbol{P}$<br>wherein: $\widehat{N}(p,t)$ is the number of vehicles class $p$ in period $t$ in country determined on the basis of forecast; |
| Number of vehicles class $p$ in agglomeration $a$ in period $t$; | $\widehat{N}(p,a,t)=\widehat{N}(a,t)\cdot\beta(p,t), \quad \forall a \in \boldsymbol{A} \wedge \forall p \in \boldsymbol{P}$ |
| Participation rate of vehicles class $p$ kind $r$ in country in the base year; | $wu1(p,r)=\frac{lp(p,r)}{lp(p)}, \quad \forall p \in \boldsymbol{P} \wedge \forall r \in \boldsymbol{R}$<br>wherein: $lp(p,r)$ is the number of vehicles class $p$ kind $r$ in country in the base year, while $lp(p)$ is the number of vehicles class $p$ in country in the base year; |
| Participation rate of vehicles class $p$ kind $r$ in period $t$; | $wu2(p,r,t)=\frac{lp(p,r,t)}{lp(p,t)}, \quad \forall p \in \boldsymbol{P} \wedge \forall r \in \boldsymbol{R}$<br>wherein: $lp(p,r,t)$ is number of vehicles class $p$ kind $r$ in period $t$ in the country, while $lp(p,t)$ is number of vehicles class $p$ in period $t$ in the country; |
| Number of vehicles class $p$ kind $r$ in agglomeration $a$ in period $t$; | $\widehat{N}(p,r,a,t)=\widehat{N}(p,a,t)\cdot wu2(p,r,t), \quad \forall p \in \boldsymbol{P} \wedge \forall r \in \boldsymbol{R} \wedge \forall a \in \boldsymbol{A}$ |
| Daily mileage of vehicles class $p$ kind $r$ in agglomeration $a$ in period $t$; | $PD(p,r,a,t)=\frac{\widehat{N}(p,r,a,t)\cdot PR(p,r,a,t)}{365}\cdot wn(p,r),$<br>$\forall p \in \boldsymbol{P} \wedge \forall r \in \boldsymbol{R} \wedge \forall a \in \boldsymbol{A}$<br>wherein: $PR(p,r,a,t)$ is an annual mileage of the vehicle class $p$ kind $r$ in agglomeration $a$ in period $t$, while $wn(p,r)$ is the coefficient of daily mileage inequality of vehicle class $p$ kind $r$ : $wn(p,r)=\langle 1.2; 1.5\rangle$; |
| The number of required recharging / refuelling in the day for a vehicle of class $p$ in agglomeration $a$ in period $t$; | $LL(p,a,t)=\frac{\sum_{r\in\boldsymbol{R}} PD(p,r,a,t)}{ZP(p,a,t)}, \quad \forall p \in \boldsymbol{P} \wedge \forall a \in \boldsymbol{A}$<br>wherein: $\mathrm{ZP}(p,a,t)$ is a medium range for a vehicle of class $p$ in agglomeration $a$ in period $t$; |
| Number of charging / refuelling points for a vehicle of class $p$ in agglomeration $a$ in period $t$; | $LPL(p,a,t)=\frac{LL(p,a,t)}{WP(p,a,t)\cdot wk(p,a,t)}, \quad \forall p \in \boldsymbol{P} \wedge \forall a \in \boldsymbol{A}$<br>wherein: $\mathrm{WP}(p,a,t)$ is a performance of charging / refuelling point for a vehicle of class $p$ in agglomeration $a$ in period $t$, while $\mathrm{wk}(p,a,t)$ is a correction coefficient of performance of charging / refuelling point for a vehicle of class $p$ in agglomeration $a$ in period $t$; |

Determining the required number of charging / refuelling points in order to ensure the continuity of transport flows in the studied agglomerations resulting from the availability of points, requires the analysis of the following assumptions:

- number of charging / refuelling points in agglomeration due to the required availability of these points should be considered in the context of the administrative division. So if:
  $LPL(p,a,t) \geq LRA(a,t)$ then $LPL(p,a,t) = LPL(p,a,t), \quad \forall p \in \boldsymbol{P} \wedge \forall a \in \boldsymbol{A}$ (1)
  $LPL(p,a,t) \leq LRA(a,t)$ then $LPL(p,a,t) = LRA(a,t), \quad \forall p \in \boldsymbol{P} \wedge \forall a \in \boldsymbol{A}$ (2)
  wherein $LRA(a,t)$ is the number of administrative divisions in agglomeration $a$ in period $t$.

### 3.2. The algorithm for determining the number of charging and refuelling points

Development of the EV and NGV market in Poland depends largely on the condition of the charging and refuelling points infrastructure, both in urban areas and also along public roads. It is reasonable to develop a methodology for designing of the network of charging / refuelling points infrastructure, both in terms of its shaping in urban areas and also along the TEN-T core network, which results from the Directive of the European Parliament and Council 2014/94/EU on the development of infrastructure for alternative fuels. In the article the authors restricted themselves to present a methodology for designing of the network of charging / refuelling points infrastructure in urban areas.

Designing of the network of charging / refuelling points infrastructure in urban agglomerations in the form of flowchart is presented in **Figure 1**.

## 4. CASE STUDY FOR SELECTED URBAN AGGLOMERATION

The analysis includes the Warsaw agglomeration and concerns the development of the network of charging / refuelling points infrastructure in 2020. Conducting complete analysis requires obtaining a number of statistical data and carry out forecasting in terms of the development both the vehicles market in total in the country and also for each class of alternative fuel vehicles. Therefore, in order to obtained results, the number of charging and refuelling points in specific agglomerations will be reliable, we must have a verified statistical data and forecasts with the highest credibility.

In analyses of the Warsaw agglomeration we assumed that the base year is 2014, the year in which in Warsaw was 1 248 661 vehicles (there were cars, trucks, tractor trucks and buses). It was also assumed that the analyses will be conducted for EVs. We considered fast charging points (AD), in which may occur loader with a capacity of about 50 kW for charging DC and 22 kW for charging AC. Charger of this type allow for charging of batteries from 30 to 80% of their capacity in vehicles both BEV and PHEV. It was assumed further that the average charging time of the vehicle is about 30 min. Fully charge of the battery of the vehicle should take place at night, in points of slow charging (AC).

Analysing the problem of the number of charging points for EVs in Warsaw and using the algorithm presented in chapter 3 it was estimated that in 2020, when the number of EV vehicles will be equal to 2732 it will be necessary to build 38 fast charging points (**Figure 2**). Therefore, considering the number of districts in Warsaw, which is equal to 18, it will be fulfilled dependence (1). Under this assumption, in 16 districts it should be build two fast charging points, while in 2 districts three points.

Assuming that vehicles should be additionally recharged at night, and that 50% of EV is not used at this time, it must be assumed that in Warsaw also should be 1.366 charging points free.

Another parameter influencing the number of fast charging points (AD) for EV is the charging time of the vehicle. The parameter value is varied and depends on the class of charging stations, e.g. for the charging station GARO DC QC 20 with the power 20 kW charging time is up to 60 min., while for the charging station

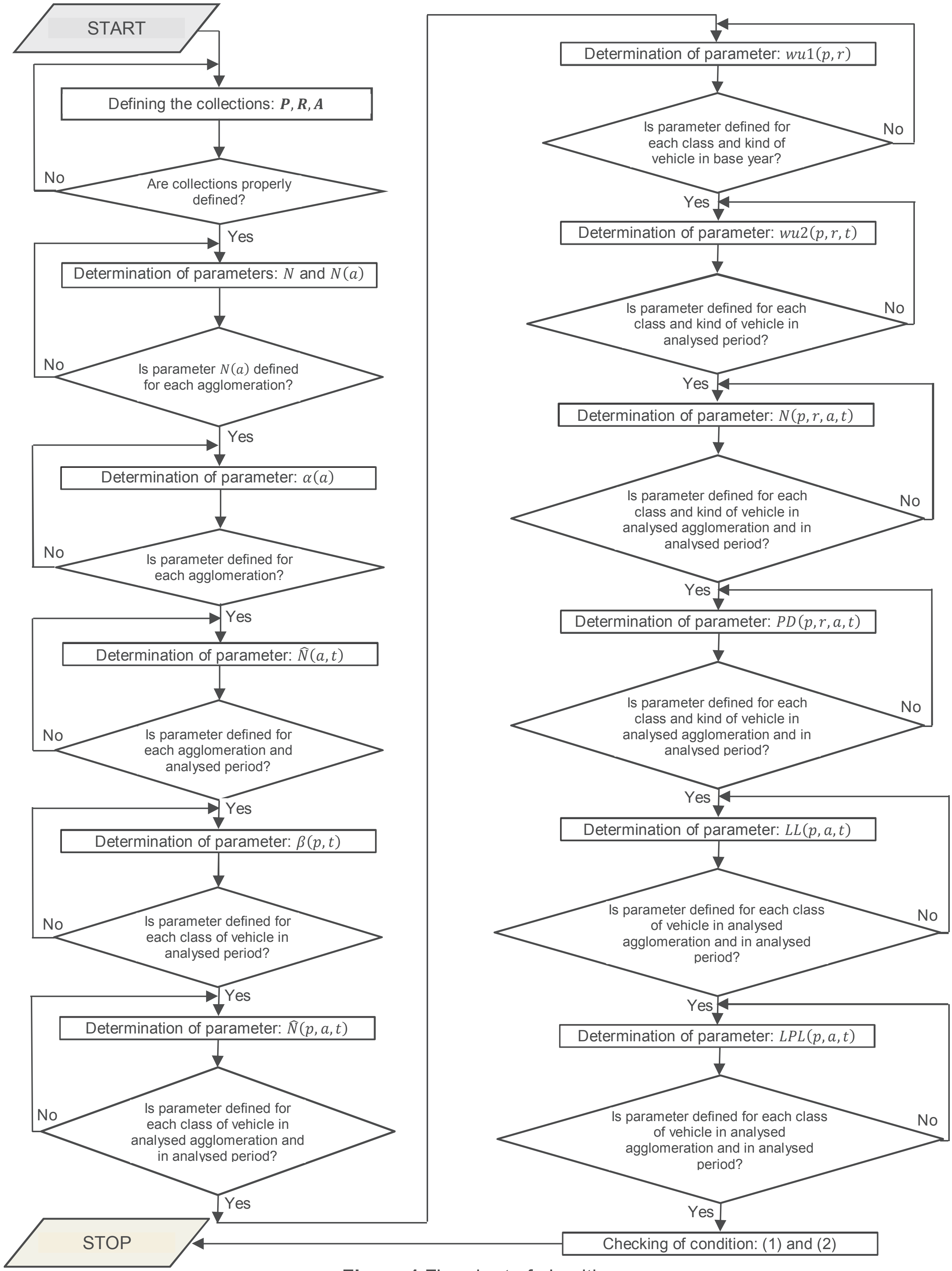


**Figure 1** Flowchart of algorithm

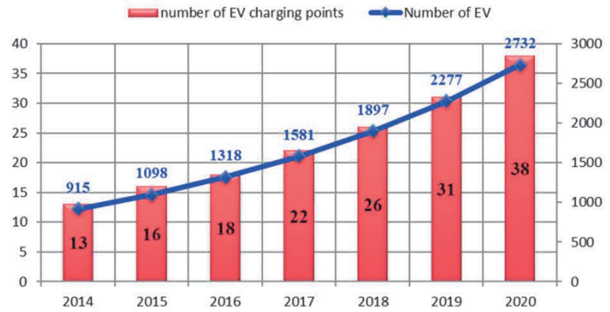


**Figure 2** Chart of the number of charging points fast in Warsaw at the established structure and number of vehicles in the years 2014 ÷ 2020 (Source: own work)

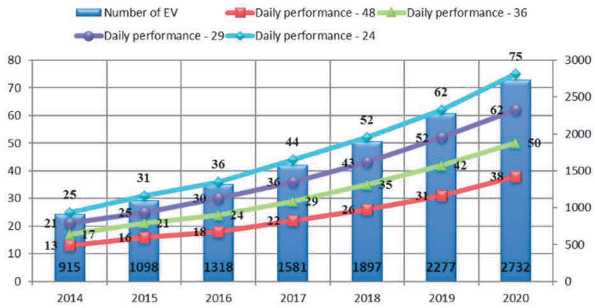


**Figure 3** Chart with the number of fast charging points in Warsaw taking into account the established structure and number of vehicles in the years 2014 ÷ 2020 and different daily capacity of points (Source: own work)

GARO DC QC 45 with the power 50 kW charging time is up to 30 min. Change the number of charging points in function to their capacity, established structure and the number of EVs in Warsaw is presented in **Figure 3**.

The number of charging points is influenced by other parameters such as the number of EVs and their structure, the average annual mileage and their average reach. Proposed approach allows for carrying out simulation experiments, in which are taken into account different values of presented parameters.

## 5. CONCLUSIONS

The number of EV charging points is dependent on both the development of the vehicle market and technical-operational parameters of charging stations. Values obtained under analysis for the year 2020 require constant monitoring they should be subject of revision connected with obtaining of more data for the respective periods. The proposed approach is a universal approach, it allows for carrying out simulation experiments for different values of input parameters. This approach can be used both for designing of the network of EV charging points infrastructure and network of NGV refuelling points for vehicles infrastructure. Conducting analyses using the proposed approach allow the decision-makers to make rational decisions, both in terms of the instruments of support for EV and NGV users and entities investing in the development of charging and refuelling points infrastructure in urban areas.

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