The Technical and Operational Aspects of the Introduction of Electric – Powered Buses to the Public Transportation System

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Because of the need of introducing ecologically clean transport technologies, activities bound up with using electric propulsion in motor vehicles operating in public transport are undertaken. Technical and operational possibilities of introducing electric–powered buses to the communal public transport are shown in the article. The operation of that kind of fleet requires appropriate technical infrastructure involving charging electric-powered urban transport. Simultaneously, former experiences show strong mutual connection between technical sphere and organizational system of communal public transport in agglomerations. Hence, essential significance among other things is given to the layout of the functioning bus lines network and the organisation of bus operations on the lines (timetable). The models of the technical, organizational, economical and ecological links enabling optimal choice of type of bus propulsion were worked out, with the aim of solving this problem rationally.

Keywords: public transport, traction batteries, traffic models, technical infrastructure.

1. INTRODUCTION

Many agglomerations in the European Union faced problems connected with mobility in accordance to rules of sustainable development, such us: high traffic intensity and traffic congestion (traffic jam), harmful emissions, and lack of developmental balance leading to social exclusion that negatively impact the growth of economy. Urban transport is a weak link in the whole passenger and cargo transport system (the "last mile" problem, that is the transport on its last section and the necessity of possessing efficient multi-modal junctions, which have effective localisation), because of low effectiveness of activities bound up with mobility in the cities undertaken on local and regional level. Mobility is crucial for internal market, and for citizens' lives quality as they want to travel comfortably. It is particularly connected with increasing requirements within the scope of environmental preservation, which are executed thanks to the new technologies which reduce harmful emissions. For a few years the attempts have been made to introduce electric-powered buses to public transportation system which would, depending on local conditions, permit to eliminate high – emission diesel buses. However, in order to solve this problem rationally, depending on local public transport system conditions, models of technical, organizational, economical and ecological links enabling optimal choice of type of propulsion for particular bus line should be developed.

2. TECHNICAL ASPECTS OF THE INTRODUCTION OF ELECTRIC-POWERED BUSES TO THE PUBLIC TRANSPORTATION SYSTEM

2.1. ELECTRIC – POWERED VEHICLES AND THE STRATEGY OF THE EUROPEAN UNION

In the researches on the transport systems development, strategies are built which are the record of communication choices of local society, orientated towards the solution of main transport problems and remaining permanent and sustainable development of the permanent region and making it more competitive.

The following issue should be analysed: how to combine the wish of population for mobility and economy needs concerning the cargo transport with predicted diminishing access to resources and restrictions in the field of environment? In the sector of transport which is a considerable and still growing source of greenhouse gas, it is essential to reduce the emission of this gas to at least 60% until 2050 in comparison with the level in 1990, which means that practical elimination of traditional combustion propulsion is assumed.

At the same time until 2030 reduction of greenhouse gas in this sector of about 20% in comparison with the level in 2008 needs to be done [3].

Lowered demands concerning the range of vehicles and bigger population density may ease the transition into more ecological transport in cities. Thanks to gradual elimination of conventionally-powered vehicles from cities, the dependence of transport systems on petroleum and greenhouse gas emissions will be limited to considerable degree.

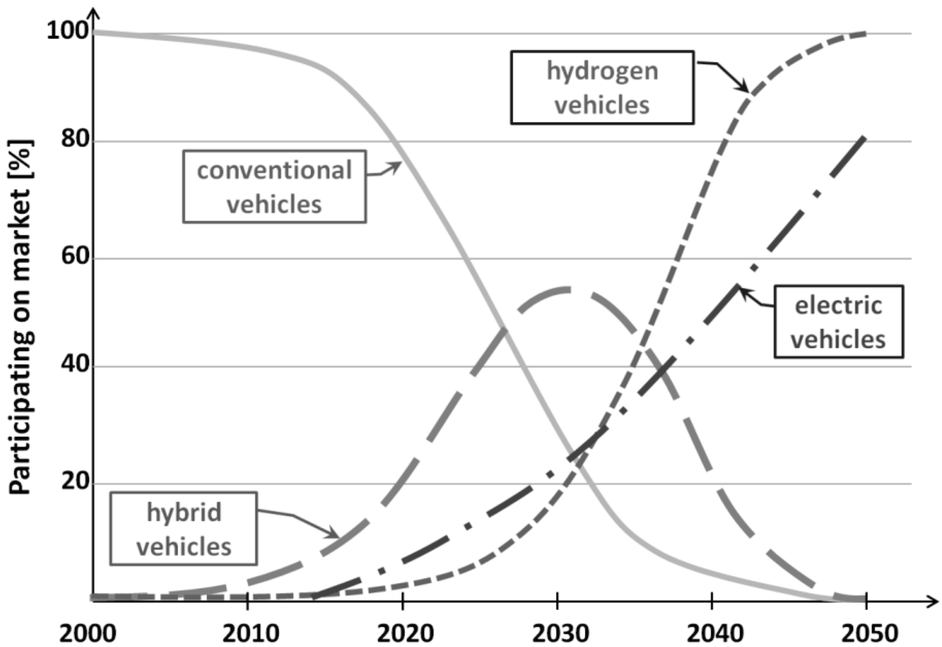

Fig. 1. Development of propulsion power concerning motor vehicles.
Source: own study

This problem is often presented as 3 x 20%:

- 20% - reduction of CO_2 emission
- 20% - reduction of energy consumption
- 20% - use of renewable energy

How to prepare for fulfillment of such radical environmental requirements programmed by the EU? Undoubtedly, searching for new technologies in the field of vehicles and traffic management which will be essential for reducing emissions which derive from transport will be one of elements of this strategy, because urban transport is responsible for ca. ¼ of total transport CO_2 emission. Delaying these activities and slow introduction of the new technologies may condemn transport in the UE to irreversible collapse, because European (EU) transport sector is battling against quickly growing world transport markets [9].

The process must be accompanied by the development of appropriate charging infrastructure. Big fleets of urban buses, taxis and delivery are particularly suitable for the introduction of alternative propulsions and fuels, such as electric propulsion from accumulator batteries or hydrogen, the energy source of the future (Fig. 1).

The position of the European Commission on the electric vehicles was presented in 2010 in the document: "The European strategy on clean and energy efficient vehicles". In this paper the strategy on ecologically clean and energy-efficient vehicles (cars and buses) promotion was presented. The strategy concerns both the vehicles equipped with conventional diesel propulsion as well as using new propulsion technologies (hybrid propulsion, electric propulsion, hydrogen propulsion) which will be introduced (Fig. 1). Furthermore, in particular for electric – powered vehicles, certification rules and technical standards will be implemented, in order to make charging these vehicle and connecting to the electric network in the whole EU possible with the use of typical chargers.

2.2. ELECTRIC PROPULSION IN URBAN BUSES

The following kinds of ecological public transport vehicles are possible: trams, trolleybus and electric – powered buses (with batteries). Public transport vehicles can be powered by the following fuels:

- petroleum (and different kinds of biofuels) – for diesel engines,
- gas fuels – natural gas (CNG/LNG), biogas,
- electric energy.

Currently, classical diesel engine dominates in public transport vehicles, wherein we have to realize stronger and stronger EU restrictions in fumes emissions (EEV – Euro 6 will have been in effect since 2014). As far as gas – powered vehicles are concerned, requirements concerning emissions of harmful substances are identical to diesel propulsion (but there are already engines which meet the EEV standard requirements that is similar to Euro 6). However, higher purchase prices of about 15-30% of these vehicles (in comparison to diesel ones) is a problem, but also limited accessibility to the petrol stations offering this kind of fuel. Natural gas (CNG) is often mixed with hydrogen what enables reducing emission of level diesel engines CO_2 emission, in comparison to conventional fuels [13].

Development of electric–powered public transport vehicles, powered by rechargeable battery can be considered as the fuel of the future. These vehicles will be powered by DC electric motor, powered by powerful lithium–ion battery [10]. Progress in lithium-ion battery technology seems to be all important here. Even if new electric-powered vehicles that are CO_2-free will appear on the market in a few years, they will be able to cover only short distances. Until 2020 we should expect no vehicles of this kind being able to cover longer distances.

The good points of electric propulsion are as follows:

- no harmful emissions,
- quiet and calm ride.

Whereas drawbacks of this kind of propulsions are as follows:

- high cost of fleet (2-3 times more expensive in comparison to diesel motors),
- the need for building additional charging infrastructure en route or in the base.

Good and bad points are determined by the quality of rechargeable batteries used in electric-powered urban transport vehicles. The users are dishearten from battery propulsion not only by high prices but also by big decrease of value of accumulators, arose due to fear for their durability. In case of cars, decrease of EVs value, with mileage of 30,000 km is much higher than the decrease of diesel cars with the same mileage (www.lrta.info/articles). After seven years accumulator is worthless on secondary market. A high price of the whole vehicle is a problem as well. The development of EV’s market depends on government subsides.

The conditions of electric – powered buses operation require providing them with en route battery charging. Two variants of charging rechargeable batteries are possible:

- charging with use of pantograph on selected bus stop (Fig. 2),
- plug – in charging (Fig. 3).

a) Pantograph located on the bus

b) Pantograph located on the bus

Fig. 2. Bus being charged with use of the pantographs en route.

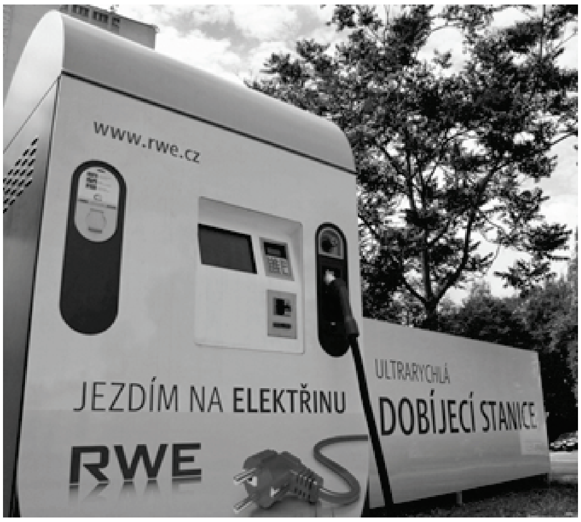

Fig. 3. An example of plug-in terminal.

The pantograph system consists of the 250kW-powered station equipped with movable charging rails which are pulled out only during the charging time, and a bus equipped with two pantographs. It is assumed that charging stations should be placed in the bus terminus, where it will be possible to charge the battery for the next run (15 – 25 km) in approximately 5 – 6 minutes. Taking into account such a small charging time it is necessary to use lithium-titanium battery. Currently, because of the lack of additional technical infrastructure that would enable charging bus accumulator batteries en route, this kind of vehicles is eliminated from use.

Technical infrastructure carries high costs, the results of operation, however, both transport and ecological, may weigh in favour of introducing such kind of solution [7]. Certain analogy can be found in the analysis concerning introducing special technical infrastructure for hydrogen-powered buses. At present, urban electric cars are experimentally introduced in many cities worldwide. This system requires building special docking/charging technical infrastructure, too [2].

In general assumptions providing energy exchange can be made by charging - with the use of pantograph (Fig. 2) or plug – in (Fig.3) but also by efficient replacement of the whole battery in replacement points in a bus route (if construction of such battery is appropriate). In every case one has to remember that effective service for passengers retaining optimal operation of company's fleet should be a priority. This requires determining the location of charging stations on the area covered by the bus company.

Appropriate selection of infrastructure should be examined from the perspective of organization. Electric propulsion and limitations concerning the distance which is possible to be covered without charging require significant changes in previous models of bus traffic planning (timetable building). It seems that it will be appropriate to look for compromise between an attempt to keep the existing timetables or routes on selected area of operation, and investment limitations concerning new technical infrastructure enabling bus battery charging.

3. OPERATION PROBLEMS IN PUBLIC TRANSPORTATION SYSTEMS USING ELECTRIC-POWERED BUSES

3.1. THE DILEMMAS OF THE PROCESS OF OPERATION OF ELECTRIC – POWERED BUSES IN PUBLIC TRANSPORTATION SYSTEMS IN POLISH CITIES

Buses being the all-purpose means of public transport require adapting of operation system for specificity of the used fleet to keep this value. The same concerns electric-powered buses. This kind of fleet determines solutions in scopes of:

- the organization of technical base of depot, which is given a task to efficiently, reliably and effectively run current fleet operation,
- the layout of functional bus lines network,
- the operational plan, being realized with timetable.

For that reason, it is necessary, for appropriate course of electric – powered buses operation in public transport systems, to solve three basic issues:

- Selecting routes being served with the use of electric – powered buses in order to efficiently and effectively realize the current timetable, which should be a point of reference for all undertaken problems. Achieving satisfactory results from the passenger, public transport organiser and operator point of view require decisions in the following questions concerning:
  - fleet structure (amount of buses of the following kinds: conventional propulsion, hybrid, e – buses, mixed fleet or consisted of homogenous e- bus fleet,
  - keep existing routes and public transport lines layout and the timetable or make

changes arose due to the structure of the owned fleet.
- Arranging optimal location of charging stations, having assumed given operation plan (routes and lines layout and the timetable) and taking into consideration the process of discharging the batteries in the function of:
  - the timetable,
  - the plan and profile of communications route,
  - ride conditions (number of stops and moves caused by traffic congestion or traffic lights).
- Selecting optimal bus charging strategy which requires the decision on the question of battery charging or battery changes, having assumed given operation plan and having defined the process of battery discharging.

In the subsequent part of the article the structure of the model concerning electric-powered buses operation in urban public transport will be shown in a synthetic presentation.

3.2. MODELING OF ELECTRIC-POWERED BUSES TRAFFIC IN PUBLIC TRANSPORT NETWORK

The technical infrastructure of bus public transport, closely connected with planning and transport organization, is formed by:
- bus routes,
- bus stops,
- transfer nodes,
- bus terminus.

From the e-buses point of view the bus terminuses, located at the ends of the bus routes, in the spot of change of transport and points, in which change of frequency caused by significant change of passenger flow occurs seem to be an issue of special importance. These are exactly the points where e-bus (accumulators) charging station installation is potentially possible.
Listed elements of technical infrastructure are the components of public transport network, whose parameters determine significant technical – operational feature of bus fleet realizing passenger transport. To the above - mentioned belong:
- schedule speed,
- rational inter-stop distance,
- transport capacity,
- collision grade with other means of transport,
- influence on the environment.

In order to make good use of the bus fleet, providing appropriate passenger service level at the same time, traffic models that enable building the timetables in the network based on computer simulation, are built up. The traffic models do not represent actual situation on the network, yet they allow the analysis of the “what would happen if?” situation. The task of building the model is a difficult and complex task because of diversity and amount of needed data (which should authenticate the model). The more and better described (formalized) are the input data of the model, the more precise the real traffic conditions are described. The model should be verified basing on actual network measurements on selected routes of the network in order to make the traffic model more reliable [8].

Thanks to the data from measurements and the results of forecasts concerning the traffic in the network, it is possible to coordinate the distribution of public transport needs, the bus routes layout with taking into account their routes and communication with other transport systems (e.g. integration of transportation knots, terminus), with the localization of charging stations variants, and with the variants of operating defined lines (electric fleet only, diesel fleet only, mixed fleet – part of lines, e.g. these heading the integrated transportation node with the use of electric fleet, the rest with the use of diesel fleet).

The traffic model consists of sub-models that consider the input and output problems significant for them. Such a model structure consists of:
1. *Transportation model* containing: the road network sub-model (plan and profile of road network, speed of the flow, speed of congestion), bus network sub-model (stop locations, routes and lines, timetable, vehicle operation plans), bus speed profile sub-model (free flow and bound flow, bus declaration and acceleration on bus stops and on intersections), ride time sub-model (depending on bus line profile and traffic flow conditions) (Fig. 4).

   Traffic modelling in the public transport in which e-buses fleet is used should have the following aims:
   - ascertainment there are no stops caused by the battery exhaustion during realization of the given timetable,
   - looking for optimal localisation of battery charging stations,

- looking for optimal battery charging strategy.

2. *Technical model*, describing parameters obtained from the transportation model (network, speed and road profile, the ride time), mechanical of the bus and electrical characteristics of the accumulators as the input data, and allocations of vehicles (buses to current timetable and specified timetable locations of charging and switching facilities, strategy of battery recharging or replacement as the output data [1] (Fig. 5).

3. *Economical model*, describing relationships between financial factors (credits, leasing, cash), costs purchase and infrastructural investments, maintenance and operation, and the bus fleet structure (electric or mixed), charging strategy (recharging, recharging + loading, battery replacing).

   The economical model must take into consideration both external and internal costs of the transport systems which are different for every country and region. Such a model should answer the questions concerning the fleet, infrastructure and human resources, that is:
   - What model and what variables are adopted for the economical model of:
     - fleet purchase (with diesel, hybrid or electric propulsion),
     - construction of infrastructure for diesel and hybrid buses as well as for electric-powered buses (charging stations, re-charging systems on the stops and on the sections),
     - employment of additional staff for technical – operational support.
   - What model and what variables are adopted for the economical model of:
     - fleet maintenance (with diesel, hybrid or electric propulsion),
     - maintenance of infrastructure for diesel and hybrid buses as well as for electric-powered buses (charging stations, re-charging systems on the stops and on the sections),
     - training of additional staff for technical-operational support.
   - What model and what variables are adopted for the economical model of:
     - fleet operation (with diesel, hybrid or electric propulsion),
     - operation of infrastructure for diesel and hybrid buses as well as for electric-powered buses (charging stations, re-charging systems on the stops and on the sections),
     - additional staff for technical-operational support.

4. *Ecological model*, containing the Directive 2008/50/EC of the European Parliament and of the council of 21 May 2008 on ambient air quality and cleaner air for Europe, as the input, whereas the effects in the form of the adverse effect of emissions (local and global) on environment depending on the power and fleet composition (diesel, CNG, hybrid, battery operated) as the result.

The combined effect of separate sub-models can be analyzed in the realization of electric-powered bus transportation structural model (Fig. 6).

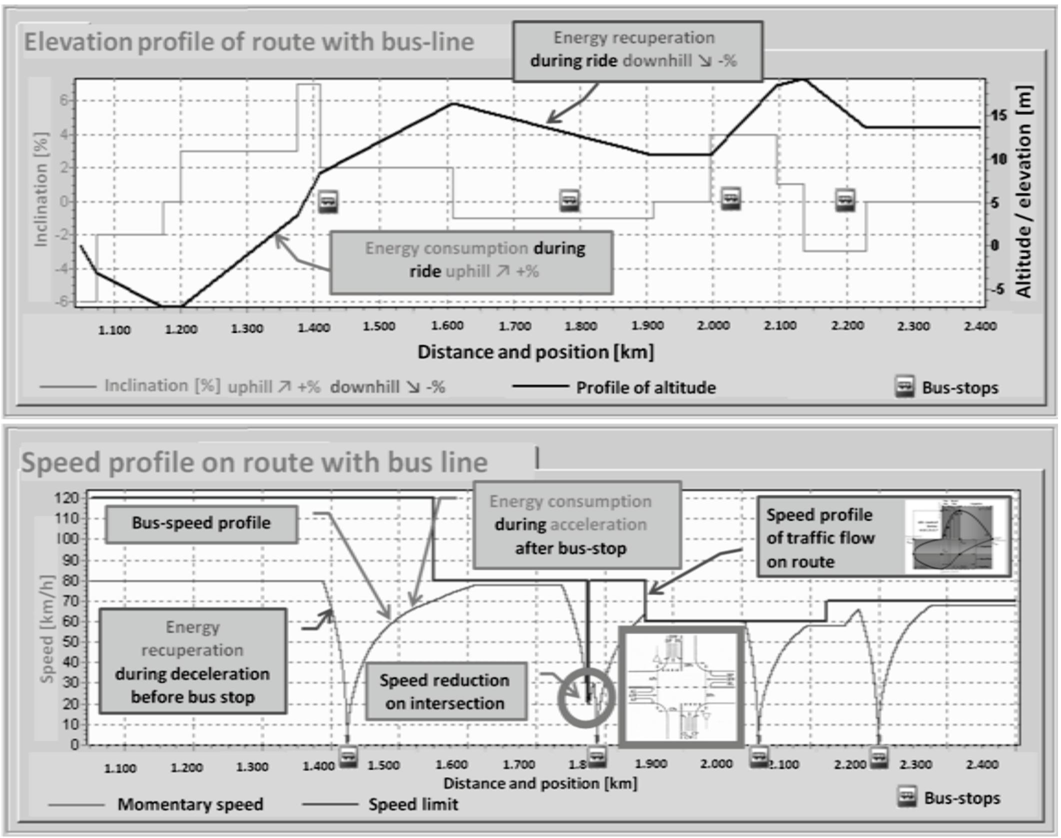

Fig. 4. Elevation profile and speed profile as sub-models of transport model for electric buses.
Source: own study

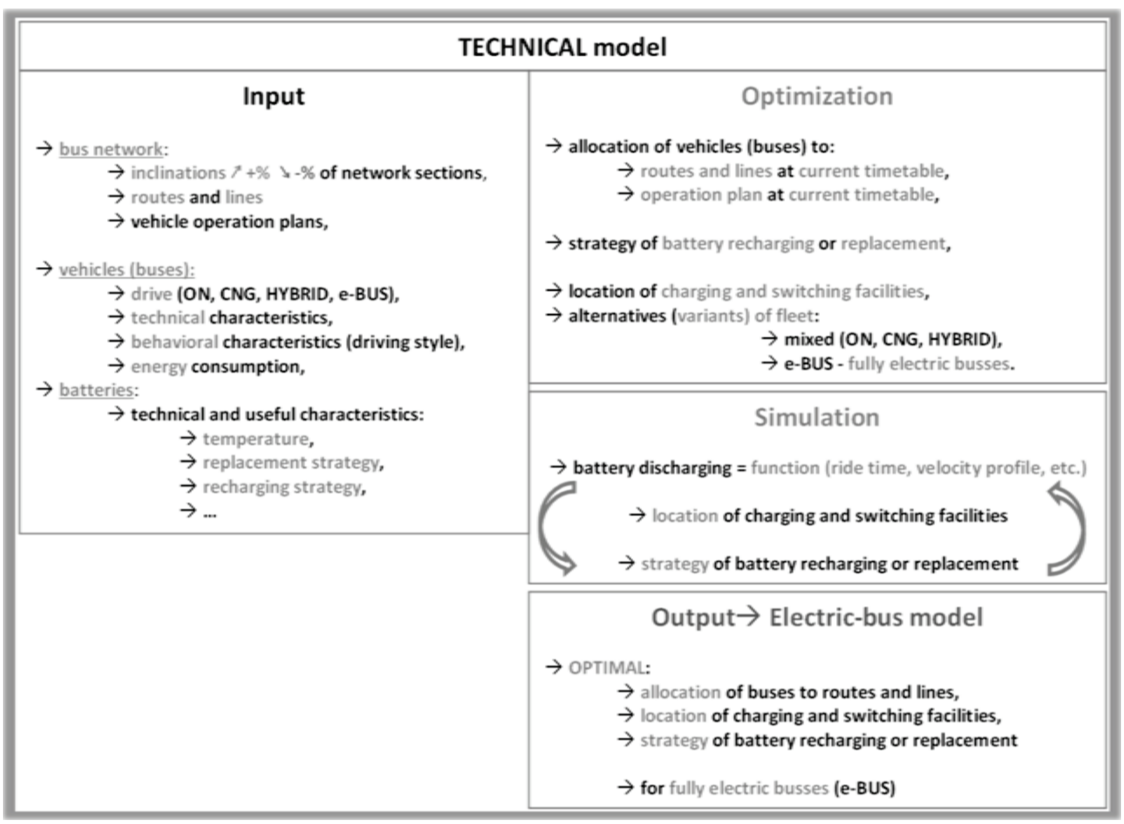

Fig. 5. The elements of technical model, based on Solaris Urbino 8,9 Electric.
Source: own study

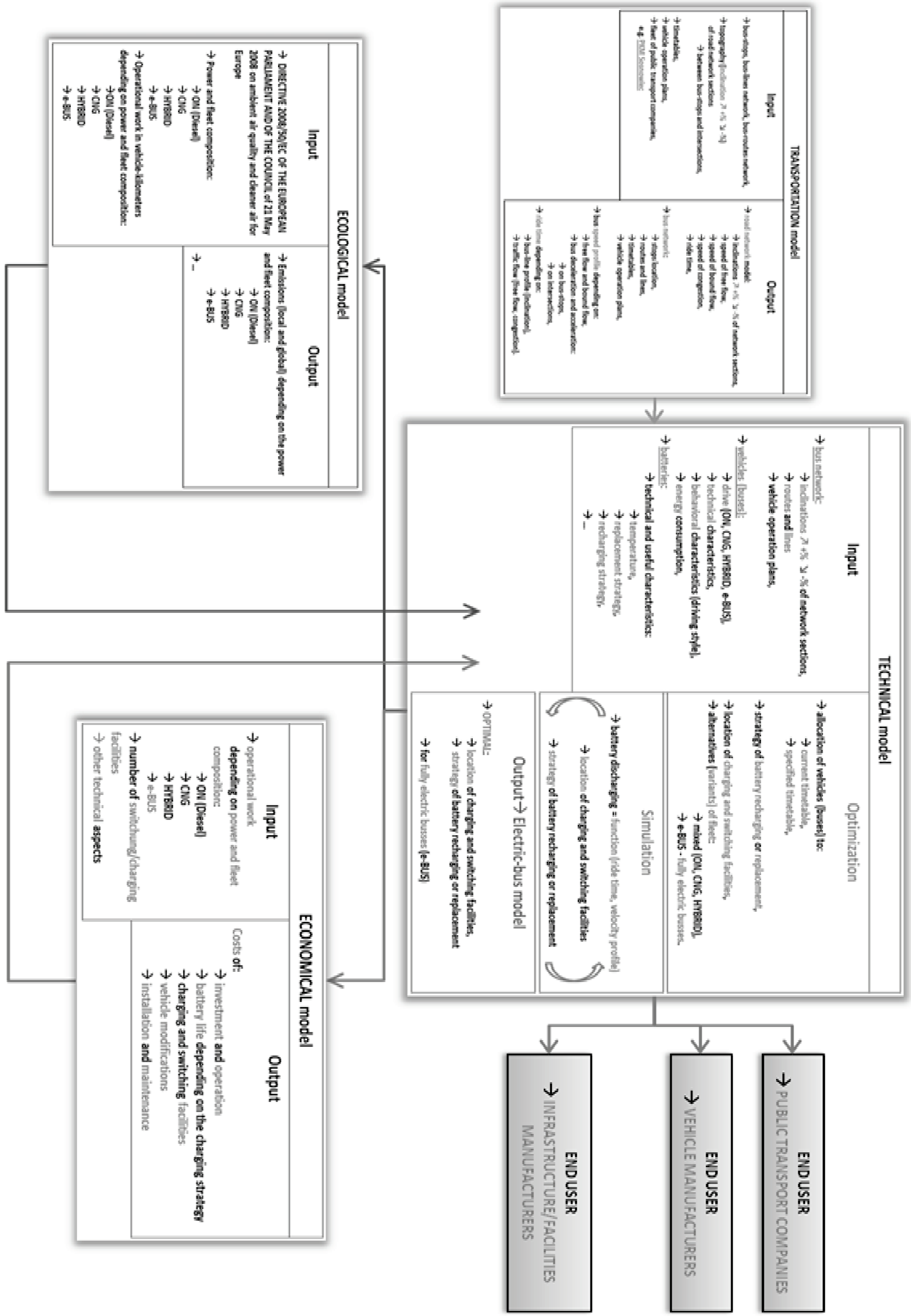

Fig. 6. The model of the introduction of electric-powered buses to communal public transport network in a selected city.
Source: own study

4. SUMMARY

The model presented in the article enables the analysis and forecasting of the flow, provides co-coordinating distribution of public transport needs, the bus routes layout with taking into account their routes and communication with other transport systems (e.g. integration transportation knots, terminues), with the localisation of charging stations variants, and with the variants of operating defined lines (electric fleet only, diesel fleet only, mixed fleet – part of lines, e.g. these heading integration transportation knots, terminus with use of electric fleet, the rest with use of diesel fleet). The model gives the answer to the questions considering cost-effectiveness of electric-powered fleet operation, and the influence of buses being powered with the use of different types of propulsion on the environment

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