PLATON –

Planning Process and Tool for Step-by-Step Conversion of the Conventional or Mixed Bus Fleet to a 100% Electric Bus Fleet

Deliverable: WP 4.1 Efficient Data Structures and Models

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1 Introduction

The Deliverable 4.1 presents the results of the project work WP 4.1 Efficient Data Structures and Models.

Section 2 contains an analysis of approaches to solving problem of transition to electric urban transport, their classification and typical examples. Section 3 describes basic models, data structure and tools of PLATON project. Section 4 is devoted to assessing bus energy consumption as one of the key elements in the tool system for the transition process. Section 5 presents software ECBus that is designed to calculate the energy consumption of vehicles on the route. Summary is in Section 6.

The Deliverable 4.1 includes three annexes. Annex A (Section 7) contains information files from addition 01 to database of PLATON project. User's manual for Software ECBus v0.1 is in Annex B (Section 8). Annex C (Section 9) gives an example of methodology application on calculation of bus energy consumption.

2 Approaches to solving problem of transition to electric urban transport

Dozens of projects on electric buses have been completed and continue to be implemented around the world (for example, Charging Strategies, Electric Storage Systems, Route Scheduling, Timetable etc.). But at present there is no typical methodology and recommendations for transiting to the urban electric bus fleet. Replacing a modern fleet of diesel buses with electric vehicles requires a complete change in the transportation system with a complex technological assessment.

The most suitable system solution is a way to overcome the complexity of the problem. As it is pointed in (Göhlich et al. 2019): “Three charging strategies can be combined with different charging interfaces. Additionally, different battery technologies are available. Considering the three most widely used battery types, this leads to a morphological matrix with 45 different system solutions which are theoretically possible as shown in Figure 1. A complete evaluation of this design space is prohibitive. Additionally, the determination of charging power and battery capacity adds further variables to this complex technology selection problem. Therefore, a profound assessment strategy is necessary to find a “*most suitable system solution*” under given strategic and operational requirements”.

Function	**Options**				
Charging Strategy	depot	opportunity	in motion		
Charging System	manual (plug, pump nozzle)	induction	pantograph	trolleybus current collector	battery swapping
Battery System	**battery**				
	LFP	NMC	LTO		

Figure 1 Morphological matrix of available technology options in electric bus systems

Mathematic complexity of the problem. Mathematic complexity is underlined in (Iliopoulou, 2019): “The problem of optimally designing surface public transportation systems has attracted the interest of the research community for five decades (Kepaptsoglou and Karlaftis, 2009). The associated Transit Route Network Design

Problem (TRNDP) deals with determining the optimal structure (routes, stops etc.) and operational characteristics of a surface urban public transportation system, following specific design objectives, assumptions on demand, and financial and operational constraints (Farahani et al.,2013), (Ló pez-Ramos et al, 2014). The TRNDP is among the most complex and demanding problems of transportation planning; its computational complexity stems from the discrete nature of design variables, the non-convexity of the solution search space, and its classification as ''NP-hard'' (Newell, 1979), (Baaj and Mahmassani, 1991), (Chakroborty, 2003). As such, a realistic description and solution of the TRNDP requires complex mathematical and lexicographic representations along with heuristic/ metaheuristic solution algorithms (Ibarra-Roja et. al. 2015)".

The introduction of electric buses leads to a change in the planning of the public transport system. The work (Häll et al., 2018) investigates and discusses how the introduction of electric buses (EB), both battery and plug-in hybrid EB, will and should change the operations planning of a public transit system. It is shown that some changes are required in the design of a transit route network, and in the timetabling and vehicle scheduling processes. Other changes are not required, but are advisable, using this opportunity upon the introduction of EB. The work covers the main characteristics of different types of EB with a short description, including the most popular charging technologies, and it presents the generally accepted transit operations planning process. Likewise, it describes and analytically formulates new challenges that arise when introducing EB. The outcome of the analyses shows that multiple new considerations must take place. It is also shown that the different charging techniques will influence the operations planning process in different ways and to a varying extent. With overnight, quick and continuous charging, the main challenges are in the network route design step, given the possibility of altering the existing network of routes, with efficient and optimal changes of the timetabling and vehicle scheduling components. An illustrative example, based on four bus lines in Norrkoping, Sweden, is formulized and introduced using three problem instances of 48, 82, and 116 bus trips. The main results exhibit the minimum number of vehicles required using different scenarios of charging stations.

Typical approaches. Thus, the complexity of the problem under consideration and the rapid change in the technical characteristics of the objects and components involved in the transition process do not make it possible to comprehensively analyze and find the one-time optimal solution. *Therefore, there are many separate approaches, the most characteristic of which are described below*.

Additional analysis can be found in the article (Algin, 2018), prepared on the thematic of the PLATON project.

A wide range of sources devoted to the problem is presented in Annex A, which is part of the database being developed related to the problem.

2.1 General approaches and decision support systems

Conceptual design of urban e-bus systems

The main focus of the study (Göhlich et al. 2019) was the introduction of a *feasible methodology*. Based on viable technology specifications and reasonable cost data a feasible combination of technologies and design parameters was identified. However, the specific results, are bound to the chosen operational scenario. *The battery aging models* used here are based on recently published data which should be validated with additional experiments in the near future.

The methodology is applicable to identify most advantageous concepts for electric bus systems but it could be expanded to the electrification of other vehicle fleets like city logistics or other services. Before taking final decisions, however, a detailed analysis of the total cost of ownership (TCO) should be carried out. Such a TCO assessment for the concepts identified in this study has been carried out by Jefferies and Göhlich (2018). In the future**,** *other technologies* such as partial trolleybus catenaries and fuel cell powered bus systems could become competitive and should be analysed based on the proposed methodology.

Decision support systems

Some decision support systems are created and developed. Typical example is described in (Conti, 2017). This study reports the results of the application of a Decision Support System (DSS) named Better Electric Solutions for public Transport (BEST) developed by ENEA within the Research program on Electric System and founded by the Italian Ministry of the Environment. BEST deals with *the design and the evaluation of technological solutions* for the electrification of public transport in urban areas. Specifically, it works analyzing *several proposed architectures*, based on the most recent battery electric buses technologies, in terms of their *technical feasibility*, as well as in terms of *investment and management costs*. Moreover, it permits to compare the best resulting electric alternative with standard fuel alternatives, as CNG and diesel, both in terms of *internal costs and external costs due to vehicle emissions and noises*. The application of BEST to several bus lines in Rome has shown, in most cases, the convenience of the electrical architecture based on *combining* the overnight slow charge at the depot and the opportunity charge at the terminals. Moreover, results of BEST confirm that operating costs of a full electric vehicle are less than of its conventional counterparts and the electrification would seem to be, in the medium to long term, more cost effective than conventional technologies.

Integrated design methodology

The paper (Iliopoulou, 2019) proposes an integrated design methodology which considers the allocation of charging infrastructure during the route design process.

The E-TRNDP under consideration refers to the determination of public transport routes operated by battery electric buses which recharge using *fast chargers placed at terminals and bus stops.*

Overall, energy requirements associated with the deployment of electric vehicle fleets in public transportation call for a careful consideration of *energy supply* to buses. Therefore, the transportation and energy supply systems must be analyzed in an integrated manner and should be represented using comprehensive design models. In this context, the present study focuses on the integrated design of an electric bus route network and the determination of optimal locations and characteristics of charging infrastructures, using advanced algorithmic approaches.

In the specific case of the E-TRNDP variant, the problem should account for both the *energy and the transportation-related design requirements*.

In the work (Iliopoulou, 2019), the trade-offs between user and operator cost are taken into account and a multi-objective optimization methodology

(MOPSO) is proposed to obtain non-dominated solutions, that is, solutions where any further improvement to the value of one objective is detrimental to the quality of the other (Fan, 2009). In this manner, the relative importance of objectives is not a priori determined, in contrast to the studies that solve a single-objective optimization problem using the weighted sum method to handle different objectives (Mauttone and Urquhart, 2009).

A bi-level formulation is adopted for the E-TRNDP. Without loss of generality, the upper-level problem is a TRNDP formulation which aims at determining a set of routes that minimize user costs while satisfying design constraints. The lower-level problem aims to minimize the number of chargers required and it is formulated as a mixed-integer Programming (MIP) problem.

Results show that operator costs can be reduced considerably if the average travel time per passenger is increased by 25% (4 min). Furthermore, the scenario analysis underlines the complex trade-offs between the design parameters, showing that battery capacity, CP, minimum depth of discharge, and recharging times are interrelated and should be carefully considered.

Overall, the algorithm produces a variety of non-dominated solutions which the operator could evaluate based on policy perspective. Such an approach to the problem is all the more important considering the purchase cost of a fast charger, which ranges between €100,000 and €220,000 and can roughly approach the cost of buying a typical thermal bus. Thus, in all cases, it is important to apply a solution method which generates a set of efficient solutions and facilitates the decision-making process.

The tool for (re)designing existing and new depots

The paper (Lauth et al., 2019) presents a methodology that addresses the challenges of *designing a depot for electric vehicle fleets*. The wide variety of possible solutions are structured using a morphological matrix. A modular simulation and *planning tool* is introduced which takes technical and operational aspects into account. The tool can be used to determine the effects of depot layouts and processes. Different from most existing works, the *charging process is integrated into main depot operations*, which consist of daily service, maintenance, parking and vehicle dispatch. In a real-world case study, the developed algorithms for dispatching and price-oriented charging are applied. The results show the depot processes of 74 electric buses over a week and a charging profile in low-cost electricity price intervals as well as a 56.6 % reduction in peak load compared to charging without management.

2.2 Economic analysis

Feasible electric bus system and economic analysis base on TCO

The paper (Göhlich et al., 2018) presents a *holistic design methodology* to identify the "most suitable system solution" under given strategic and operational requirements. The relevant vehicle technologies and charging systems are analysed and structured using a morphological matrix. A modular simulation model is introduced which takes technical and operational aspects into account. The model can be used to determine a *feasible electric bus system* (Fig. 2).

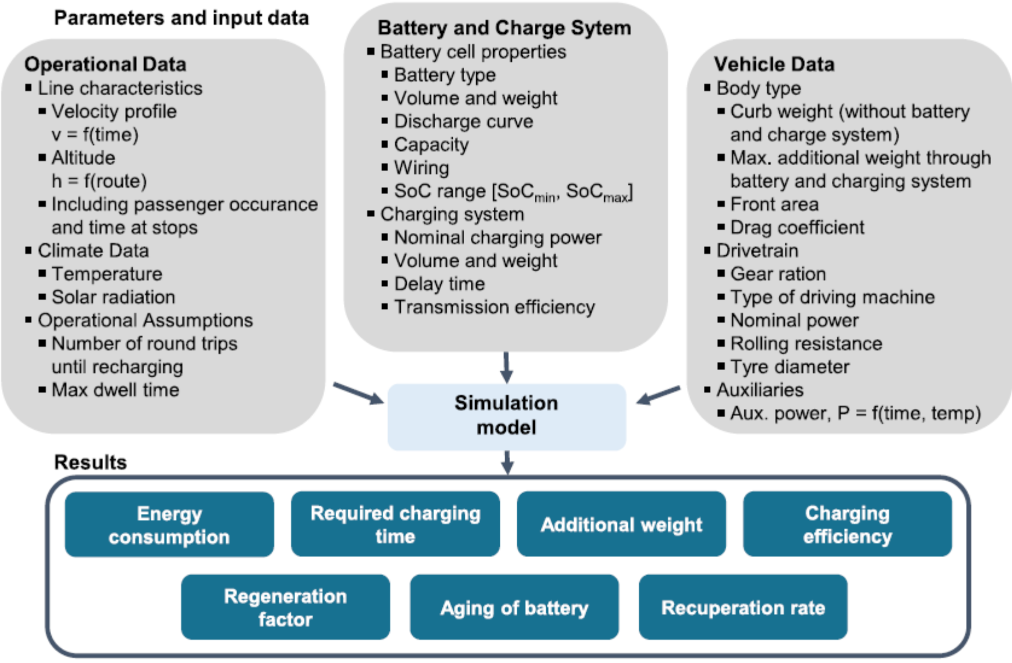


Figure 2 Input and output data for bus system simulation

For a holistic electric bus system design it is first necessary to define the *operational conditions*. This study assumes a short bus line that is two times the Manhattan cycle with an overall length of 6.65 km and a dwell time of 10 min. Exemplarily, a 12 m single-deck bus is considered. The passenger occupancy is set to 20% (Verband Deutscher Verkehrsunternehmen (VDV) 2016, Statistic checked on 2/1/2018). The power of auxiliaries in winter is set to maximum 24 kW, while the average auxiliary power is 8 kW. The battery capacity has to be chosen such that in winter conditions (scenario 1), the bus can be driven from terminus to terminus. Furthermore, it is stipulated that in average conditions the unavailability of one charging station should not affect the normal operation service, hence the vehicle range must be sufficient to cover two trips from terminus to terminus (i.e., one round trip, scenario 2).

In order to determine design parameters, an appropriate *simulation model* has been developed. The parameters are examined for specific bus systems under specific operational conditions. Therefore, the input data covers operational data, as described above, vehicle data, battery cell properties and charging system data. The traction energy consumption is dependent on the sum of resistance forces.

The vehicle speed is given by the driving cycle **(**e.g., the Manhattan bus cycle**)**.

Detailed *economic analysis* is conducted by means of a total cost of ownership (TCO) model (Fig. 3). The TCO model is composed of acquisition and operational cost for vehicles and infrastructure (en-route and in the depot), capital financing cost, personnel cost and emission cost. It is based on the net present value method. The model input comprises operational, technical and cost data. The final TCO value is expressed in €/km based on the total mileage over the operational period.

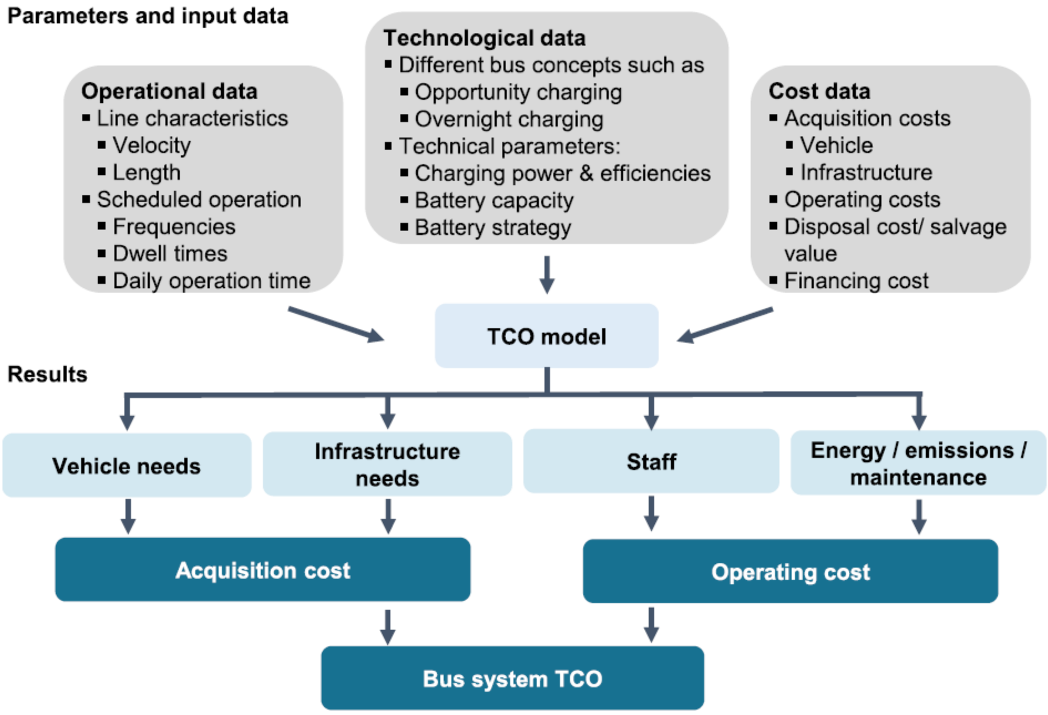


Figure 3 TCO model for the bus line electrification assessment

The applicability of the *model was verified in a pilot project in Berlin* and the methodology was applied to a realistic operational scenario. Obtain results indicate that electric bus systems are technically feasible and can become economically competitive from the year 2025 under the conditions examined.

TCO analysis for different charging strategies.

In the paper (Jefferies and Göhlich, 2018) a new methodology is introduced to compare the economics of various electric bus charging strategies that lifts several restrictions inherent to other contemporary approaches. In particular, it does not assume unchanged vehicle schedules, but instead determines new schedules adapted to the range and charging time restrictions imposed by electric buses. It therefore allows calculation of the required fleet size as a function of vehicle and charging parameters. The methodology was implemented within a *new toolbox for transport system simulation*, planning and TCO (total cost of ownership) analysis. A case study was conducted to compare the TCO for two electric bus system variants: Opportunity charging at terminal stops (OC) and depot charging (DC).

The simulation of 145 existing bus schedules from a metropolitan transport operator revealed that, in practice, it is often impossible to substitute diesel buses with electric buses unless adjustments to the schedules are made. The simulation also highlighted the importance of considering delays, especially when dealing with OC, as OC systems depend on sufficient charging time at terminal stations

A TCO analysis was conducted for a single bus route. Schedules were replanned for an OC and a DC scenario; based on these schedules, fleet size, charging infrastructure demand, annual energy consumption and driver hours were evaluated for each scenario. The results reveal a TCO of 4.29 €/km for the

OC scenario and 4.39 €/km for the DC scenario. While we can confirm the common finding that DC incurs higher cost than OC, the cost difference of 2.3% is much smaller than usually reported. This is attributed to the fact that TCO studies by other authors operate on the basis of several assumptions that do not hold in our practical case.

Due to the narrow TCO difference and the degree of uncertainty inherent to some cost parameters, the authors conclude that a purely cost-based decision between the two systems is infeasible under the specific conditions examined.

2.3 Estimation of the energy demand of electric buses

This is one of the key problems associated with many aspects of the implementation of the electric bus fleet in various real operating conditions.

Planning the introduction of electric buses in existing public transport networks calls for careful consideration, including, but not limited to: deciding which bus lines to electrify, choosing an electric bus model and its battery capacity as well as the charging strategy (opportunity charging versus overnight charging, for example). *The first step for all of these considerations is estimating the energy required to operate the existing bus lines with electric buses.* In large transportation networks, this can be challenging to do in practice due to the lack of readily available data describing the detailed driving profiles of each bus route.

Using real-world trip data. In the paper (Gallet et al., 2018), a **simplified longitudinal dynamics model was introduced**, which overcomes this issue while facilitating the use of existing real network-wide data sets. Unlike previous approaches, which either oversimplify the estimation, or require high-resolution driving profiles, the model only requires information about the bus arrival and departure times at each bus stop. This allows bus operators to use commonly available data sources to estimate the energy requirements of electric buses in their existing bus networks. Examples of such data sources include low-resolution location records from a fleet management system or data from the fare payment system, which records when and where buses stop in order to pick up or drop off passengers. By using real, large-scale data sets, this approach encourages an analysis of the statistical distribution of observed values instead of focusing on single numeric values (usually averages). This enables more realistic insights into the energy requirements of the bus network.

The model presented in (Gallet et al., 2018) was applied to a case study based on a real data set covering the entire bus network of Singapore. As far as the authors know, this is the first time that a detailed, network-wide estimation of the energy demand of BEBs in a large bus network of a megacity was performed *on the basis of real-world trip data*.

The mentioned paper presents a method of building a speed profile based on trapezes and triangles which are combined to reach average speed of bus on segment “from stop-to-stop”. In this aspect the approach (Gallet et al., 2018) differs from the well-known SORT method (UITP, 2014).

SORT method. In well-known SORT approach (UITP, 2014) that is similar to standard driving cycles, a standardized set of trapezes is used (Figure 4). A criterion for the proximity the SORT cycle and real route is the key parameter: the same commercial speed V_c.

The three SORT base cycles (modules) in shape of trapezes are used to form artificial SORT route. Where are: 1) Heavy urban cycle (V_c = 12 km/h), 2) Easy urban (mixed) cycle (V_c = 18 km/h), 3) Easy suburban cycle (V_c = 25 km/h). The consumption C is obtained by using the formula:

$$C = a\text{SORT1} + b\text{SORT2} + c\text{SORT3} \tag{1}$$

The definition of the coefficients *a*, *b*, and *c* is the responsibility of the operator.

The SORT method is intended for measurements of bus performance under standardized on-road cycles. Such measurements cannot reflect the specific application of buses (vehicle configuration, topography, driver influence, climate, loading conditions, etc.).

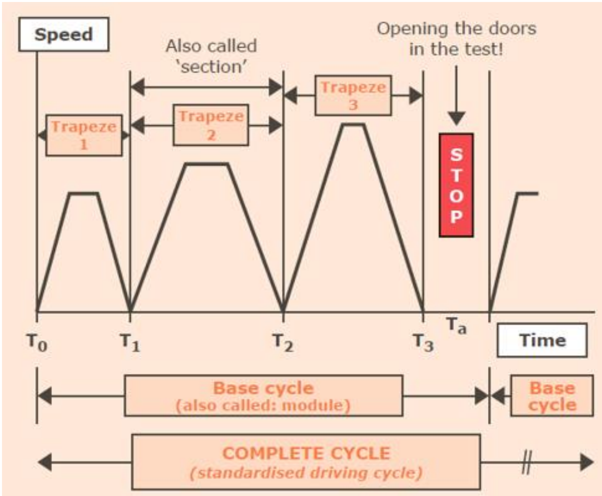


Figure 4 SORT method: making base cycle from trapezes

Features for the construction of the speed profile in (Gallet et al., 2018) are as follows. The duration of each trip between two visited bus stops Δt_{trip} and the dwell time at each stop Δt_{dwell} is calculated from arrival and departure times. Combined with the known distance D between the stops, this yields the average speed of the trip $v_{\text{avg}} = D/\Delta t_{\text{trip}}$.

In order to better reproduce the real driving conditions to which a bus is exposed, a simplified speed profile is derived dynamically for each trip between each pair of bus stops so that it matches the available real-world data (inter-stop distance D and trip duration Δt_{trip}). It consists of a succession of n_h+1 identical phases of the length $D' = D/(n_h+1)$. n_h corresponds to the number of intermediate halts between two stops, e.g. in order to stop at a traffic light or give way at an intersection.

Each phase starts with constant acceleration $+a$ over distance d_0, followed by constant speed v_1 over distance d_1 and comes to a halt with constant deceleration rate $-a$ over distance d_2, so that $d_0+d_1+d_2=D'$. The values of n_h and v_1 are chosen dynamically based on the **measured** average speed v_{avg}. For n_h, it is assumed that there is at least one intermediate halt per trip, and one more for each 5 km/h-step that v_{avg} takes under 25 km/h. I.e. $n_h = 1$ for $v_{\text{avg}} \geqslant 25$ km/h, $n_h = 2$ if $20 \leqslant v_{\text{avg}} < 25$ km/h, $n_h = 3$ if $15 \leqslant v_{\text{avg}} < 20$ km/h, etc.

2.4 Digitalization

Trends in the development of modern technical facilities and their production largely refers to Digitalization and ideology of Industry 4.0 (i4. 0), where a key role is played by the development of the sensor base and intellectualization of machines and materials [1], the Internet of Things (IoT), the creation of Digital Twins (DTs) of items, etc. The central concept of i4.0 is a “cyber-physical system” (CPS), which is characterized by a physical object, for example, a machine, and its DT, in the form of a model or a set of models that implemented in software simulating behavior of the physical object. Fundamentally new parts in i4.0 are the model approach and the Digital Twin of the product, as well as sensor bases, wireless data transmission, diagnostics and analytics. The model approach involves designing on the basis of a complex of models that accompanies a product during the entire life cycle and includes the concept of a DT. The Digital Twin of an item is a computer image corresponding to a real one. It is created for each item during the design process, then DT is detailed during the production of the item and becomes its exact (in the ideal case) digital copy, which allows reproducing all the basic properties of the item. Then DT goes through all stages of the life cycle of a physical object.

With regard to vehicles and the topics discussed, Digitalization is the process of providing vehicles with sensors to acquire information, storing this information in the cloud data storage and analyzing the data. This new trend enables to monitor the energetic operation of each vehicle.

Intelligent Transportation Systems (ITS). Paper-review (Iliopoulou and Kepaptsoglou, 2019) describes perspectives ITS and their positions among approaches based on optimization models. Optimization models have been useful planning tools for decades and are utilized to solve problems at every stage of the public transport planning process. The explosion of data stemming from ITS systems calls for a readjustment of such models to incorporate actual knowledge of passenger demand patterns and bus arrival times. It is thus expected that data-driven public transport planning will be the mainstream approach in a few years, following the introduction of ITS systems on urban centers under the sustainable mobility paradigm.

Up until now, there is no clearly defined path for translating ITS data streams in meaningful inputs, thus comparative analyses between different approaches are needed to identify the most efficient strategies. The relationship between optimization and public transport planning, although being constantly redefined, remains indispensable and will continue to evolve in parallel with the emerging significance of the role of transit systems.

Bus-to-Route and Route-to-Bus Approaches.

The paper (Lopez-Ibarra, 2019) proposes a methodology for managing the battery lifetime of a whole fleet with the aim to improve the total cost of ownership of hybrid electric buses. This approach has been addressed from two points of view the bus-to-route and route-to-bus approaches. The bus-to-route optimization is focused on the energy management strategy generation of each bus of the fleet. A techno-economic, route energetic evaluation and battery aging analysis of the fleet have been performed. From the outcome of this analysis, the buses have been grouped, according the state of health of each bus. Based on the analysis and classification, the route-to-bus approach is applied. This technique lies on both, a re-evaluation of the energy management system and/or the re-organization of the buses according to the state of health of each bus. Increases of BT lifetimes up to 10.7% are obtained with the proposed approach.

3 Basic models, data structure and tools of PLATON project

The economic, environmental, social problems in the project are considered at the city level, in which the electric bus fleet is being introduced. That is, in the wording and solution of the tasks of the project there is no deepening into such problems as the effects/costs of obtaining fossil fuels, their processing, etc.

Information and data architecture of PLATON Toolkit System and its components is presented in Figure 1 of Deliverable 3.2.

Analysis of the typical approaches presented above shows that there is not possible to create a single universal tool for using by all interested parties and for covering all mentioned aspects. That is why not one but several tools are being developed (Fig. 5). These tools are related to the most popular problems in the transition process and are based on new models and data structures developed in the project.

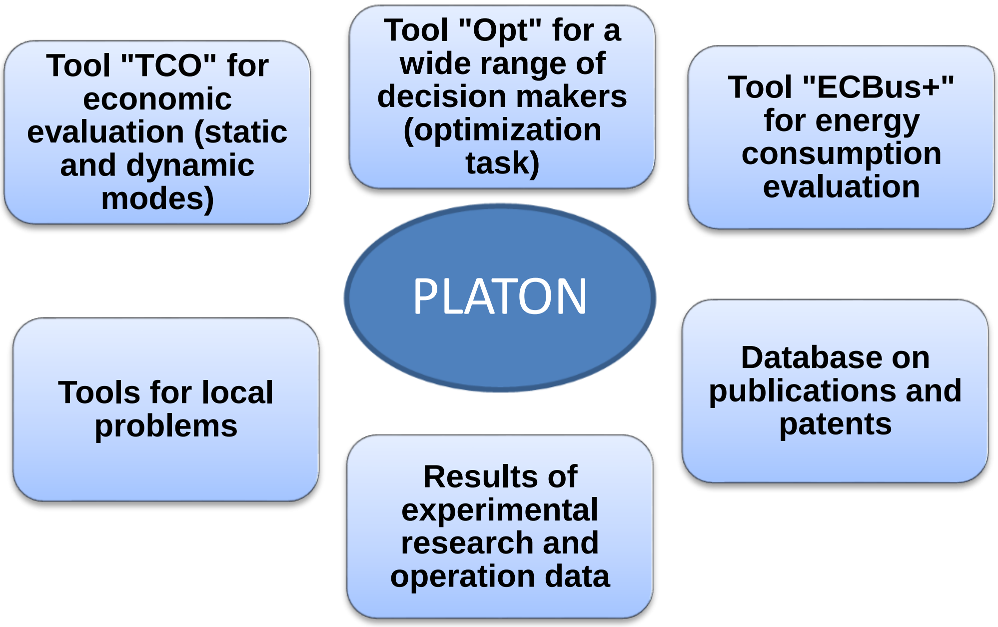


Figure 5 Main data structures and tools of PLATON project

3.1 Tool "Opt" for a wide range of decision makers (optimization task)

This tool is to solve the Opt problem, which considers the design of a bus fleet with both fast charging on the route and slow charging in the depot.

Problem Opt assumes that an e-bus charges each time when it visits a non-depot charging station. This problem is to determine an e-fleet, places for charging stations and transformers, assignment of charging stations to the specified places, assignment of charging stations to the transformers and assignment of charging stations to the routes such that all e-buses can feasibly drive, the required traffic interval is maintained, and the output power of any transformer is not exceeded.

The objective is to maximize the total value, which can be related to the total passenger load of conventional vehicles replaced by e-buses, provided that the total capital cost and the total operating, depreciation and energy cost do not exceed their upper bounds. Problem Opt is a model for e-buses with fast-charging batteries. An adaptation of this model to the case of slow-charging batteries is made.

*Main idea to implement the step-by-step conversion***.** In order to implement the dynamic (step-by-step) nature of the conversion process, it is suggested to solve the optimization problem repeatedly for the years of the planning horizon. The decisions made for the past years are used as part of the input for the future year. This approach is justified by the fact that the input data for the near future is more reliable and precise than that for the far future. There are two main approaches to make a decision for a planning horizon of several years: *one-stage decision* and *multi-stage decision*.

This tool is considered in detail in Section 4.2 of the Deliverable 4.3.

3.2 Total Cost of Ownership model

The Total Cost of Ownership (TCO) model is the last link for the decision support system presented already in the Deliverable 2.2 'Planning process'. Its task is to make an economic assessment of actions to be planned with the use of other components of the PLATON toolkit, regardless of the fleet replacement strategy chosen beforehand (vehicle cycle approach, vehicle-scheduling approach). Part of the input data comes from other PLATON toolkit's components (mainly these related to the daily mileage of the bus, charging facilities and strategy), some of them - strictly economic in nature – need to be filled in by the user.

The input data are the following:

Technical variables:

- Bat_{life} – lifetime of the bus battery [years]
- Bat_{cap} – battery capacity [kWh]
- Bus_{life} – bus lifetime [years]

Economic variables:

- i_{bat2} – market interest rate for bat2 [%],
- i_{bus} – market interest rate [%],
- i_{infra} – market interest rate of infrastructure [%],

External costs:

- $EPoll_{cost\_er}$ – cost rate of pollutant emission per 1 vehicle-km [EUR/vkm],
- $Noise_{cost\_r}$ – cost rate of noise emission per 1 vehicle-km [EUR/vkm], about 50% of value for diesel bus
- $HPoll_{cost\_er}$ – cost rate of pollutant emission per 1 vkm (bus heating) [EUR/vkm],
- pl_r – residual value rate of the bus [-]

Financial variables

- AC_{bat2_self} $(t = Bat_{life})$ – acquisition costs of spare battery [EUR] after period t equal lifetime of the bus battery bat_life, ,
- $Bat_{unit_{Cost}}$ – cost of battery unit capacity [EUR/kWh],

- $BatD_i\ (t = Bat_{life})$ – costs of battery disposal for i-th bus[EUR] after period t equal lifetime of the bus battery bat_life,

BUS

- $AC_{bus\_nom_i}$ – nominal acquisition costs of bus [EUR],
- Bus_{self_i} – costs of bus acquisition (self-financing) [EUR],
- Bus_{sub_i} – subsidies for bus [EUR],
- Bat_{cap} – battery capacity [kWh],
- $Bat_{unit_{Cost}}$ – cost of battery unit capacity [EUR/kWh],
- Bus_{cost} – bus costs [EUR],
- $Capac_{cost}$ – costs for double-layer capacitors [EUR],

Leasing

- $Vbus\_init_i$ – value of the leased bus without initial fees,
- $Vbus\_pur_i$ – value of the leased bus purchase,
- $i_{bus_{leas}}$ – lease interest rate [-],

Bank credit

- $AC_{bus\_cred_i}$ – amount of credit for the bus purchase [EUR],
- s_{bus} – credit interest rate (bus) [-],

Bus fleet operation

- OC_{bus}– annual buses operating costs [EUR],
- OC_{bus} – annual operating costs of the bus fleet [EUR],
- OC_{ener} – annual energy costs [EUR],
- OC_{maint} – annual maintenance costs [EUR],
- OC_{insur} – annual insurance cost [EUR],
- OC_{ener_supp} – annual costs of daily energy supply [EUR],
- $\mathrm{OC}_{\mathrm{other}}$- other annual costs (for example vehicle tax) [EUR],
- $Ener_{supp\_cost\_r}$– energy supply cost rate [EUR/km],
- $Staff_{cost\_r}$– staff service cost rate [EUR/staff-service-hours],
- $Ener_{cost}$ – cost rate of energy [EUR/kW],
- Tax_{relief} – tax relief [EUR/kW],

INFRASTRUCTURE

- AC_{infra_self}- costs of infrastructure acquisition (self-financing) [EUR],
- $Infra_{sub}$ –subsidies for infrastructure [EUR],
- AC_{infra_nom} – infrastructure nominal acquisition costs [EUR]
- AC_{infra_dep} – acquisition costs of depot conductive plug-in charging [EUR]

- AC_{infra_swap} – acquisition costs of battery swapping-charging [EUR]
- AC_{infra_panto} – acquisition costs of pantograph charging [EUR]
- AC_{infra_stop} – acquisition costs of on bus-stop charging [EUR]
- AC_{infra_induct} – acquisition costs of in-motion inductive charging [EUR]

Leasing

- i_{infra_lease}– lease interest rate [-]
- V_{infra_init} – value of the leased infrastructure without initial fees,
- V_{infra_purch}– value of the leased infrastructure purchase,

Bank credit

- AC_{infra_cred} – acquisition costs of infrastructure with credit [EUR],
- s_{infra} –credit interest rate (infrastructure) [%]

Maintenance

- MC_{infra_dep} – annual maintenance costs of depot conductive plug-in charging [EUR],
- MC_{infra_swap} – annual maintenance costs of battery swapping-charging [EUR],
- MC_{infra_panto} – annual maintenance costs of pantograph charging [EUR],
- MC_{infra_stop} – annual maintenance costs of on bus-stop charging [EUR],
- MC_{infra_induct} – annual maintenance costs of in-motion inductive charging [EUR],
- MC_{other}- other annual costs (for example insurance, taxes) [EUR],

Operational variables

- Bus_{oper_ann} – annual transport work [vkm/year],
- $Bus_{oper\_ann\_h}$- annual transport work of bus fleet with oil heating [vkm/year],
- $Ener_{cons}$ – energy consumption [kWh/vkm],

Maintenance variables

- $Work_{staff\_service}$ – staff service hours [staff-service-hours/bus],

The TCO model’s calculation results in a report on the economic impact.

In general, the TCO consists of two models: static (S-TCO) and dynamic (D-TCO). The static TCO model involves one-time purchase of the necessary number of buses (without tranches) and construction and operation of the required infrastructure.

The developed dynamic TCO model, however, provides different ways of financing of the investment (own funds, leasing, subsidies, bank credits), as well as its implementation in parts over various periods of time. The variables are time-dependent and additional variants of the cost distribution into various stakeholders and beneficiaries are available.

This tool is considered in detail in the Deliverable 4.2 ‘Efficient Models’.

3.3 Tool "ECBus+" for energy consumption evaluation

The Tool "ECBus+" is designed to evaluate energy consumption (EnC) of vehicles and related tasks. EnC evaluation of the buses has very wide range of application, for example, as input in the above tools and independently in solving the problems depicted in Fig. 6.

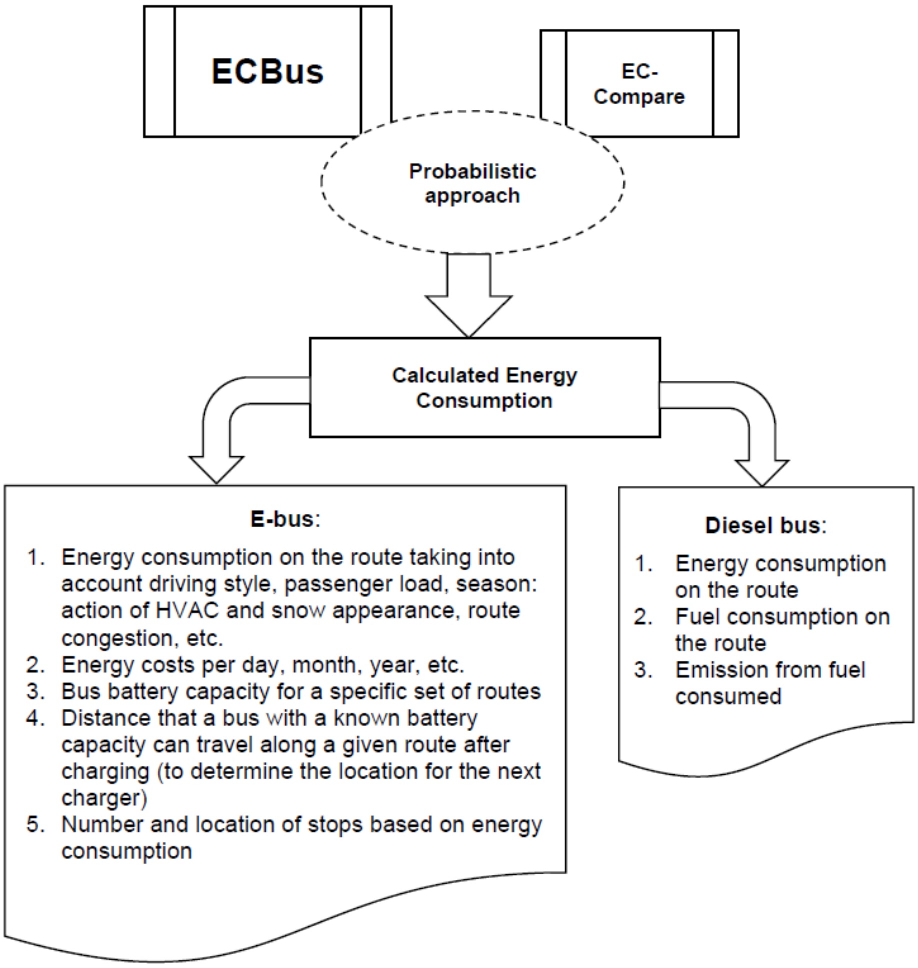


Figure 6 Tool ECBus+ and its application

The full tool "ECBus+" includes: (1) software ECBus, (2) procedure EC-compare and (3) probabilistic approach to choosing the calculated energy consumption value.

Information on procedure (2) and approach (3) is presented in the Deliverable 2.2 and (Algin, 2019). An input template for ECBus software was developed in Deliverable 2.3.

A detailed description of the ECBus software, including preliminary testing, is presented below.

3.4 Database on publications and patents

The database is the result of patent information research, which is going by JIME. It contains publications and patents on thematic of PLATON project. The database provides a basis for developing models, selecting a list of source data and their values so that the user can accept them by default in the absence of the necessary information.

The initial stage of creating the database was presented in the report on patent information research that was registered by National Intellectual Property Center of Belarus and also presented in the project cloud: https://next-cloud.ifak.eu/s/QfNqteN8XK8xGex?path=%2FProject%20work%2FJIME%2F!Patent-info%20research_PLATON! (see the Deliverable 3.1).

Addition 01 to database. Fig. 7 shows a fragment of an information file that includes publication data from the first database addition on the date 2019-11-01. Besides the information file (_InfLit_2019-11-01.pdf) full versions of publications are into the same folder (_Lit01). Fragment of this folder is depicted in Fig. 8.

Addition 01 for the database on publications as of 01/11/2019
Пополнение 01 базы данных по публикациям на дату 01.11.2019

Number	Title	Date of publication	Author(s)
001	ZeEUS eBus Report #2 An updated overview of electric buses in Europe	2018	ZeEUS
002	Technology assessment of an electric urban bus system for Berlin	2014	D. Göhlich, A. Kunith, T. Ly
003	Open Systems Dependability and DEOS: Concept, Retrospect and Prospects	2017	M. Tokoro
004	Battery Electric Buses Smart Deployment. Zero Emission Bus Conference	2016	J. Hanlin
005	Optimal Strategy of Efficiency Power Plant with Battery Electric Vehicle in Distribution Network	2017	T. Ma, S. Su, S. Li, W. Wang, T. Yang, M. Li; Y. Ota
…			
115	Conceptual design of urban e-bus systems with special focus on battery technology	2019	D. Göhlich, T-A.Fay
116	Charging Network Planning for Electric Bus Cities: A Case Study of Shenzhen, China	2019	Y. Lin, K. Zhang, Z.- J.M. Shen, L. Miao
117	What Hinders Adoption of the Electric Bus in Canadian Transit? Perspectives of Transit Providers	2017	M. Mohamed, M.Ferguson, P.Kanaroglou

Figure 7 Fragment of information file on publications

111(20191027) Vepsalainen(2018)Cost-Benefit Analysis...	27.10.2019 10:19	Adobe Acrob...	775 КБ
112(20191027) Lauth(2019)Simulation-based Planning ...	27.10.2019 10:28	Adobe Acrob...	2 770 КБ
113(20191027) Bertoli(2019)StorEn Technologies	29.10.2019 9:57	Adobe Acrob...	4 057 КБ
114(20191029) Velasco(2019)Studying pedestrians' cro...	29.10.2019 12:33	Adobe Acrob...	1 088 КБ
115(20191029) Göhlich(2019)Conceptual Design of Ur...	29.10.2019 15:46	Adobe Acrob...	743 КБ
116(20191030) Lin(2019)Charging Network Planning	30.10.2019 21:29	Adobe Acrob...	5 789 КБ
117(20191030) Mohamed(2017)What Hinders Adoption	30.10.2019 20:30	Adobe Acrob...	671 КБ

Figure 8 Show of folder with publications

Fig. 9 shows a fragment of an information file (_InfPat_2019-11-01.pdf), which includes patent data. Patent descriptions are located in the folder (_Pat01) along with the information file.

Addition 01 for the database on inventions as of 01/11/2019
(Дополнение 01 базы данных по изобретениям на дату 01.11.2019)

Number	Publication number	Title	Applicant (patent holder)
001	US9252417	Low-floor electric bus	PROTERRA INC
002	CN203486030	Pure electric articulated bus	BYD CO LTD
003	TWM452082	Electric bus	BYD CO LTD
004	RU000241869	Transport facility and method of its control	TOJOTA DZIDOSJa KABUSIKI KAJSJa
005	CN104044477	Motor vehicle with plug-in charging device	MAN TRUCK & BUS AG
006	EP2848448	Vehicle having an electric drive and a display device for indicating the operating condition of an energy store of the electric drive	MAN TRUCK & BUS AG
...			
124	RU2017105756	Vehicle charging station comprising an articulated arm	SIEMENS AG
125	WO2018183289	Tanks embodiment for a flow battery	A. Danzi; C. A. Brovero; G. Piraccini; M. Tappi
126	WO2018183301	An advanced electrolyte mixing method for all vanadium flow batteries	A. Danzi; C. A. Brovero; G. Piraccini; M. Tappi
127	WO2018183222	Multipoint electrolyte flow field embodiment for vanadium redox flow battery	A. Danzi; C. A. Brovero; G. Piraccini; M. Tappi
128	WO2018183269	Novel leaks containment embodiment for electrochemical stack	A. Danzi; C. A. Brovero; M. Tappi; G. Piraccini

Figure 9 Fragment of information file on patents

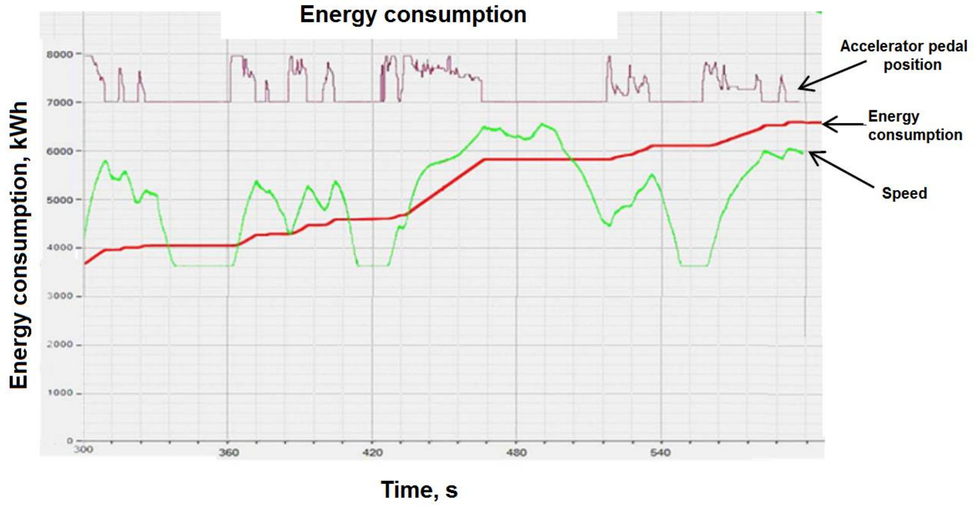
Full contains of the information files are given in Annex A.

Addition 01 to the database, which includes information files, as well as publications and patents, is presented in the PLATON project cloud: https://next-cloud.ifak.eu/s/QfNqteN8XK8xGex?path=%2FProject%20work%2FJIME%2F!Patent-info%20research_PLATON!_Add01(2019-11-01 .

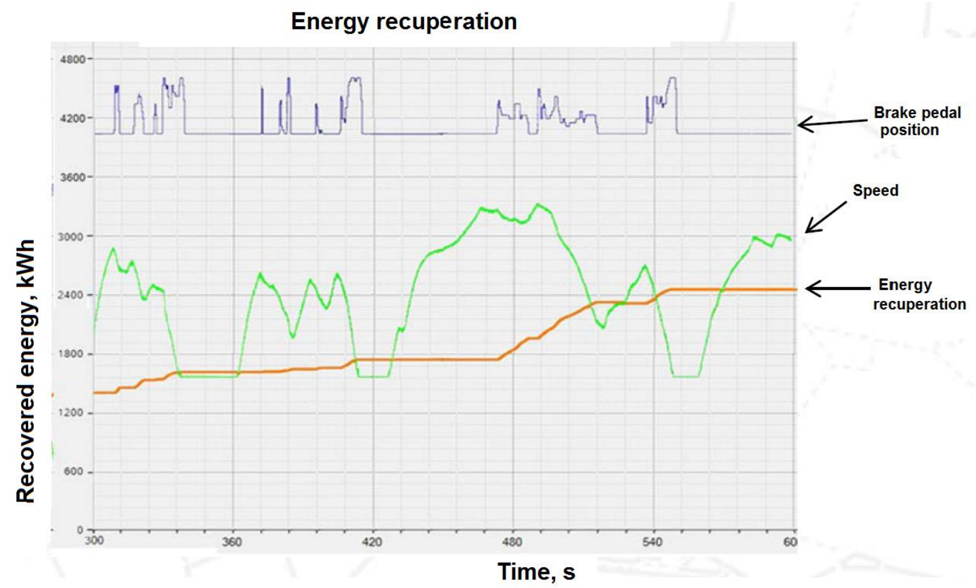
3.5 Results of experimental research and operation data

Experimental studies of electric buses were conducted jointly by Belkommunmash and JIME. The objective of experimental research was to determine energy consumption depending on driving styles, passenger load, traffic interferences and their relationships with energy consumption. Also, data on the energy consumption of electric buses in ordinary operation (Belkommunmash) were presented and their analysis have been performed. The effect of the seasonal factor (ambient temperature) was shown.

Typical records of processes are depicted in Fig. 10.



a



b

Figure10 Typical control, speed and energetic processes: a=energy consumption, b=energy recuperation

More detail description of results is presented in the Delivery 3.1.

These results created the prerequisites for a new approach to calculating energy consumption in real conditions, taking into account the driving style and road obstacles, which is implemented in the ECBus software (see below).

3.6 Tools for local problems

An example of a tool to solve a local problem, designated as OptSched, is to determine a balanced (with respect to the passenger transfer demand) *route timetable* such that the same average traffic interval of all public vehicles of the same route is maintained and departures of public vehicles of the same passenger capacity assigned to the same route are distributed as smoothly as possible over departures of all public vehicles in the decisive time period. Results on the problem OptSched are described in Section 4 of Deliverable 4.3.

The another local tool is DepOpt, which models the case of slow-charging batteries of e-buses that charge at the same depot to be equipped with the charging stations of the same type. The decision is to determine the maximal electric power supplied to the depot, the type and the number of identical slow-charging stations in the depot and types of the batteries for e-buses such that the e-buses can feasibly serve a given set of routes. The objective is to minimize the per day total cost of the required energy and equipment. This tool is described in Section 3 of Deliverable 4.3.

4 Energy assessment is one of the key elements in the tool system for the transition process, which leads to an electric bus fleet

In PLATON project the comprehensive and flexible tool ECBus for assessing energy consumption is developed. The main features of the tool are as follows.

The full ECBus tool includes: *software ECBus*, *procedure EC-compare* that is comparative method for evaluating energy consumption for an electric buses based on data for diesel buses and *probabilistic approach* to choosing the calculated energy consumption value.

The user can estimate the bus power consumption using ECBus software and / or the EC-compare procedure for local cases, and then select the calculated value by using the probabilistic representation of the total space for power consumption values for the bus and route (route cycle) being considered.

The probabilistic approach places the responsibility on the user for deciding that with the probability chosen by him, the real value of energy consumption will be less than the value accepted for the calculated one. This feature is especially important for electric buses, and usually when solving problems, a restriction is set on the permissible degree of battery discharge. In real practice, this hard restriction can sometimes be violated.

As it be mentioned, the developed probabilistic approach and EC-compare method gave been presented in the Deliverable 3.1 and publication (Algin, 2019). The features of ECBus software are considered below.

4.1 Development of methodology for energy consumption evaluation

Speed profile. Speed profile under energy consumption calculation can be specified or generated (synthesized).

The first approach is the calculation when a **bus speed profile is specified**. The speed profile can be obtained from data of the bus operation on a real route. A limitation of this approach is that it refers to one local case and can be a source of errors in estimating energy consumption and other properties of vehicles.

The second approach involves the **generation of a speed profile.** Of the well-known approaches, the most rational is the approach that takes into account the features of the route under consideration (Gallet et al., 2018). This approach has been reviewed above. However, this one also has disadvantages and may be improved.

An analysis of PLATON project experiments and (Gallet et al., 2018) leads to the following conclusion. Entering intermediate stops to obtain a measured average speed, like method of (Gallet et al., 2018), is too artificial way. Thus, intermediate stops and delays should be carried out during modelling in accordance with *real route obstacles and interference* on the considering segment of the route.

The creation of synthetic speed profiles depicting the longitudinal movement buses has some relating with the work that was conducted within the Ph.D. thesis (Cebrat, 2014). In mentioned work namely the distance to the assumed “obstacles” was used for tactical control of the serial hybrid propulsion system. This was consisting of electric double-layer capacitor, power generator and electric propulsion machine.

An algorithm was developed using distances to:

1. Bus Stops
2. Stops for two buses
3. Traffic lights
4. Traffic lights having bus priority
5. Pedestrian crossings with traffic light
6. Pedestrian crossings without traffic light
7. End of the congestion zone in front of traffic lights
8. 90° Turns without intersection or traffic light

Development of method of a speed profile generation. The second approach that involves the generation of a speed profile is under development. This one uses a description of operating conditions including the traffic obstacles. In this case, obstacles (interferences) to movement are “placed” in each segment, i.e. speed profiles for passage of the obstacles are described. Then, the speed profiles on the free sections of the segment are designed and “docked” to the obstacle profiles. For the obtained speed profile of the *i*-th segment, time $t_x(i)$ between arrivals at the *i*-th and (*i*+1)-th stops is calculated. The time $t_x(i)$ includes the time of passengers boarding/alighting $t_s(i)$ (see Fig. 11). After that, the movement speeds on free sections of the segment are adjusted based on the criterion $t_x(i) \approx t(i)$, where $t(i)$ is a time according bus schedule.

Driving style. Driving style is taken into account. When designing speed profiles for obstacles and free sections of a segment, information on accelerations is needed. Acceleration values are set in accordance with the accepted driving style. Calculations are carried out for two driving styles: calm (L) and accelerated (A1). The calculation results are used to justify the calculated value of energy consumption in accordance with the probabilistic approach discussed earlier.

Stopping time: relationship between stopping time and bus passenger loading. Stopping time t_s(i) is also necessary for the calculation. It can be set or adopted based on the experience of operating a bus-analog. In addition, another approach is proposed. It is assumed that there is a relationship between the stopping time $t_s(i)$ and the degree of passengers loading of the bus *Pas*(*i*) in the segment under consideration.

This relationship can be described using the four passenger loading ranges as follows (figures are given as real cases): 1) Pas(i)≤25%, $t_s(i)$=13 sec; 2) 25<Pas(i)≤50%, $t_s(i)$ =18 sec; 3) 50<Pas(i)≤75%, $t_s(i)$=23 sec; 4) 75<Pas(i)≤100%, $t_s(i)$=28 sec (also see the Deliverables 3.2).

4.2 Real-world conditions: route obstacles and interferences schematization

A trip of an electric bus on the route consist of movement within segments. Each segment includes a passenger boarding and/or alighting phases and a traffic phase that can be interrupted by intersegmental stops (Fig. 11).

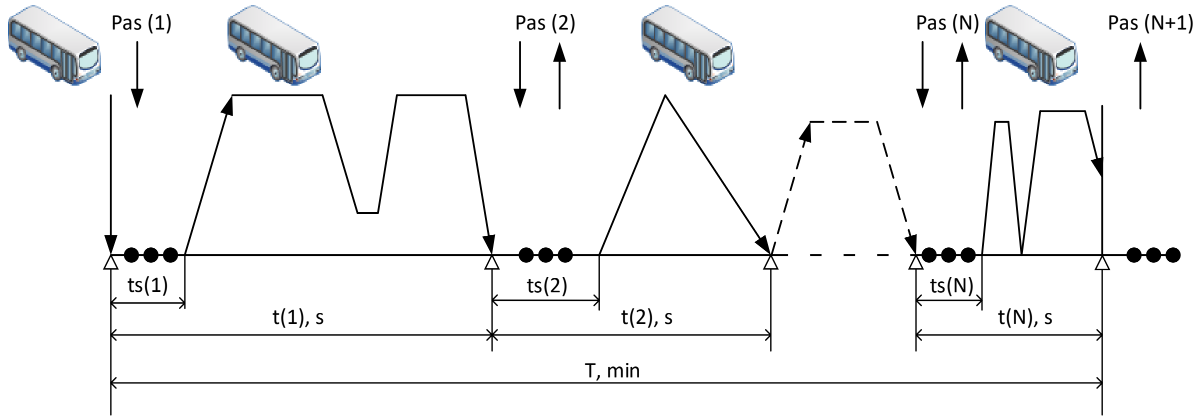


Figure 11 Basic stages in movement of an electric bus on the route

Basic traffic obstacles and interference determining a speed mode (and speed profile) en route are the following: 1) Turns (factor of constant action), 2) Intersection (factor of constant action), 3) Artificial irregularity (factor of constant action), 4) Pedestrian crossings without traffic lights (factor of variable action: it may be without pedestrians), 5) Traffic lights or traffic lights with pedestrian crossings (factor of variable action, 6) Traffic speed, including traffic jams. These number (1…6) are used as identifiers of mentioned factors types.

The location of the factors 1...6 within the segment is determined by the distances relative to the left initial points of the corresponding segment "from-stop-to-stop".

For the sixth factor, the speed limit and the end point of the speed limit are indicated additionally.

Characteristics of factors 1 ... 5 are given in Table 1, where Δs_0 = "length" (zone of action) of the obstacle, Δt_0 = time, v_0 = speed to overcome the obstacle, L_A = bus length. Fig. 12 shows inverted trapezoids related to typical traffic obstructions. As an example current electric bus speed v_D is 40 km/h.

Table 1. Parameters for typical traffic obstacles and interference

Parameter	Artificial irregu-larity	Pedestrian crossing	Right turn	Traffic light, Left turn, Intersection
$\Delta s_0 = k_{ob} L_A$, m	$0.9L_A$	$2L_A$	$3L_A$	0
$\Delta t_0 = \Delta s_0 / v_0$, s	3.89	8.64	13.0	40.0

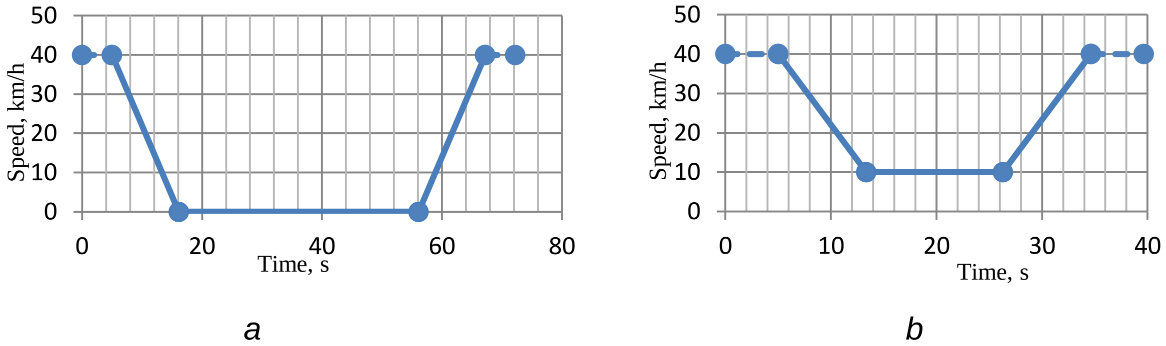
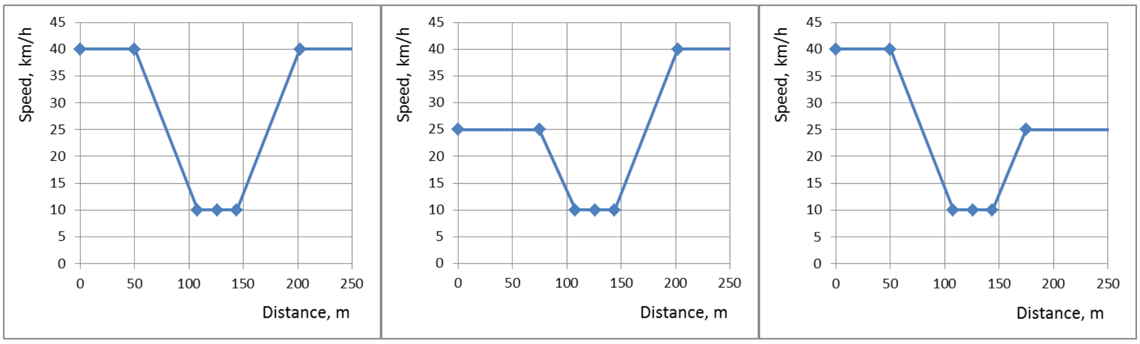


Figure 12 Speed profiles with typical traffic obstacles/interferences: a= Traffic light (red), Left Turn, Intersection; b = Artificial irregularity, Pedestrian crossing, Right turn

An obstacle can travel by three different scenarios (Fig. 13), which differ in vehicle speed before and after the obstacle.



a *b* *c*

Figure 13 Options for driving obstacles

Option "*a*" describes the case when the electric bus moves before and after overcoming an obstacle at the same speed (no interferences "before" and "after"). Option "*b*" corresponds to overcoming two closely spaced obstacles, if they are followed by a free path. Option "c" takes place if, after passing the obstacle, the next obstacle or other interference to the movement are close enough.

In all examples below the following parameters are used: the deceleration $j_1 = -1.0$ m/s^2, acceleration $j_2=1.0$ m/s^2, L_A = 12 m, bus calculated weight m_A=15000 kg.

To select model "*a*" for passing an obstacle, it is necessary to estimate the minimum distance between obstacles at which the electric bus can accelerate from the speed of overcoming the obstacle to the maximum speed, followed by decelerating again to the speed of overcoming the next obstacle (Fig. 14).

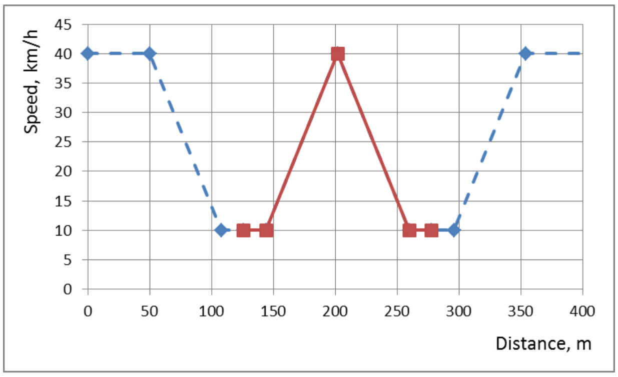


Figure 14 Assessment of the minimum distance between obstacles at which acceleration to maximum speed is possible

The calculation for option "*a*" is carried out by the formula

$$S_{\min} = \frac{(k_{ob1} + k_{ob2})L_a}{2} + \frac{v_D^2 - v_0^2}{j} \qquad (2)$$

where k_{ob} = coefficient taking into account the location of the vehicle relative to the obstacle during its passage (see Table 9).

For v_D = 40 km/h = 11.11 m/s, v_0=10 km/h = 2.78 m/s and $k_{ob1} = k_{ob2}$= 0.9 (overcoming artificial irregularity), the result is as follows

$$S_{\min} = \frac{(0.9+0.9)12}{2} + \frac{11.11^2 - 2.78^2}{1} = 126.5\, m \qquad (3)$$

So, for the implementation of scenario “*a*” in the presence of two artificial irregularities it should be at least 125 meters between them. If this distance is shorter, scenario “*b*” for the first obstacle and “*c*” for the second will be implemented. A similar situation is possible when entering a dense traffic stream. The obstacle here is speed limitation. An example of an experimental electric bus passage of such a part of route is shown in Fig. 15.

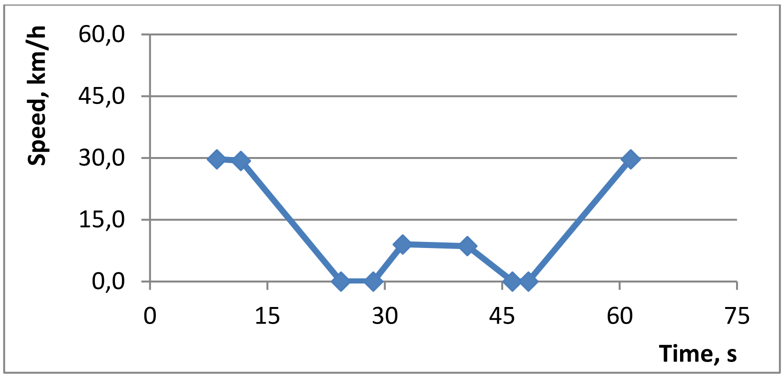
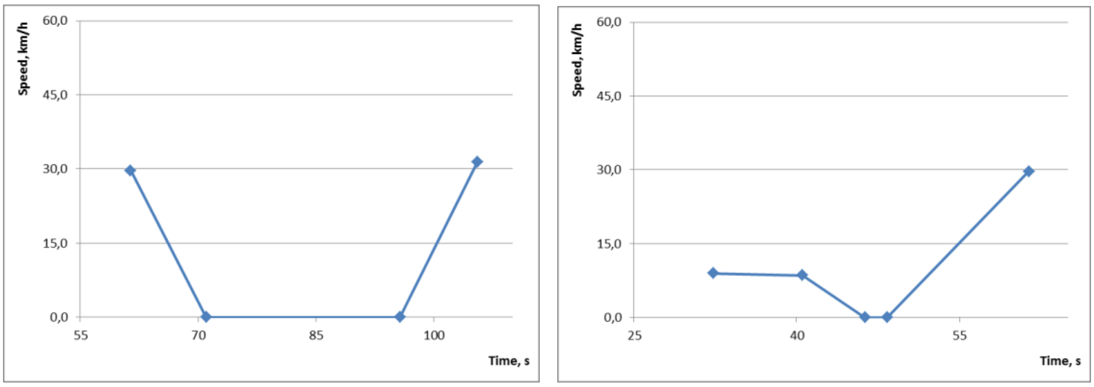


Figure 15 Bus movement through traffic light in a dense traffic stream

To test the developed approach to schematizations of typical obstacles, experimental studies were carried out with an electric bus E-420 manufactured by Belkommunmash during its passage through typical obstacles on a real route.

Examples of the implementation of **options “*a*” and “*b*”** are shown in Figures 16*a* and 16*b*. The experimental data on energy consumption for these examples are depicted in Table 10.



a *b*

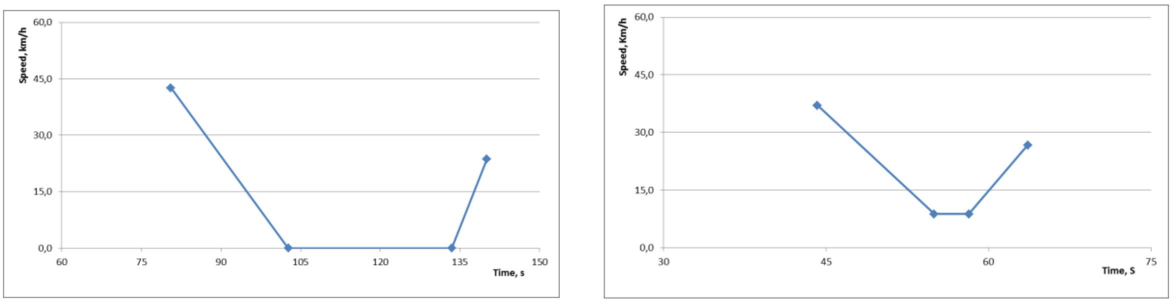
Figure 16 Speed profiles with real traffic obstacles: a = Pedestrian crossing; b = Traffic light (red)

Table 2 —Experimental data on energy consumption for cases presented in Fig. 16

Parameter	Traffic obstacles/interferences			
	Pedestrian crossings		Traffic light	
	deceleration phase	acceleration phase	deceleration phase	acceleration phase
Speed variation v_1– v_2, km/h	29.7 – 0	0 – 31.4	8.6 – 0	0 – 29.7

Acceleration j, m/s^2	–0,86	0,89	–0.41	0.63
Distance S, m	41.1	47.7	6	60
Time t, s	9.59	9.84	5.77	13.07
Energy consumed E_c, Wh	0	238.51	0	188.41
Energy recuperated E_r, Wh	127.14	0	5.74	0.00
Energy consumption total, Wh	238.51–127.14=111.37		188.41–5.74=182.67	

Examples of the implementation of **option "c"** when passing a real route are shown in Fig. 17: traffic light (Fig. 18 *a*) and artificial irregularity before the pedestrian crossing (Fig. 18 *b*). Results of experiments and calculations are in Table 3. Bus data for calculation are given above as default (besides rolling resistance coefficient f=0.012 and regeneration factor r_{reg}=0.075).



a *b*

Figure 17 Speed profiles for bus movement through real obstacles: a = Traffic light (red); b = Artificial irregularity + Pedestrian crossing

Table 3 Comparison of experimental and calculated energy consumption

Part	Parameter	Traffic obstacles			
		Traffic light		Artificial irregularity	
		Experiment	Calculation	Experiment	Calculation
1	Time t, s	22.16		10.78	
	Speed variation v_1– v_2, km/h	42.6 – 0		37.0 – 8.6	37.0 – 8.8
	Speed variation v_1– v_2, m/s	11.83 – 0		10.28 – 2.39	10.28 – 2.44
	Acceleration j, m/s^2	–0.534		–0.732	–0.727
	Distance S, m	156.4	131.1	76.5	68.6
	Energy consumed E_c, Wh	7.82	0	2.79	0
	Energy recuperated E_r, Wh	160.17	156.07	147.87	120.44
2	Time t, s	30.79		3.2	
	Speed V, km/h	0		8.6 – 9.0	8.8

	Speed V, m/s	0		2.39 – 2.50	2.44
	Acceleration j, m/s^2	0		0.035	0
	Distance S, m	0	0	7.3	7.8
	Energy consumed E_c, Wh	1.07	0	0.77	4.38
	Energy recuperated E_r, Wh	0	0	0	0
3	Time t, s	6.61		5.43	
	Speed variation v_1– v_2, km/h	0 – 23.7		9.0 – 26.7	8.8 – 26.7
	Speed variation v_1– v_2, m/s	0 – 6.58		2.50 – 7.42	2.44 – 7.42
	Acceleration j, m/s^2	0.996		0.905	0.916
	Distance S, m	22.8	21.8	26.8	26.8
	Energy consumed E_c, Wh	136.48	119.65	136.39	136.79
	Energy recuperated E_r, Wh	0	0	0	0
Summarizing values	Distance S, m	179.2	152.9	110.6	103.2
	Energy consumed E_c, Wh	145.37	119.65	139.95	141.17
	Energy recuperated E_r, Wh	160.17	156.07	147.87	120.44
	Energy consumption total, Wh	–14.8	–36.42	–7.92	20.73

4.3 Calculation of bus energy consumption on the route

When studying the movement of an electric vehicle and evaluating its energy consumption, the following parameters are used:

t – driving time, s;

v – vehicle speed, m/s;

j – vehicle acceleration/deceleration, m/s^2;

S – distance, m;

m_A – vehicle weight, kg (default is 15000 kg);

g = 9.81 m/s^2 (acceleration of gravity);

f – rolling resistance coefficient for planned types of tires and road surfaces (default is 0.008);

α – inclination angle of the road (default is 0);

δ – rotational inertia coefficient (default is 1.05);

k_W – coefficient of air resistance, N·s^2/m^4 (default is 0.4 N·s^2/m^4);

A_W – frontal area of the vehicle, m^2 (default is 6.6 m^2);

TtW (Tank-to-Wheel) – Efficiency including η_{PE}, η_m, η_t;

η_{PE} – average efficiency of the invertor (default is 0.98);

η_m – average efficiency of the motor (default is 0.95);

η_t – average efficiency of the transmission (default is 0.95);

r_{reg} – regeneration (recuperation) factor (default is 0.6).

The slope angle of the road is determined for each segment between two adjacent stops from the ratio

$$\sin\alpha = \Delta h / S_k \tag{4}$$

where Δh is the difference in altitude of stops above sea level; S_k is the distance between stops (length of the k-th segment),

Accelerations and paths (distances). The mode of movement of the electric bus is set in the form of a speed profile, that is a sequence of horizontal and inclined lines corresponding to movement at a constant speed or acceleration. At each segment between stops, time intervals are set [t_i; t_{i+1}], where the movement occurs with the speed v_i = cost or with acceleration $j_i \neq 0$ and the changed value of the speed from $v_i = v(t_i)$ to $v_{i+1} = v(t_{i+1})$. The path covered by time (t_{i+1}–t_i) is $S_{i,i+1}$. Accelerations and paths are calculated by formulas

$$j_i = \frac{v_{i+1} - v_i}{t_{i+1} - t_i} \tag{5}$$

$$S_{i,i+1} = \frac{(v_{i+1} + v_i)(t_{i+1} - t_i)}{2} \tag{6}$$

Acting forces. Force and energy flows of the electric bus ae presented in Fig. 18. The signs "+" and "−" mark the area of possible values of forces.

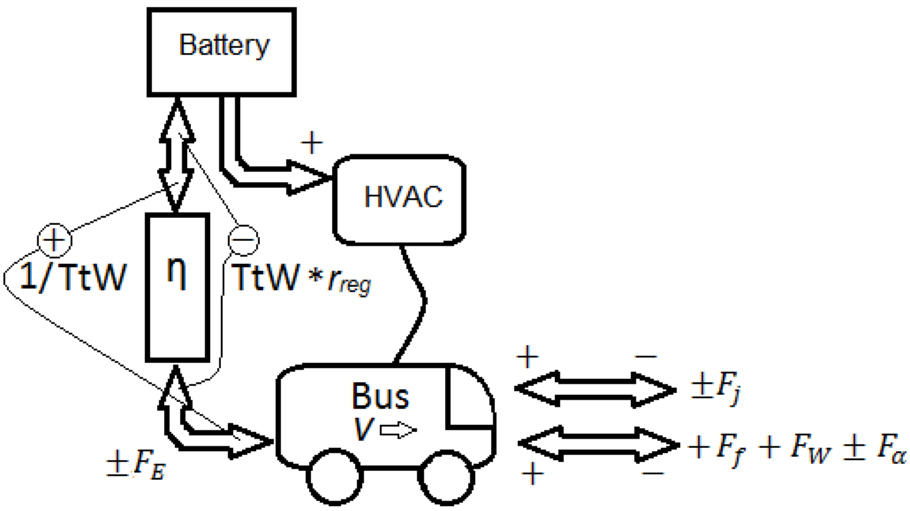


Figure 18 Force and energy flows of the electric bus

When the electric bus moves, the following forces act on it:

- rolling resistance force

$$F_f = f m_A g \cos\alpha \tag{7}$$

- climbing resistance force (skating force /roll down force at α <0)

$$F_\alpha = m_A g \sin\alpha \tag{8}$$

- acceleration resistance force

$$F_j = \delta m_A j \tag{9}$$

- air resistance force

$$F_W = k_W A_W v^2 \tag{10}$$

At a constant speed $v = v_c$= const

$$F_W = F_{Wc} = k_W A_W v_c^2 \tag{11}$$

With constant acceleration j = const, instead of F_W, F_{Wekv} is used. This is the equivalent air resistance force acting during the path S.

Introduction of a such constant force is one of features for developed method. This equivalent force is introduced so that the work of the variable force FW, can be represented as a product of some constant force on the corresponding path. Introduction a such constant force is one of features for developed method.

With constant acceleration/deceleration j, when the speed changes from 0 to V_d (or from V_d to 0), F_{Wekv} can be calculated using one of the following formulas:

$$F_{Wekv} = k_W A_W jS \tag{12}$$

$$F_{Wekv} = 0.5 k_W A_W V_d^{\,2} = k_W A_W (\sqrt{0.5} V_d)^2 \approx k_W A_W (0.707 V_d)^2 \tag{13}$$

In general case, when the speed changes from V_1 to V_2 ($V_1 < V_2$ for acceleration, $V_1 > V_2$ for deceleration), the formula is used

$$F_{Wekv} = 0.5(k_W A_W V_1^2 + k_W A_W V_2^2) = k_W A_W (\sqrt{0.5(V_1^2 + V_2^2)})^2 \tag{14}$$

When driving with constant acceleration / deceleration, the work of the air resistance force can be determined using the equivalent resistance force F_{Wekv} and the path S according to the formula

$$A_{FW} = F_{Wekv} S \tag{15}$$

This is the main purpose of the introduced equivalent force.

Traction force on driving wheels

$$F_E = F_f + F_\alpha + F_j + F_W \tag{16}$$

Note. Formulas above are most suitable for calculation energy consumption when speed profile contain line horizontal and incline elements (movement as set of elementary modes with constant speed or acceleration). In this case energy is calculated as

Work=Force • Distance

In addition, a simple calculation of traction force and the determination of its sign allows to set the type of mode: traction or recuperative. This is important for properly accounting for the energy recovered.

Modes of movement of the electric bus. In the general case, two modes of movement for the electric bus are possible: 1) traction, in which the energy of the energy storage is consumed, and 2) braking, in which the recuperation of mechanical energy into the electrical energy of the storage can occur. The mode is determined by the ratio of forces acting on the car.

The traction mode occurs when the traction force FE> 0. At the same time, the traction power applied to overcome the resistance to movement is supplied to the driving wheels. The energy consumed by the drive in the traction mode of the electric bus is calculated by the formula

$$E_{ECcons,i} = \frac{A_i}{\mathrm{TtW}},\ \mathrm{J} \quad \text{or} \quad E_{ECcons,i} = \frac{A_i}{\mathrm{TtW} \cdot 3.6 \cdot 10^6},\ \mathrm{kWh} \tag{17}$$

where TtW (Tank-to-Wheel) is the efficiency of the electromechanical power unit, equal to the product of the efficiency factors of the components:

$$\mathrm{TtW} = \eta_{\mathrm{PE}} \eta_m \eta_t \tag{18}$$

where η_{PE} is the efficiency of the inverter; η_m is the efficiency of the traction motor; η_t is the transmission efficiency.

The braking mode takes place when the traction force FE <0. At the same time, the power is not supplied to the drive wheels, and part of the kinetic energy can be recovered into the electrical energy of the storage. It is assumed that the recovery energy enters the storage is equal

$$E_{ECreg,i} = r_{reg} \mathrm{TtW} \left| A_i \right|,\ \mathrm{J} \quad \text{or} \quad E_{ECreg,i} = \frac{r_{reg} \mathrm{TtW} \left| A_i \right|}{3.6 \cdot 10^6},\ \mathrm{kWh} \tag{19}$$

where r_{reg} is the regeneration (recuperation) factor.

Change in traction force sign. When using any numerical methods, the calculation is reduced to the consideration of time periods for which it is assumed that the acceleration on them is constant. In this case, a situation may arise when at the ends of the time interval t_i and t_{i+1} the values of the traction force F_E have different signs. This situation is especially relevant when the speed profile is schematized by sufficiently long sections of traffic with constant acceleration.

It should be keep in mind that with a schematized representation of the velocity profile by a plurality of linear sections corresponding to motion with a constant speed or acceleration, in the points common to two adjacent sections, the traction force will change abruptly. This is due to an instantaneous change in the acceleration / deceleration value j and, accordingly, the acceleration resistance F_j. Therefore, it is necessary at each internal point of the velocity profile adjacent to its neighboring sections (where the driving mode changes) to calculate two values of the traction force corresponding to the sections located to the left and to the right of this point. So, for time t_i and velocity v_i, the values $F_{ELeft,i}$ и $F_{ERight,i}$ should be determined.

Comparison of the traction force signs should be performed within the same section of the speed profile, where the value F_E change continuously, i.e. $F_{ERight,i}$ and $F_{ELeft,i+1}$ are considered for a given i. If the signs of these values are different, then exists a point at which $F_E = 0$.

Then, the velocity v_x is determined at which $F_E = 0$:

$$v_x = \sqrt{-(m_A g(f \cos\alpha + \sin\alpha) + \delta m_A j_i) / k_W A_W} \tag{20}$$

After that the corresponding time tx is found (see Fig. 19)

$$t_x = t_i + (t_{i+1} - t_i)(v_x - v_i) / (v_{i+1} - v_i) \tag{21}$$

The consumed or recovered energy is calculated separately for the plots [t_i; t_x] and [t_x; t_{i+1}] depending on the sign of the traction force in these areas.

Fig. 20 schematically shows situations when on the interval [t_i; t_i + 1] the sign of FE changes.

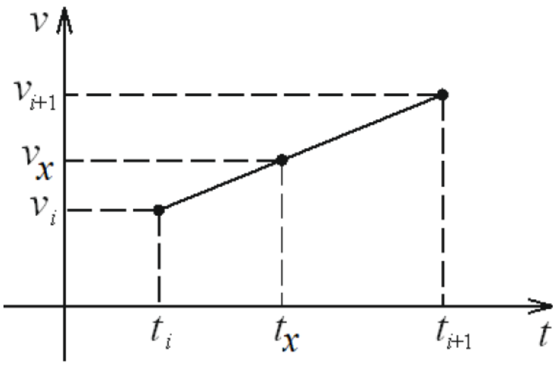
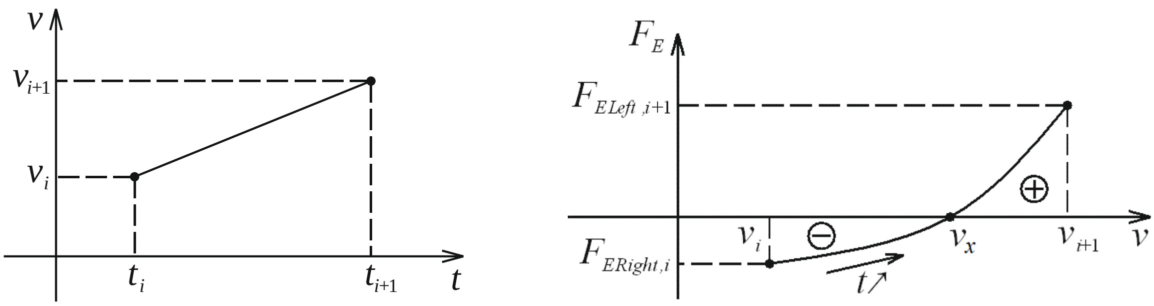
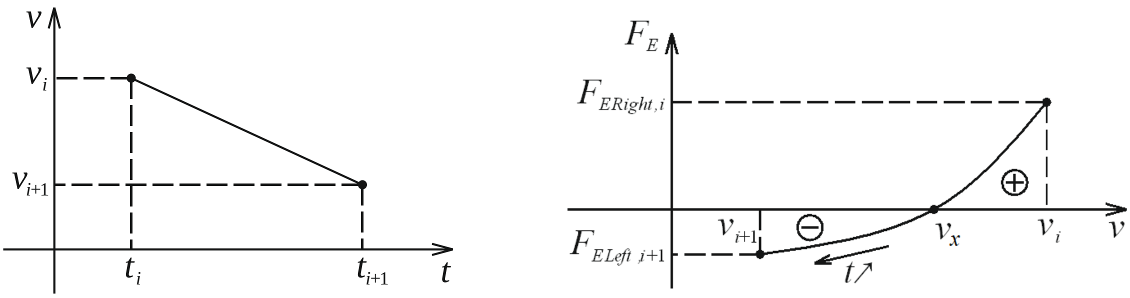


Figure 19 Determination of time point t_x



a

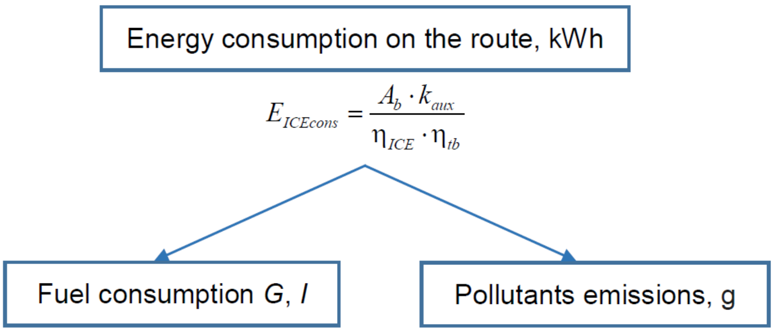


b

Figure 20 Traction force versus speed: *a*) for v_i+1 > v_i and *b*) v_i +1 < v_i

4.4 Ecological calculations

The environmental assessment scheme is shown in Fig. 21 for a diesel bus.



$$G = \frac{E_{ICEcons}}{Q}$$

Q = Specific heat of combustion of fuel, J/l

Emission standards for diesel buses, g/kWh

Standard	CO	CH	NO_x	PM
Euro I	4.5	1.1	8.0	0.36
Euro II	4.0	1.1	7.0	0.15
Euro III	2.1	0.66	5.0	0.1
Euro IV	1.5	0.46	3.5	0.02
Euro V	1.5	0.46	2.0	0.02
Euro VI	1.5	0.13	0.4	0.01

https://en.wikipedia.org/wiki/European_emission_standards

Figure 21 Ecological evaluations

The starting point is the bus energy consumed on the route

$$E_{ICEcons} = \frac{A_b \cdot k_{aux}}{\mathrm{TtW}_b} \tag{22}$$

where

A_b – the work performed by the bus to overcome the forces of resistance to movement, kWh

k_{aux} – coefficient of energy consumption for auxiliary drives

$\mathrm{TtW}_b = \eta_{ICE} \cdot \eta_{tb}$ – the efficiency of the bus power unit

η_{ICE} – effective efficiency of the internal combustion engine

η_{tb} – the efficiency of the bus transmission.

The environmental consequences of the operation of a diesel bus on the route are evaluated according to the following two criteria: 1) the amount of fuel used, and 2) the mass of emissions of pollutants into the air (see Fig. 21).

4.5 An algorithm for calculating energy consumption

An algorithm is based on the use of the developed force method and it includes the following steps:

1) Data on the electric bus is set, speed and road profiles are formed for each segment of the route

2) The accelerations j_i are determined

3) Paths $S_{i,i+1}$, and total path S are calculated

4) Road slopes for segments are calculated

5) The values of the forces acting on the vehicle are determined: $F_{f,i}$, $F_{\alpha,i}$, $F_{j,i}$, $F_{W,i}$; equivalent air resistance forces $F_{Wekv,i}$ are calculated

6) Traction forces $F_{ERight,i}$ and $F_{ELeft,i+1}$are calculated for each point of the speed profile at which the acceleration changes; the signs of traction forces are compared

7) In sub-segments where the traction force retains its sign, the work of forces $A_{Ff,i}$, $A_{F\alpha,i}$, $A_{Fj,i}$, $A_{FW,i}$ and the total work A_i are calculated

8) For sub-segments [t_i; t_{i+1}] with a varying sign of traction force, the values of speed v_x and time t_x are determined at which $F_E = 0$; for sections [t_i; t_x] and [t_x; t_{i+1}] calculations are carried out according to items 2), 3), 5), 7)

9) For each section, consumed $E_{ECcons,i}$ and recuperated $E_{ECreg,i}$ energies are calculated depending on the driving mode (traction or braking), as well as for the entire path S the following values are determined: E_{ECcons} , E_{ECreg}, the total energy consumption $E_{ECtotal} = E_{ECcons} - E_{ECreg}$, and the specific energy consumption E_{ECspec}.= $E_{ECtotal}/S$.

An example of the application of the method and software is placed in the Annex.

4.6 Speed profile generation based on GTFS data

For the task of energy consumption forecast by using the software ECBus+ and similar microscopic simulation approaches that are based on bus vehicle models the generation of realistic speed profiles is necessary. The speed profile is more realistic if actual geometric conditions of the route and road network properties are taken into account.

Geometric route conditions are an integral part of the GTFS data feed that is provided either by the public transport agency or may be downloaded from transit associations. The data feed contains among other data information on route shapes, stop locations, trips, and stop times. Based on these basic data, and in consideration of the road network from open sources such as OpenStreetMap, the speed profile data for a given bus route can be generated without having collected real time data of longitudinal acceleration movements in advance.

The software denoted as PREPARE was developed to solve this task as an integral part of the Platon Toolkit to complement the created existing toolkit components and to connect to these by the defined data/file interface. The software is currently implemented in Matlab/Octave. In the further course of the project it will be implemented as a stand-alone software such as the existing tool component ECBus+.

Input data for the PREPARE software are the shapes of a given bus route including bus stops that are enriched with elevation information for the shape points. The shapes of the bus route follow the road network layout and therefore include intersections and turns. The input files are formatted as simple comma separated text files. The list of stops is ordered by the sequence of visiting by bus vehicles of the route. For each of the segments between the given stops, the shape points of the entire route are allocated and mapped. The given shape points may not be equidistant to each other since the method of their collection by GPS receivers is usually neither time-equidistant nor space-equidistant. Primarily, the receivers are set to record a point related to a threshold of deviations from a propagated path of the recorded track. The following step is to generate the second by second velocity plan as the needed speed profile for the bus vehicle. In this step are used maximum acceleration, deceleration, and velocity limits in accordance with definitions of SORT for easy or heave urban cycles.

The generation of speed profile data is achieved with numerical integration to obtain vehicle speeds and travelled distances. Special cases of close distances between stops exist and lead to speed profile fragments in which the maximum speed is not reached. For example, if the distance between stops is lower than the distance travelled during acceleration to maximum speed and the distance travelled during deceleration to zero velocity, the resulting speed profile is abridged accordingly.

Currently a parameterizable random dwell time with a uniform distribution from 10 to 20 seconds during a stop is inserted into the speed profile. Furtherly speed reductions at intersections and turns are taken into account. This is realized by observing the distance between shape points and deriving the desired speed between those. If shape points are closer than an adjustable threshold the desired speed is reduced according to the following equation,

$$v_{desired} = v_{max} \cdot \frac{distance}{d_{\ threshold}} \tag{23}$$

applied if $distance < 40\ m$ with experimentally chosen values of $v_{max} = 13.8\ m/s$ and $d_{\ threshold} = 40\ m$ and the calculated geometric distance between shape points. Desired velocity may not exceed maximum velocity. This linear approach is justified by comparison with velocities observed in real-time collected speed profiles. The output files of the software PREPARE include the generated speed profile that are compatible for input to ECBus+ for further processing and energy consumption forecast.

5 Software ECBus

5.1 General data

The program is developed in the integrated environment of Microsoft Visual Studio 2012 based on NET.Framework 4.5, the application type is Windows Application, the programming language is C #.

Input files downloaded to the program must be created in Microsoft Excel, and have the extension “*.xls”.

The program is designed to calculate the energy consumption of vehicles on the route.

Input includes data on vehicle, road and operating conditions. With regard to electric buses, most of the initial data may not be specified. They are accepted in the program by default.

The template for the input data is described in detail in the Deliverable 3.2.

Options of input data forming that refer to speed and road profile are depicted in Fig. 22.

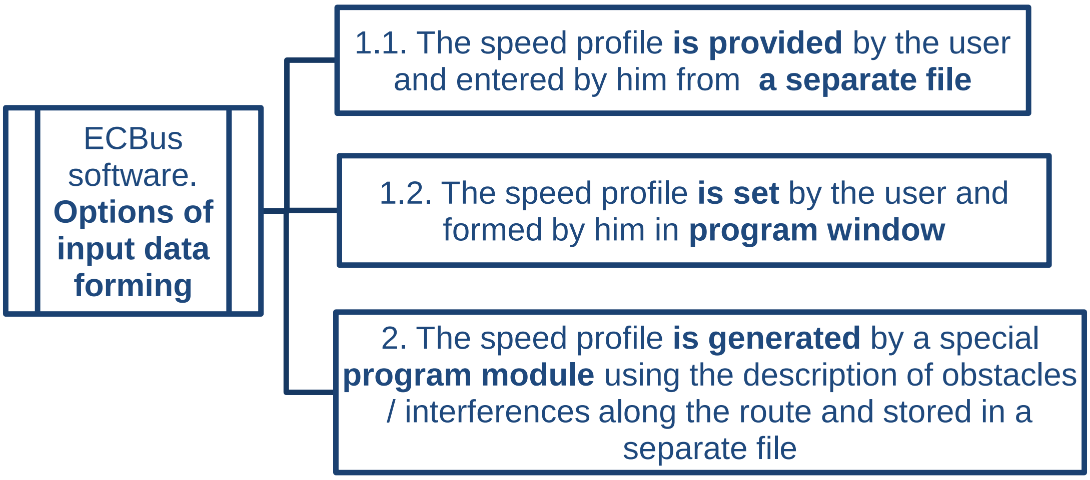


Figure 22 ECBus software. Options of input data forming (speed and road data)

User's manual for program version 01 are in Annex B.

5.2 Testing the ECBus methodology and program by comparing calculations and experiment

1. Data on the electric bus

The data on the electric bus located in the “Bus Data” tab in the ECBus program window is shown in Fig. 23.

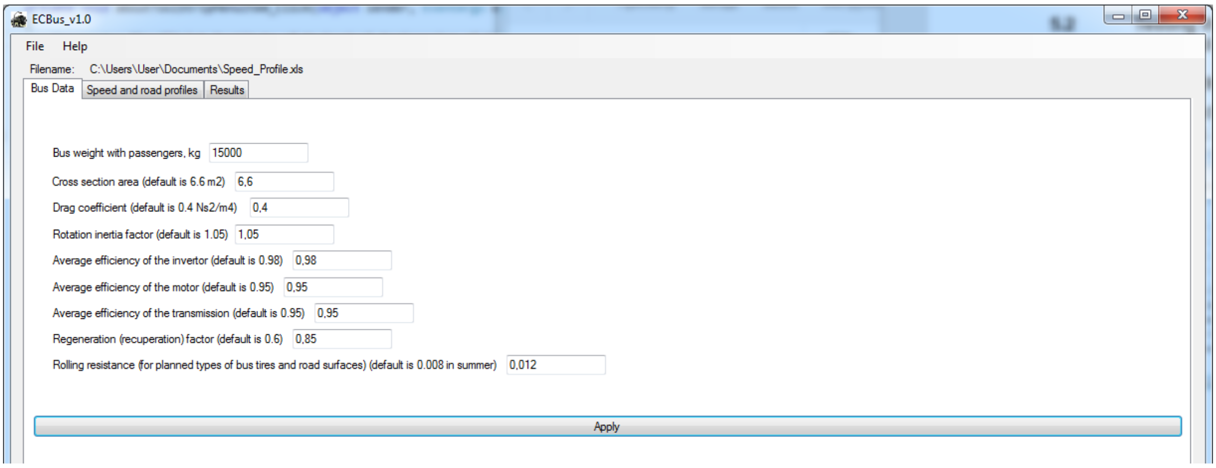


Figure 23 Data on the bus

When forming the initial data, the ECBus program data, taken by default, were mainly used. Two parameters were adjusted: corrected rolling resistance coefficient = 0.012 and regeneration factor = 0.85.

2. Speed and road profiles

The speed profile is loaded from the Excel file “Speed_Profile”, a fragment of which is shown in Fig. 24.

The speed profile read from the file and the given values of the altitudes for the segment points in the ECBus window in the “Speed and road profile” tab are shown in Fig. 25.

	A	B
1	t	v
2	0	0.0
3	1.07	1.9
4	2.14	6.4
5	3.01	9.9
6	4.07	14.6
7	5.12	17.6
8	6.09	20.7
9	7.05	23.7
10	8.1	27.1
11	9.07	29.7
12	10.4	31.8
13	11.01	33.6
14	12.1	35.7
15	13.06	37.4
16	14.04	39.2
17	15.02	40.4
18	16.09	42.2
19	16.64	42.6
20	17.08	42.6
21	18.03	42.2
22	19.1	40.9
23	20.03	39.6
24	21.1	35.7
25	22.07	32.3
26	23.02	30.1
27	24.1	28.0

Figure 24 A fragment of a set speed profile in an Excel-file

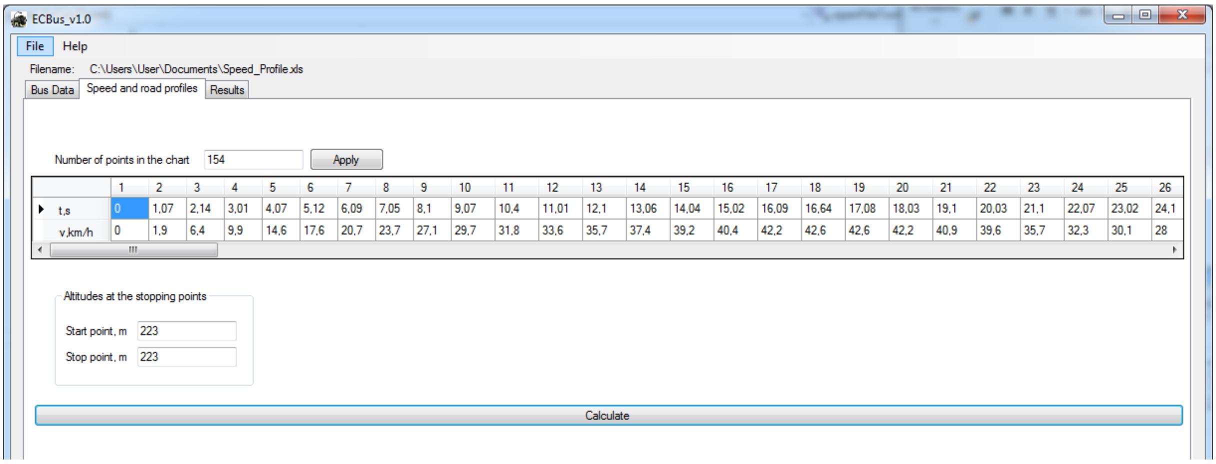


Figure 25 Speed profile and altitudes values of segment points: representation in the program

3. The calculation results

A graphical representation of the speed profile and the obtained numerical data are located in the “Speed profile” tab, which is located in the “Result” tab, shown in Fig. 26.

Energy costs in graphical form are displayed in the “Energy graph” tab, which is located in the “Result” tab (Fig. 27).

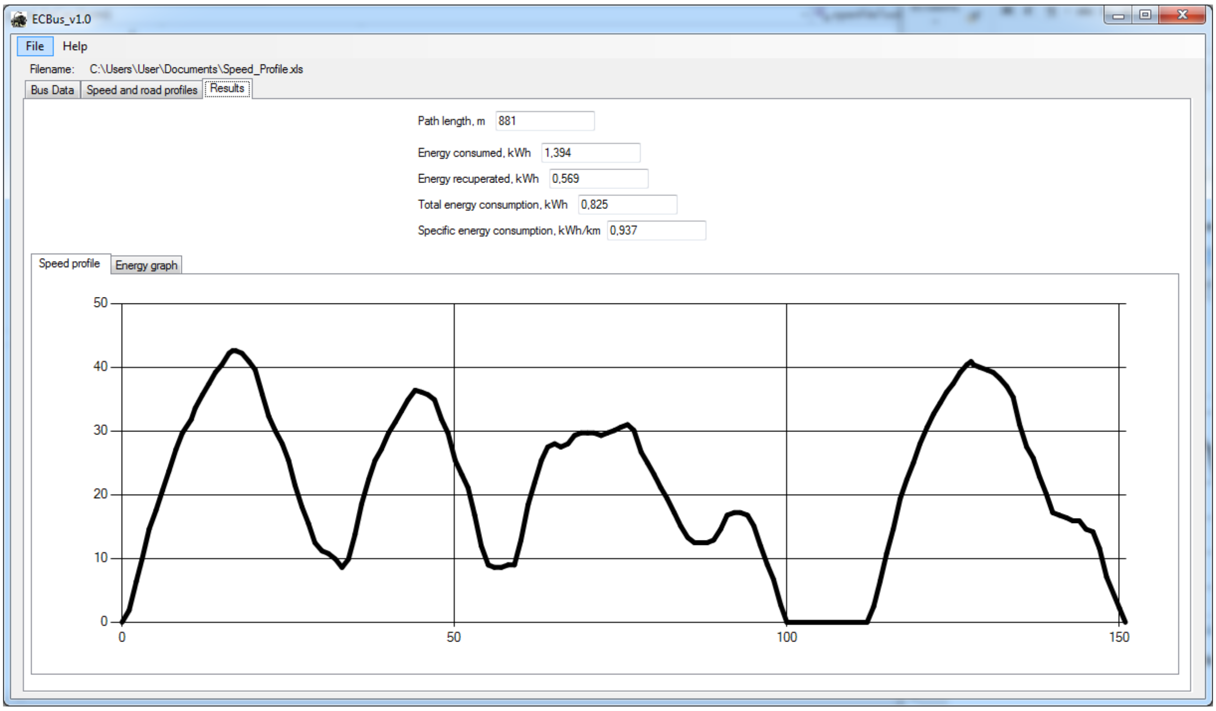


Figure 26 Results: a graphical representation of the speed profile and numerical values of indicators

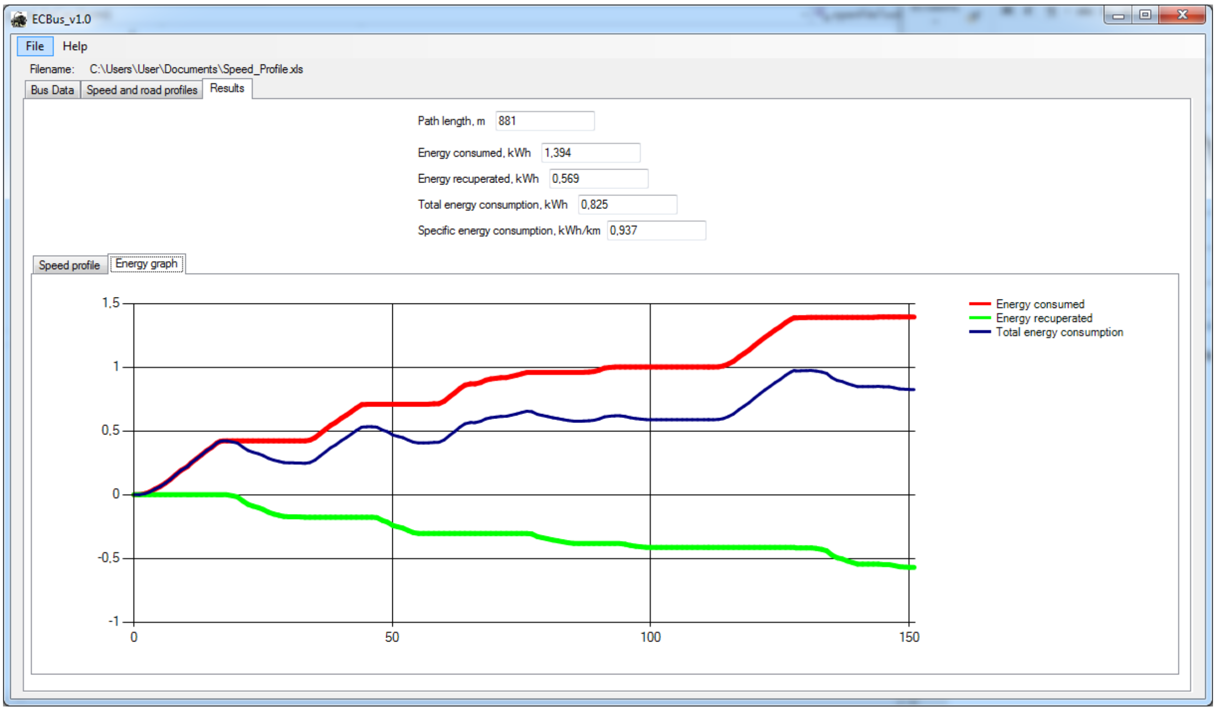


Figure 27 Calculation results: graphical representation of energy costs

Fig. 28 shows a graph of the change in the speed, energy consumed and recuperated according to the results of an experiment conducted jointly by JIME NASB and OJSC “Management Company of Belkommunmash Holding” during the implementation of the PLATON project.

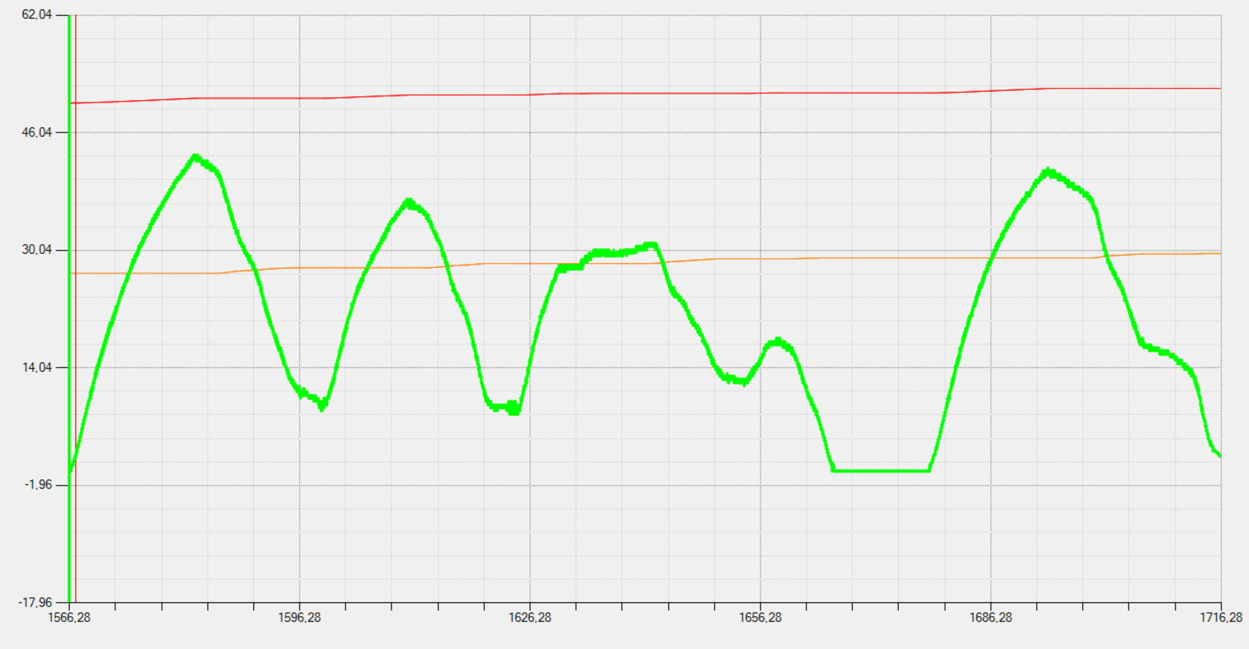


Figure 28 Experimental results: resulting graphs of the speed profile (green curve), energy consumed (red curve), energy recuperated (orange curve)

After digitizing the data of energy expended and energy recovery obtained as a result of the experiment, and comparing them with those calculated in the ECBus program, the results are presented in Table 4.

Table 4 Comparison of calculation results and experiment

Indicator	Experiment	Calculation	Deviation,%
Path length, m	882	881	−0.11
Energy consumed, kWh	1.485	1.394	−6.13
Energy recuperated, kWh	0.675	0.569	−15.70
Total energy consumption, kWh	0.809	0.825	14.1
Specific energy consumption, kWh/km	0.917	0.937	2.18

It can be seen that the energies do not differ significantly. The greatest difference is values of energies recuperated. This is due to a possibly inaccurate parameter describing the recovery, which is the most uncertain and difficult to reproduce in the estimated energy consumption of electric vehicles. This factor relates to methodological (non-computational) aspects.

6 Summary

Analysis of the typical approaches (Section 2), shows that there is not possible to create a single universal tool for using by all interested parties and for covering all mentioned aspects of transition process to full electric bus fleet. That is why in project PLATON not one but several tools are being developed (Fig. 5). These tools are related to the most actual problems in the transition process and are based on new models and data structures developed in the project.

New effective models and data structures developed and used in the PLATON project make it possible to create a series of tools for solving the most urgent problems of transition to an electric bus fleet.

These tools are designed to solve optimization problems, economic assessments based on a static and dynamic model of TCO, energy consumption assessment and environmental assessments.

Substantial support in the development of these tools is provided by databases on publications and patents, as well as the results of experimental studies obtained in the framework of the project.

7 Annex A. Information files from addition 01 to database of PLATON project

7.1 Addition 01 for the database on publications as of 01/11/2019

Пополнение 01 базы данных по публикациям на дату 01.11.2019

Number	Title	Date of publication	Author(s)
001	ZeEUS eBus Report #2 An updated overview of electric buses in Europe	2018	ZeEUS
002	Technology assessment of an electric urban bus system for Berlin	2014	D. Göhlich, A. Kunith, T. Ly
003	Open Systems Dependability and DEOS: Concept, Retrospect and Prospects	2017	M. Tokoro
004	Battery Electric Buses Smart Deployment. Zero Emission Bus Conference	2016	J. Hanlin
005	Optimal Strategy of Efficiency Power Plant with Battery Electric Vehicle in Distribution Network	2017	T. Ma, S. Su, S. Li, W. Wang, T. Yang, M. Li; Y. Ota
006	Foothill Transit Battery Electric Bus Demonstration Results	2016	L. Eudy, R. Prohaska, K. Kelly, M. Post
007	Foothill Transit Battery Electric Bus Demonstration Results: Second Report	2017	L. Eudy, M. Jeffers
008	King County Metro Battery Electric Bus Demonstration—Preliminary Project Results	2017	NREL
009	Fast Charge Battery Electric Transit Bus In-Use Fleet Evaluation	2016	R. Prohaska, L. Eudy, K. Kelly
010	Duty Cycle Characterization and Evaluation Towards Heavy Hybrid Vehicle Applications	2007	M. P. O'Keefe, A. Simpson, K. J. Kelly D. S. Pedersen
011	Making electric buses a reality	2018	M. Faltenbacher
012	Electric Buses in Cities Driving Towards Cleaner Air and Lower CO2	2018	Bloomberg
013	Introducing a fleet of zero emission buses	2018	M. Vanhoutte

Number	Title	Date of publication	Author(s)
014	Electric Buses: A Review of Alternative Powertrains	2016	M. Mahmoud, R. Garnett, M. Ferguson, P. Kanaroglou
015	A model for transit design with choice of electric charging system	2013	G. Fusco, A. Alessandrini, Ch. Colombaroni, M. Pia Valentini
016	Economic conditions to introduce the battery drive to busses in the urban public transport	2016	S. Krawiec, G. Karoń, R. Janecki, G. Sierpiński, K. Krawiec, S. Markusik
017	Overview and Progress of United States Advanced Battery Consortium (USABC) Activity	2016	R. Elder
018	Battery Chargers and Charging Methods	2018	Electropaedia
019	Electric Vehicle Charging Infrastructure	2018	Electropaedia
020	Conventional and Sustainable Electrical Energy Supply Overview Characteristics and Comparisons	2018	Electropaedia
021	Full electrification of Lund city bus traffic - A simulation study	2015	L. Lindgren
022	A sensitivity analysis of total cost of ownership for electric public bus transport systems in Swedish medium sized cities	2014	L. Nurhadi, S. Borén, H. Ny
023	Battery Electric Bus Technology Review	2017	A. Lamb
024	BU-402: What Is C-rate?	2017	Charles-Augustin de Coulomb's C-Rate for Batteries
025	Grid compatible flash charging technology. TOSA e-bus infrastructure	2017	L. Lonoce, B. Worner, V. Holz
026	A Passenger Traffic Assignment Model with Capacity Constraints for Transit Networks	2012	F.Leurent, E. Chandakas, A. Poulhès
027	Flash charging is just the ticket for cleaner transportation	2015	TOSA

Number	Title	Date of publication	Author(s)
			P. Dvorak
028	Battery capacity and recharging needs for electric buses in city transit service	2017	Z. Gao, Z. Lin, T. J. LaClair, C. Liu, J.-M. Li, A. K. Birky, J. Ward
029	Implementation Plan for Electrification of Public Bus Transport in Bengaluru Project	2018	M. Bharadwaj, S. Rathi, H. Sridhar, E. Mandal
030	Power consumption analysis on large-sized electric bus	2017	G. Heryana, S. Prasetya, M. Adhitya, D. A. Sumarsono
031	City Bus Powertrain Comparison: Driving Cycle Variation and Passenger Load Sensitivity Analysis	2018	K. Kivekäs, A. Lajunen, J. Vepsäläinen, K. Tammi
032	Fuel and Emissions Calculator (FEC) Version 2.0	2016	National Center for Sustainable Transportation (NCST)
033	The Impact of Electric Mobility Scenarios in Large Urban Areas: The Rome Case Study	2018	C. Liberto, G. Valenti, S. Orchi, M. Lelli, M. Nigro, M. Ferrara
034	Assessing life cycle impacts and the risk and uncertainty of alternative bus technologies	2018	A. Harris, D. Soban, B.M. Smyth, R. Best
035	A universal kinematic analysis of geared mechanisms	2017	Essam L. Esmail
036	The role of instrumental, hedonic and symbolic attributes in the intention to adopt electric vehicles	2013	G.Schuitema, J. Anable, S. Skippon, N. Kinnear
037	Experimental Investigation of the Energy Efficiency of an Electric Vehicle in Different Driving Conditions	2014	M. De Gennaro, E. Paffumi, G. Martini, U. Manfredi, H. Scholz
038	Determination of the required energy consumption of electric bus drives by simulation methods (In Russian)	2016	A. A. Smirnov, N. A. Pikalov

Number	Title	Date of publication	Author(s)
	Определение потребной энергоемкости накопителей электробуса методами имитационного моделирования		
039	Understanding the Linkage between Electric Vehicle Charging Network Coverage and Charging Opportunity Using GPS Travel Data	2019	E. Kontou, C. Liu, F Xie, X. Wu, Z. Lin
040	Will Advanced Public Charging Infrastructure Speed Up Electrification of Future Transportation?	2018	F. Xie, Z. Lin, Y. Zhou, C. Rames, E. Wood, E. Kontou
041	Optimal vehicle control strategy of a fuel cell/battery hybrid city bus	2009	L. Xu, J. Li, J. Hua, X. Li, M. Ouyang
042	Method to analyze cost effectiveness of different electric bus systems	2016	O. Olsson, A. Grauers, S. Pettersson
043	Public investment in environmental infrastructures, growth, and the environment	2010	T. Brechet, F. Prieur
044	Long-term strategic planning of inter-city fast charging infrastructure for battery electric vehicles	2018	F. Xie, C. Liu, S. Li, Z. Lin, Y. Huang
045	Stochastic driving cycle synthesis for analyzing the energy consumption of a battery electric bus	2018	K. Kivekäs, J. Vepsäläinen, K. Tammi
046	Energy Uncertainty Analysis of Electric Buses	2018	J. Vepsäläinen, A. Ritar, A. Lajunen, K. Kivekäs, K. Tammi
047	Commercial bus speed diagnosis based on GPS-monitored data	2011	C. E. Cortés, J.Gibson, A.Gschwender, M.Munizaga, M.Zúñiga
048	Charging into the Future: An economic and GHG analysis of fleet conversion to electric buses	2015	C. Mickle, J. Siegel, K. Sutton
049	Fast-Charge Life Cycle Test on a Lithium-Ion Battery Module	2018	F. Vellucci, G. Pede
050	A Hybrid Method for Real-Time Short-Term Predictions of Traffic Flows in Urban Areas	2019	A. Attanasi, L. Meschini, M. Pezzulla, G. Fusco, G. Gentile, N. Isaenko

Number	Title	Date of publication	Author(s)
051	Research on Power Demand Suppression Based on Charging Optimization and BESS Configuration for Fast-Charging Stations in Beijing	2018	Y. Yan, J. Jiang, W. Zhang, M. Huang, Q. Chen, H. Wang
052	Design and evaluation of electric solutions for public transport	2017	V. Conti, S. Orchi, M. Pia Valentini, M. Nigro, R. Calò
053	On specific fuel consumption of both conventional and electric buses on real urban applications	2017	C. Villante
054	Novel model-based heuristics for energy optimal motion planning of an autonomous vehicle using A	2017	Z. Ajanović, M. Stolz, M. Horn
055	Planning of Electric Vehicle Charging Infrastructure for Urban Areas with Tight Land Supply	2018	C. Guo, J. Yang, L. Yang
056	Electric buses arrive on time. Marketplace, economic, technology, environmental and policy perspectives for fully electric buses in the EU	2018	L. Mathieu
057	Implementation Schemes for Electric Bus Fleets at Depots with Optimized Energy Procurements in Virtual Power Plant Operations	2019	A. F. Raab, E. Lauth, K. Strunz, D. Göhlich
058	Lifecycle costs and charging requirements of electric buses with different charging methods	2017	A.Lajunen
059	The role of instrumental, hedonic and symbolic attributes in the intention to adopt electric vehicles	2013	G. Schuitema, J. Anable, S. Skippon, N. Kinnear
060	What is the most energy efficient route for biogas utilization: Heat, electricity or transport?	2017	R. Hakawati, B. M. Smyth, G. McCullough, F. De Rosa, D. Rooney
061	Quantitative Evaluation of MD/HD Vehicle Electrification Using Statistical Data	2018	Z. Gao, Z. Lin, S. C. Davis, A. K. Birky
062	Evaluation of electric vehicle component performance over eco-driving cycles	2019	Z. Gao, T. LaClai, S. Ou, S. Huff, G. Wu, P. Hao,

Number	Title	Date of publication	Author(s)
			K. Boriboonsomsin, M. Barth
063	Design of urban electric bus systems	2018	D. Göhlich, Tu- Anh Fay, D. Jefferies, E. Lauth, A. Kunith, X. Zhang
064	Safe learning-based optimal motion planning for automated driving	2018	Z. Ajanovic, B. Lacevic, G. Stettinger, D. Watzenig, M. Horn
065	Power-based Electric Vehicle Energy Consumption Model: Model Development and Validation	2017	C. Fiori, K. Ahn, H. A. Rakha
066	Theoretical analysis of electric vehicle energy consumption according to different driving cycles	2018	W/ Gołębiewski, M. Lisowski
067	Modeling of Full Electric and Hybrid Electric Vehicles	2012	Fe Luigi Mapelli, D. Tarsitano
068	Simulation of Electric Buses on a Full Transit Network: Operational Feasibility and Grid Impact Analysis	2016	M. Mohamed, H. Farag, N. El- Taweel, M. Ferguson
069	Energy Efficiency of Electric Vehicles	2012	Z. Stevic, I. Radovanovic
070	The Effects of Driving Style and Vehicle Performance on the Real-World Fuel Consumption of U.S. Light-Duty Vehicles	2010	I. M. Berry
071	Online Driving Style Recognition using Fuzzy Logic	2014	D. Dorr, D. Grabengiesser, F. Gauterin
072	Driving Styles: A mobile platform for driving styles and fuel consumption characterization	2016	J. E. Meseguer, C. K. Toh, C. T. Calafate, J. C. Cano, P. Manzoni
073	Electric Vehicle Battery Technologies	2013	K. Young, C. Wang, L. Y. Wang, K. Strunz

Num-ber	Title	Date of pub-lication	Author(s)
074	Impact of driving style on fuel consumption and exhaust emissions: defensive and aggressive driving style	2007	E. Tzirakis, F. Zannikos, S. Stournas
075	Assessing life cycle impacts and the risk and un-certainty of alternative bus technologies	2018	A. Harris, D. Soban, B. M. Smyth, R. Best
076	Lifecycle costs and charging requirements of electric buses with different charging methods	2017	A. Lajunen
077	Combined timetabling and vehicle sheduling for electric buses	2017	N-H. Quttineh, C.H. Häll, J. Ekström, A. Ceder
078	Scenario-based electric bus operation: A case study of Putrajaya, Malaysia	2018	L. E. Teoh, H. L. Khoo, S. Y. Goh, L. M. Chong
079	Developing a Large-Scale Microscopic Model of Electric Public Bus Operation and Charging	2019	M. Gallet, T. Mas-sier, D. Zehe
080	Adjustments of public transit operations planning process for the use of electric buses	2018	C. H. Häll, A.(Avi) Ceder, J. Ekström, Nils- Hassan Qut-tineh
081	Trends in Vehicle Motion Control for Automated Driving on Public Roads	2019	M. Klomp, M. Jonasson, L. Laine, L. Hender-son, E. Regolin, S. Schumi
082	Dynamic bus lanes in Sweden – a pre-study	2015	J. Olstam, C-H. Häll, G. Smith, A. Habibovic, A. Anund
083	Optimal recharging scheduling for urban electric buses: A case study in Davis	2017	Y. Wang, Y. Huang, J. Xu, N. Barclay
084	Estimation of the energy demand of electric buses based on real-world data for large-scale public transport networks	2018	M. Gallet, T. Mass-ier, T. Hamacher

Num-ber	Title	Date of pub-lication	Author(s)
085	Future Battery Management - Next generation diagonstic algorithms and advanced measure-ment technologie	2019	D. Uwe Sauer, A. Gitis, G. Fuchs, D. Jöst
086	Real-world performance of battery electric buses and their life-cycle benefits with respect to en-ergy consumption and carbon dioxide emissions	2016	B. Zhou, Y. Wu, B. Zhou, R. Wang, W. Ke, S. Zhang, J. Hao
087	Deep Discharge Behavior of Lead-Acid Batteries and Modeling of Stationary Battery Energy Stor-age Systems	2012	T. Blank, J. Badeda, J. Kowal, D. Uwe Sauer
088	Activities to convert the public transport fleet to electric buses	2018	L. Gabsalikhova, G. Sadygova, Z. Al-metova
089	Transit Route Network Design Problem: Review	2009	K. Kepaptsoglou, M. Karlaftis
090	Calculated Modes for Assessing Operation Properties and Dependability of Vehicles	2019	V. Algin
091	Implementation of Real Time Bus Monitoring and Passenger Information System	2013	S. Chandurkar, S. Mugade, S. Sinha, M. Misal, P. Borekar
092	Modelling noise reductions using electric buses in urban traffic. A case study from Stuttgart, Ger-many	2019	F. Laib, A. Braunc, W. Rid
093	Combining adaptation at supply and demand levels in microscopic traffic simulation: a multia-gent learning approach	2019	L. L. Lemos, A. L. C. Bazzan
094	Integrated Energy Solutions to Smart And Green Shipping: 2019 Edition	2019	Z. Guangrong, G. Jagan, M. Elg, J. Kataja
095	Digital twin-driven product design, manufactur-ing and service with big data	2017	F. Tao, J. Cheng, Q. Qi, M. Zhang, H. Zhang, F. Sui
096	Electrification of public transport in cities (Hori-zon 2020 ELIPTIC Project)	2016	M. Glotz-Richter, H. Koch

Number	Title	Date of publication	Author(s)
097	Integrated TCO Assessment of Bus Network Electrification Considering Rescheduling and Delays	2018	D. Jefferies, D. Göhlich
098	On the road to fossil-free public transport: The case of Swedish bus fleets	2017	M. Xylia, S. Silveira
099	Electrification of a city bus network—An optimization model for cost-effective placing of charging infrastructure and battery sizing of fast-charging electric bus systems	2017	A. Kunith, R. Mendelevitch, D. Goehlich
100	Modeling the Prospects of Plug-In Electric Buses to Reduce GHG Emissions and Cost While Meeting Route Demands: A Case Study of the "Unitrans" Bus Fleet Serving the Davis, California Urbanized Area	2016	K. Kornbluth, C. Mickle, K. Hestmark
101	Tesla Will Give Drivers More Options With New Navigation Features — Patents Filed	2019	K. Field
102	Launch of zero-emissions battery-electric buses and standardized high-powered charging systems today constitute a world-first in Pan-Canadian Pilot	2019	Canadian Urban Transit Research & Innovation Consortium (CUTRIC)
103	Combining ITS and optimization in public transportation planning: state of the art and future research paths	2019	C. Iliopoulou, K. Kepaptsoglou
104	Operational Integration of Electric Bus Fleets, Charging Process Analysis, and Field Test Results	2019	A. F. Raab, P. Teske, E. Lauthy, J. F. Heinekamp, K. Strunz, D. Gohlichy
105	Exploration of Optimal Powertrain Design Using Realistic Load Profiles	2019	A. Pathak, G. Sethuraman, S. Krapf, A. Ongel, M. Lienkamp
106	Reducing the energy consumption of electric buses with design choices and predictive driving	2019	K. Kivekäs, A. Lajunen, F. Baldi
107	Optimal motion planning for automated driving	2018	Z. Ajanović

Number	Title	Date of publication	Author(s)
108	Studying pedestrians' crossing behavior when interacting with automated vehicles using virtual reality	2019	J. P.Nuñez Velasco, H. Farah, Bart van Arem, M.P. Hagenzieker
109	An Online Prediction System of Traffi c Signal Status for Assisted Driving on Urban Streets: Pilot Experiences in the United States, China, and Germany	2015	T. Bauer, F. Offermann
110	Computationally efficient model for energy demand prediction of electric city bus in varying operating conditions	2018	J. Vepsalainen, K. Otto, A. Lajunen, K. Tammi
111	Cost-Benefit Analysis of Electric Bus Fleet with Various Operation Intervals	2018	J. Vepsäläinen, F. Baldi, A. Lajunen, K. Kivekäs, K. Tammi
112	Simulation-based Planning of Depots for Electric Bus Fleets Considering Operations and Charging Management	2019	E. Lauth, P. Mundt, D. Gohlich
113	StorEn Technologies Has Created A New Grid-Scale Flow Battery Application	2019	A. Bertoli
114	Studying pedestrians' crossing behavior when interacting with automated vehicles using virtual reality	2019	J. P. Nuñez Velasc, H. Farah, B. Arem, M. P. Hagenzieker
115	Conceptual design of urban e-bus systems with special focus on battery technology	2019	D. Göhlich, T-A.Fay
116	Charging Network Planning for Electric Bus Cities: A Case Study of Shenzhen, China	2019	Y. Lin, K. Zhang, Z.- J.M. Shen, L. Miao
117	What Hinders Adoption of the Electric Bus in Canadian Transit? Perspectives of Transit Providers	2017	M. Mohamed, M.Ferguson, P.Kanaroglou

7.2 Addition 01 for the database on inventions as of 01/11/2019

(Дополнение 01 базы данных по изобретениям на дату 01.11.2019)

Number	Publication number	Title	Applicant (patent holder)
001	US9252417	Low-floor electric bus	PROTERRA INC
002	CN203486030	Pure electric articulated bus	BYD CO LTD
003	TWM452082	Electric bus	BYD CO LTD
004	RU000241869	Transport facility and method of its control	TOJOTA DZIDOSJa KABUSIKI KAJSJa
005	CN104044477	Motor vehicle with plug-in charging device	MAN TRUCK & BUS AG
006	EP2848448	Vehicle having an electric drive and a display device for indicating the operating condition of an energy store of the electric drive	MAN TRUCK & BUS AG
007	US2018006283	Low-floor electric vehicle	PROTERRA INC
008	CN105244933	Externally rechargeable vehicle having an electric drive and recharging station for the vehicle	MAN TRUCK & BUS AG
009	RU02389618	Hybrid power plant (versions) and control method of hybrid power plant power (versions)	GENERAL ELECTRIC COMPANY
010	RU2499694	Electrically driven vehicle and electric power feeder for said vehicle	TOJOTA DZIDOSJa KABUSIKI KAJSJa
011	WO2018028518	Electric vehicle energy management system, control method therefor, and electric vehicle	BYD CO LTD
012	RU2014114041 RU2669912	Vehicle energy management system	MAN TRUCK & BUS AG
013	RU0002616484	Power supply system, vehicle and method of vehicle operation	BOMBARDIER TRANSPORTATION
014	RU2523719	Power supply unit, land vehicle, replacement station and replacement method for power supply unit installed on vehicle	CONDUCTIX-WAMPFLER AG
015	DE102012001890	Energy storage system for providing electrical driving power for drive motor of e.g. electric car, has two energy storage devices for providing electrical	MAN TRUCK & BUS AG

Number	Publication number	Title	Applicant (patent holder)
		driving power with higher energy density and higher power density, respectively	
016	CN105966248	Method for voltage regulation of an electrical system of a motor vehicle	MAN TRUCK & BUS AG
017	RU2016123642 US20160379126 DE102016111371	Rapid traffic parameter estimation	FORD GLOBAL TECHNOLOGIES LLC
018	US2018138730	Universal current charger	PORSCHE AG
019	CN108068643	Apparatus and method for controlling charging battery	HYUNDAI MOTOR CORPORATION, CORPORATION KIA MOTORS
020	EA201401233	Electrical charging apparatus	WOBBEN ALOYS
021	EA201591142	Fast charging system for electric vehicles	GJINALI AGIM; O'CONNOR BRIAN JOSEPH; GJINALI RRON
022	RU0002438887	Charging system and method of control thereof	TOYOTA MOTOR CO LTD
023	RU0002509667	Transformer substation of electric vehicle	V. Osipov; I. Krikunov; A. Bol'shakov; T. Edigarjan
024	RU0002520616	Charging system for electrical vehicles	ABB B.V.
025	RU0002534329	Multifunctional stand-alone hybrid charging station	V. Goloshchapov; A. Baklin; V. Silakov; N. Sidorov ; S. Kargin
026	RU0002550817	Quick charge system, control unit, method of control of amount of accumulated electric energy and program	NEC CORPORATION NISSAN MOTOR CO., LTD
027	RU2015118128 RU2666496	Electric charging method for vehicle and electric vehicle charging device	FORD GLOBAL TECHNOLOGIES LLC
028	EP2623362	Electric bus and electric bus battery exchange system	UNIV KOOKMIN IND ACAD COOP

Number	Publication number	Title	Applicant (patent holder)
			FOUND INDUS-TRY-UNIV COOP FOUND OF KOREA AEROSPACE UNIV
029	RU2466042	Vehicle power supply system, electric vehicle and power supply for vehicle	TOYOTA MOTOR CO LTD
030	RU0002469880	Power supply system and electrically driven vehicle	TOJOTA DZIDOSJa KABUSIKI KAJSJa
031	RU0002520640	Automotive transport power system with principle of periodic charging, dis-charging	A. Kozlov
032	CN206148997	On -vehicle charger and have electric bus of this on -vehicle charger	BYD CO LTD
033	CN104253471	Charging system and charging control method of electric vehicle	BYD CO LTD
034	US2015008850 US9290105	Electric vehicle and active discharging system for electric vehicle	BYD CO LTD
035	US2018072175	Systems and methods for charging an electric vehicle at a charging station	PROTERRA INC
036	EP3299212	Systems and methods for enabling fast charging of an electric vehicle at a charging station	PROTERRA INC
037	US9550428	Positioning system for electric charg-ing	PROTERRA INC
038	US2016362014	Charging systems for electric vehicles	PROTERRA INC
039	AU2013216685	Charging stations for electric vehicles	PROTERRA INC
040	US2017182898 US9809122	Charge head landing switch	PROTERRA INC
041	RU2012140025 RU2549598	System and method for vehicle driving style	TELEPARKING S.R.L
042	RU0002640919	Method and system for optimisation of energy consumption in vehicle	FORD GLOBAL TECHNOLOGIES, LLC
043	RU0002560825	Method of simulating road characteris-tics in region where vehicle is moving and system	FORD GLOBAL TECHNOLOGIES, LLC

Number	Publication number	Title	Applicant (patent holder)
		therefor	
044	RU0002535833	Method and module for control over vehicle speed	SCANIA CV AB
045	RU0002601133	Simulation model of traffic and pedestrian flows in urban conditions based on agent-oriented approach	LIMITED LIABILITY COMPANY “LOGOS-AGENTNYE TEHNOLOGII”
046	RU2016139696	Lane boundary detection data generation in virtual environment	FORD GLOBAL TECHNOLOGIES, LLC
047	RU0002486578	Method to build system of messages of multi-level asymmetrical transport system	D. Pilshchikov; V. Borisov; G. Zavjalov; A. Dudakov; A. Zhosanu
048	RU0002481988	System and method for optimisation of vehicle cruise	GENERAL ELECTRIC COMPANY
049	RU2002105481 DE000019935349	Verfahren zur Energieoptimierung der Fahrweise bei einem Fahrzeug/Zug unter Verwendung der kinetischen Energie	ABB DAIMLER BENZ TRANSP
050	WO2017165284	Systems and methods of adjusting operating parameters of a vehicle based on vehicle duty cycles	CUMMINS INC.
051	WO2016186560	Method and system for adjusting the acceleration of a vehicle along a route	SCANIA CV AB
052	CA2967302	Systems and methods for predicting weather performance for a vehicle	FATHYM INC
053	EP2881712	Optimized route planning	ROUTERANK LTD
054	RU0002543141	Method to identify qualification of vehicle driver	B. Efremov; J. Overin; E. Nikitin
055	US2014229087 US9129456	Method and apparatus for estimating the fuel consumption of a vehicle	INVICTUS TECH GROUP INC
056	US2014214311 US9157383	System, method and computer program for simulating vehicle energy use	CROSSCHASM TECПNOLOGIES INC
057	US2017182912	Method of docking an electric vehicle for charging	PROTERRA INC

Number	Publication number	Title	Applicant (patent holder)
058	EP3377352	Electric land vehicle for public transport, such as a bus, provided with upper electrical energy storage modules	BLUEBUS
059	CN105216874	Pure electric bus top structure and pure electric bus using top structure	ZHENGZHOU YUTONG BUS CO LTD
060	CN108790884	Self-circulating thermal management system for pure electric bus	ZHONGXING INTELLIGENT AUTOMOBILE CO LTD
061	EP3442100	Bus bar unit and dynamo-electric machine	KYB CORP
062	RU2017127915 RU2681611	Asynchronous electric drive with integration on gearbox and differential	V. Vagner; D. Shchurovskij
063	WO2018166122	Battery failure preventing cut-off system applied to electric bus	CONTEMPORARY AMPEREX TECH CO LIMITED
064	WO2018114683	Multi-phase busbar for conducting electric energy, method of manufactoring the same and switch board cabinet including such a busbar	ABB SCHWEIZ AG
065	US2018212288	Thermal event detection and management system for an electric vehicle	PROTERRA INC
066	WO2019030331	Electric storage device for providing electric energy for a charging operation of at least one electrically-driven motor vehicle, and retrofit module and operating method	BAYERISCHE MOTOREN WERKE AG
067	WO2019020561	An electric energy storage device	SHELL INT RESEARCH; SHELL OIL CO
068	WO2018224284	Method and device for operating an electric energy storage system	ROBERT BOSCH GMBH
069	WO2013093287	Method of exchanging electrical energy between an electrical network conveying a dc or ac electrical quantity and an electrical energy storage unit for hybrid or electric vehicle	VALEO SYS CONTROLE MOTEUR SAS

Number	Publication number	Title	Applicant (patent holder)
070	WO2018188678	Device for optimizing production, consumption, and storage of electric energy	CESKA ENERGETICKO AUDITORSKA SPOLECNOST S R O
071	WO2018091490	Analogue overall balancing system for an assembly of capacitive-effect electrical energy storage devices, rechargeable storage module, electric vehicle and electrical installation comprising such a system	BLUE SOLUTIONS
072	WO2018077503	Charging device for an electric energy store, electric energy storage system, and method for charging an electric energy store	ROBERT BOSCH GMBH
073	CN108571411	Methods and systems for improving electric energy storage device durability for a stop/start vehicle	FORD GLOBAL TECH LLC
074	CN108462195	Virtual energy storage capacity allocation method and system for electric vehicles	CHINA ELECTRIC POWER RES INST CO LTD
075	CN208134120	Self -service charging station of alternating current -direct current series -parallel connection microgrid be bare -is stored up - fills to highway distributing type	GUANGZHOU INST OF ENERGY CONVERSION CHINESE ACADEMY OF SCIENCES
076	WO2018122850	Supercapacitor current collectors, separators, stacks and modules	POCELL TECH LTD
077	EP3336937	Electric vehicles with adaptive fast-charging, utilizing supercapacitor-emulating batteries	STOREDOT LTD
078	WO2018048345	Supercapacitor charge system and method	E SYNERGY GRAPHENE RES PTE LTD
079	CA3038375	Systems and methods for an on-board fast charger	GOVERNING COUNCIL UNIV TORONTO

Number	Publication number	Title	Applicant (patent holder)
080	WO201906178	Intensive battery charging and swap station for electric bus	SHENZHEN FINE AUTOMATION CO LTD
081	EP3109088	Electric power supply station for an electric urban bus	IVECO FRANCE SA
082	WO2018185651	A method for sharing a can bus between a plurality of nodes, a circuit comprising a can bus and a plurality of nodes, and an electric aircraft with such a circuit	H55 SA [CH]
083	EP3282535	An arc fault detection arrangement for a dc electric bus	ABB SCHWEIZ AG
084	EP2848451	Connection system for charging batteries of a vehicle, particularly an electric bus	SOLARIS BUS & COACH S A [PL]; EKOENERGETYKA POLSKA SP Z O O [PL]
085	CN108944481	Charging circuit compatible with 12 V and 24 V charging for pure electric bus, and charging method	ZHENGZHOU YUTONG BUS CO LTD
086	CN108263220	Mobile power station of pure electric vehicle and pure electric vehicle	BYD CO LTD
087	CN108215816	Vehicle-mounted terminal, cloud server, unmanned aerial vehicles (UAVs), energy supply station, method and system	BYD CO LTD
088	CN207416579	Charging device and vehicle with fill electric pile	BYD CO LTD
089	US2018236887	Systems and methods for charging an electric vehicle at a charging station	PROTERRA INC
090	US2018229612	Electric vehicle charging interface	PROTERRA INC
091	US2018205123	Battery system cooling	PROTERRA INC
092	CA2983327	Battery system of an electric vehicle	PROTERRA INC
093	US2018037128	Multi-protocol charge port for an electric bus	PROTERRA INC

Number	Publication number	Title	Applicant (patent holder)
094	JP2018126014	Power conversion device, power conversion system, and control method of power conversion device	PANASONIC IP MAN CORP
095	CN108321892	Method and apparatus for charging an electric energy storage device	VOLKSWAGEN AG
096	CN108986720	Energy-saving and environment-friendly electronic bus stop board	ZHEN BEILU
097	CN108879748	Bidirectional energy storage converter	LESHAN INTELLIGENT MICROGRID TECH INNOVATION RESEARCH INSTITUTE CO LTD
098	CN108879921	Storage battery charge and discharge system capable of cyclic utilization of electric energy	HUANG GENCHI
099	CN108790859	High voltage bus system for electrified vehicles	GM GLOBAL TECH OPERATIONS LLC
100	CN208085512	Quick charging device	SHENZHEN TONGYE TECH CO LTD
101	WO2016012172	Vehicle charging station comprising a supply-contact device mounted on an arm	SIEMENS AG
102	RU2679489	Method and device for transmission of electric energy during movement by railless electric and hybrid transport	L. Ponyaev
103	EP3088974	Method for effective transmission of data on a bus device of a bus-oriented programmable electric installation	SIEMENS SCHWEIZ AG
104	US2018375366	Electric vehicle and vehicle-mounted charger, and method for controlling the same	BYD CO LTD
105	CN108248397	Generation control method and device, range extender system and electric vehicle	BYD CO LTD

Number	Publication number	Title	Applicant (patent holder)
106	CN107640040	Vehicle monitoring method and system and vehicle	BYD CO LTD
107	US2018043787	Method of docking an electric vehicle for charging	PROTERRA INC
108	US2018297483	Systems and methods to improve performance of an electric vehicle	PROTERRA INC
109	CN107958294	Management method and system for reservation charging of electric automobile	ZHUHAI LCOLA TECH CO LTD
110	CN107133660	Electric vehicle charging station energy interaction management system	ELECTRIC POWER RES INST STATE GRID LIAONING ELECTRIC POWER CO LTD; STATE GRID CORP CHINA; SHENYANG INST ENGINEERING; HUACHEN GROUP AUTO HOLDING CO LTD
111	WO2018231673	Multi-function energy station	S & C ELECTRIC CO
112	CN108964263	Isolated microgrid and energy management system thereof	INST ELECTRICAL ENG CAS
113	CN108802533	Electric energy quality online monitoring system	BAODING SIMAIER ELECTRICAL CO LTD
114	FR3078836	Systeme de rechargement electrique multimodal pour un vehicule electrique, et vehicule electrique equipe d'un tel systeme	BLUEBUS
115	RU2695752	Foldable power bus of vehicle	FORD GLOBAL TECH LLC
116	RU2697503	Power conversion device	NISSAN MOTOR
117	WO2019169946	Power converter for electric vehicle drive systems	CHONGQING JINKANG NEW ENERGY VEHICLE

Number	Publication number	Title	Applicant (patent holder)
			CO LTD [CN]; SF MOTORS INC
118	US2019202316	Battery charging device and method for vehicle	LEE JEONG YONG
119	US2019242936	Fault diagnosis method for series hybrid electric vehicle AC/DC converter	UNIV WUHAN
120	US2019253019	DC bus ripple elimination for multi-phase electric machines	AROS ELECTRONICS AB
121	US2019288539	Method for controlling a charging device on board an electric or hybrid vehicle	RENAULT SAS
122	US2019320549	Inverter module of an electric vehicle	SF MOTORS INC
123	WO2019144205	Electric vehicle power management system	ELETRA IND LTDA
124	RU2017105756	Vehicle charging station comprising an articulated arm	SIEMENS AG
125	WO2018183289	Tanks embodiment for a flow battery	A. Danzi; C. A. Brovero; G. Piraccini; M. Tappi
126	WO2018183301	An advanced electrolyte mixing method for all vanadium flow batteries	A. Danzi; C. A. Brovero; G. Piraccini; M. Tappi
127	WO2018183222	Multipoint electrolyte flow field embodiment for vanadium redox flow battery	A. Danzi; C. A. Brovero; G. Piraccini; M. Tappi
128	WO2018183269	Novel leaks containment embodiment for electrochemical stack	A. Danzi; C. A. Brovero; M. Tappi; G. Piraccini

8 Annex B. Software ECBus v0.1. Calculation of energy consumption by bus on the route segment. User's manual

1. Data on the electric bus

After starting the program ECBus, the “Bus Data” tab opens (Figure B1), which contains the default values that characterize the electric bus. The user can make changes and click “Apply”. After that it is necessary to open the tab “Speed and road profiles” (Figure B2).

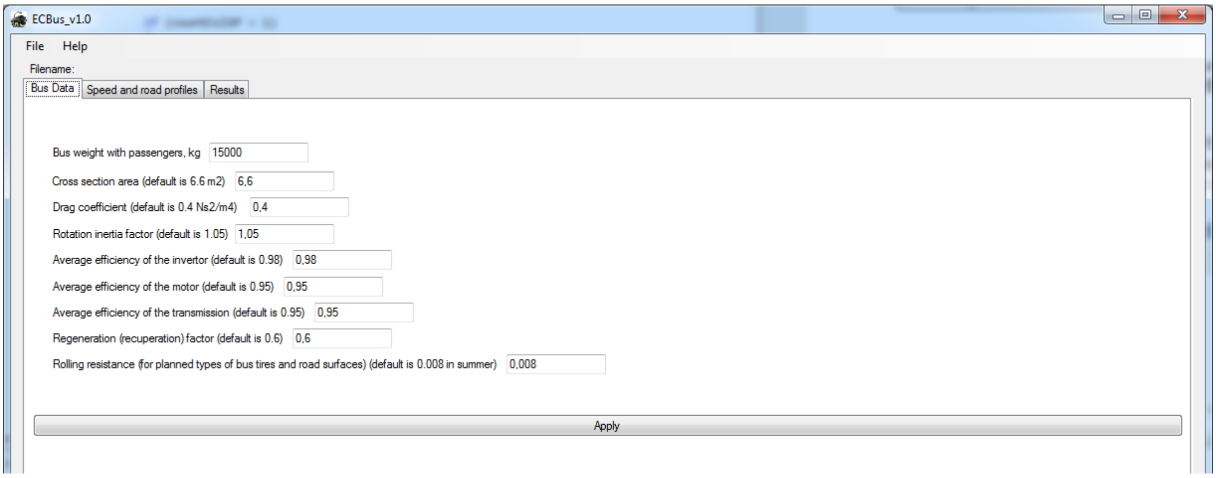


Figure B1 Tab “Bus Data”

2. Speed and road profile

2.1. After going to the “Speed and road profiles” tab, you need to enter the number of points for the route speed profile graph and click the “Apply” button.

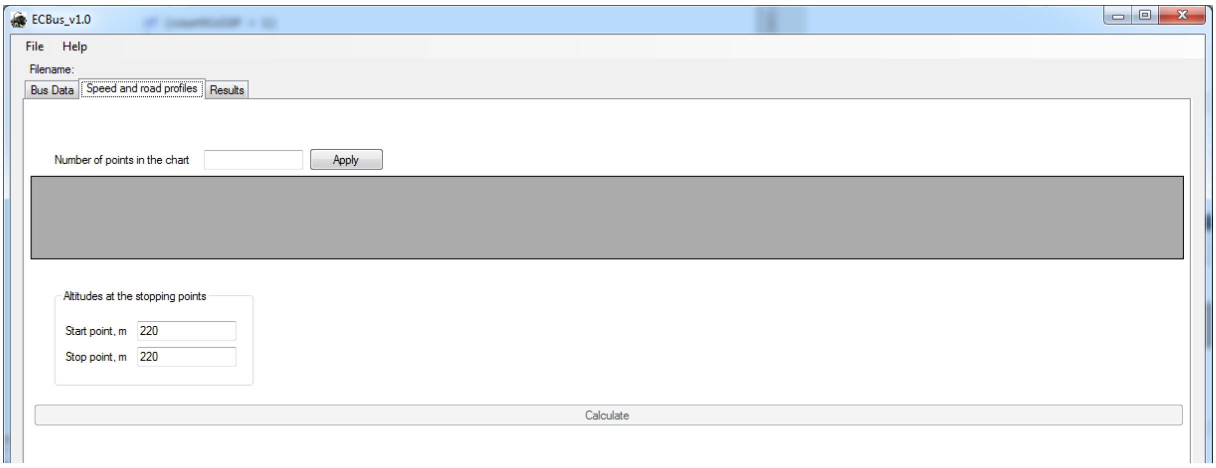


Figure B2 Tab “Speed and road profiles”. Step 1

2.2. Manual entry of the speed profile

After entering the number of points in the speed profile graph, it is necessary to enter each point in the speed profile graph: t = time (in seconds) and v = speed value at this moment in time (kilometers per hour) in the table (Fig. B3).

Altitude values are also entered at the start and end points of the route segment.

After entering the required data, click the "Calculate" button (Fig. B3).

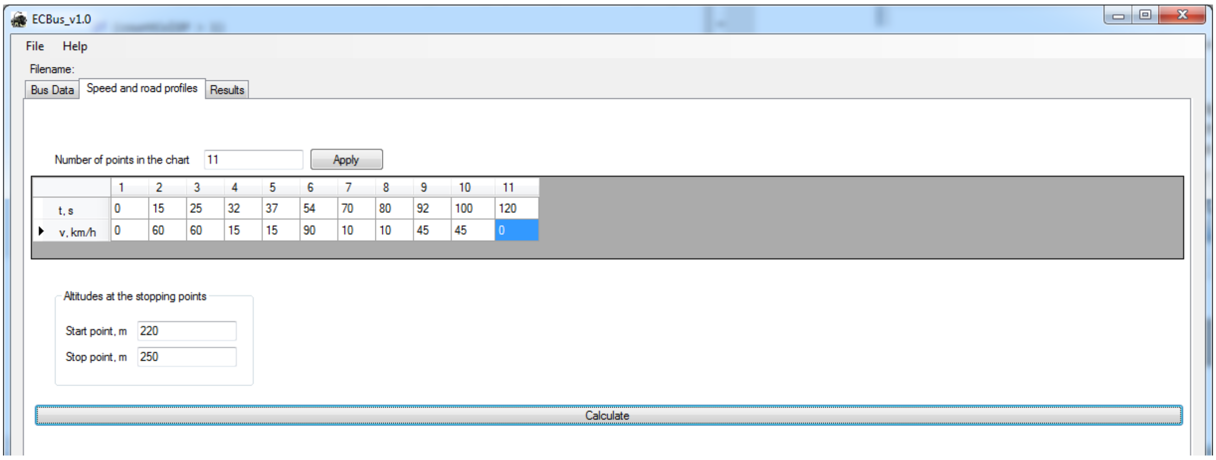
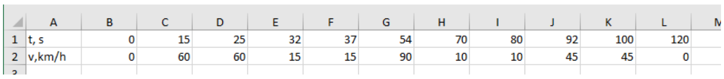


Figure B3 Tab “Speed and road profiles”. Step 2

2.3. Download a speed profile from a file

Manual entry of values characterizing the velocity profile can be replaced by loading information from a file. To do this, open an Excel file with the * .xls extension, containing data similar to those shown in Fig. 4. This data can be arranged in rows or columns.



or

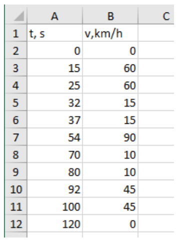


Figure B4 View of an Excel file from which a speed profile can be loaded

To download information from a file, click File -> Open file.

After selecting a file and loading its contents into the application, the point-by-point characteristic of the speed profile will be displayed on the screen (Fig. 5), and a graph will be constructed (Fig. B6), which will be displayed in the corresponding tabs of the program (Figs. B5-B6).

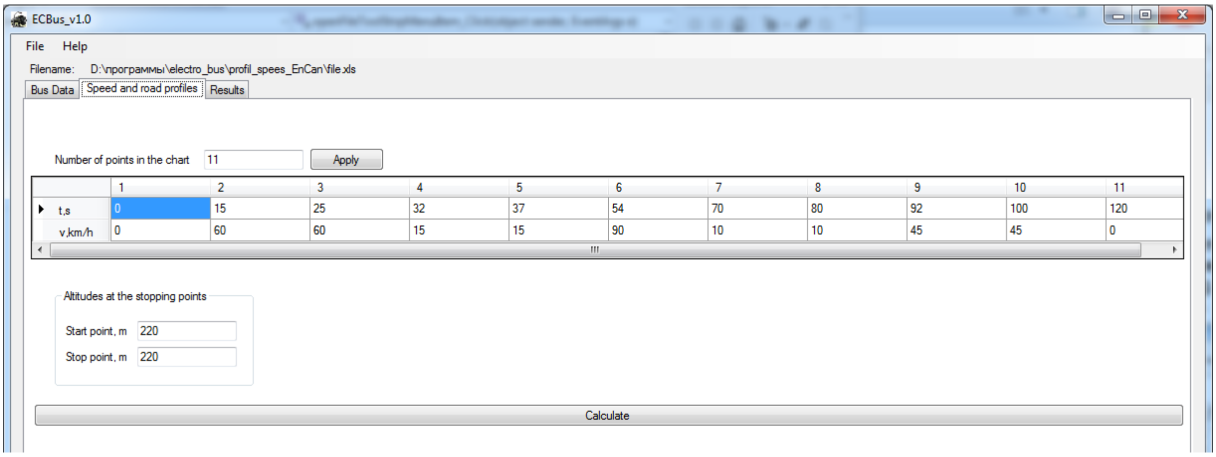


Figure B5 The tab “Speed and road profiles” of the application after loading information from a file

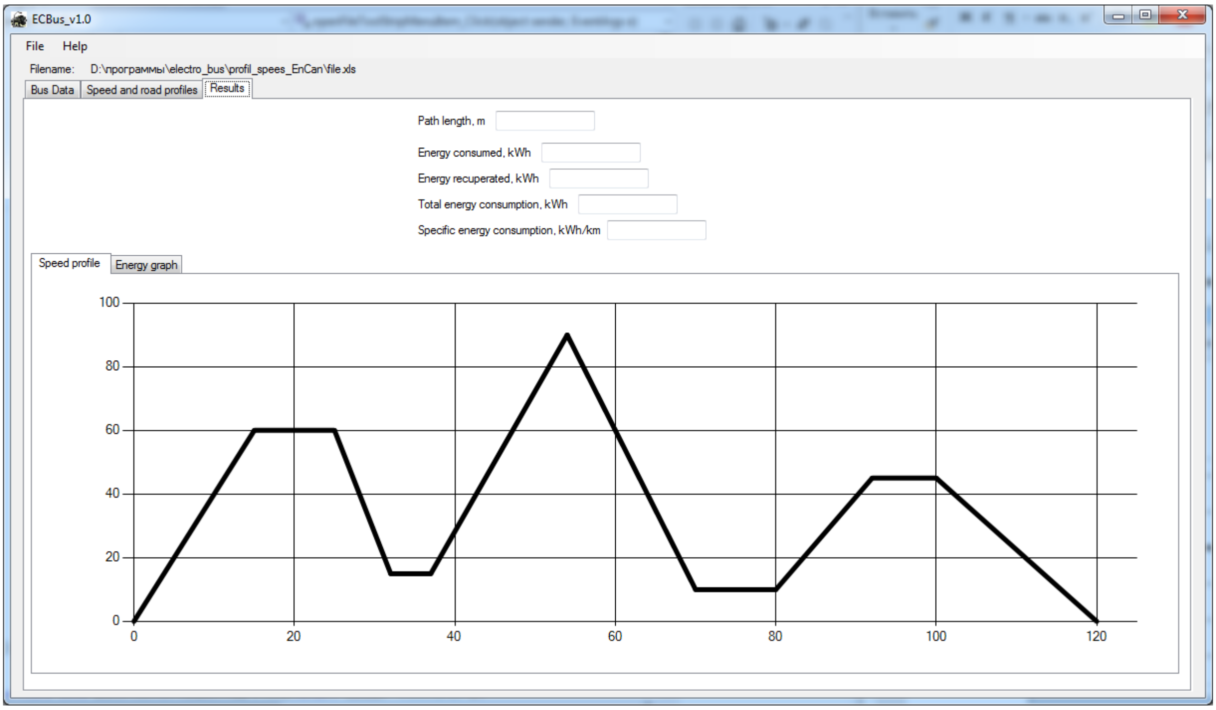


Figure B6 The tab “Results” of the application after loading information from a file

4. The results of the calculation

In the “Results” tab (Figure B7), a graphical representation of the velocity profile is displayed, as well as the " Path length ", the "Energy consumed, kWh", " Energy recovered, kWh", " Total energy consumption, kWh ", and “ Specific energy consumption, kWh / km ”.

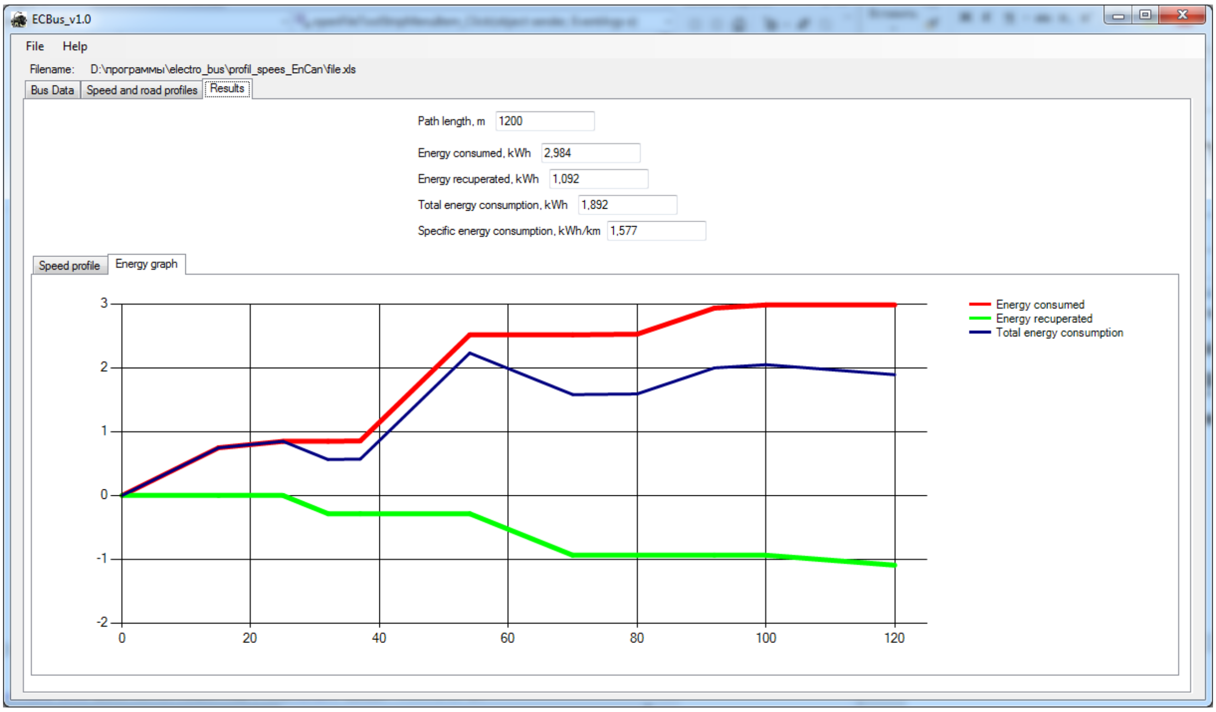


Figure B7 - Calculation results and graphical representation of energy changes

5. Program Information

To view information about the developer of the software product, you need to click Help -> About, after which background information appears that the program was developed at the Joint Institute of Mechanical Engineering of the National Academy of Sciences of Belarus as part of the PLATON project (Figure B8). After clicking on the “OK” button in the pop-up window, it will close and the user can continue working with the application.

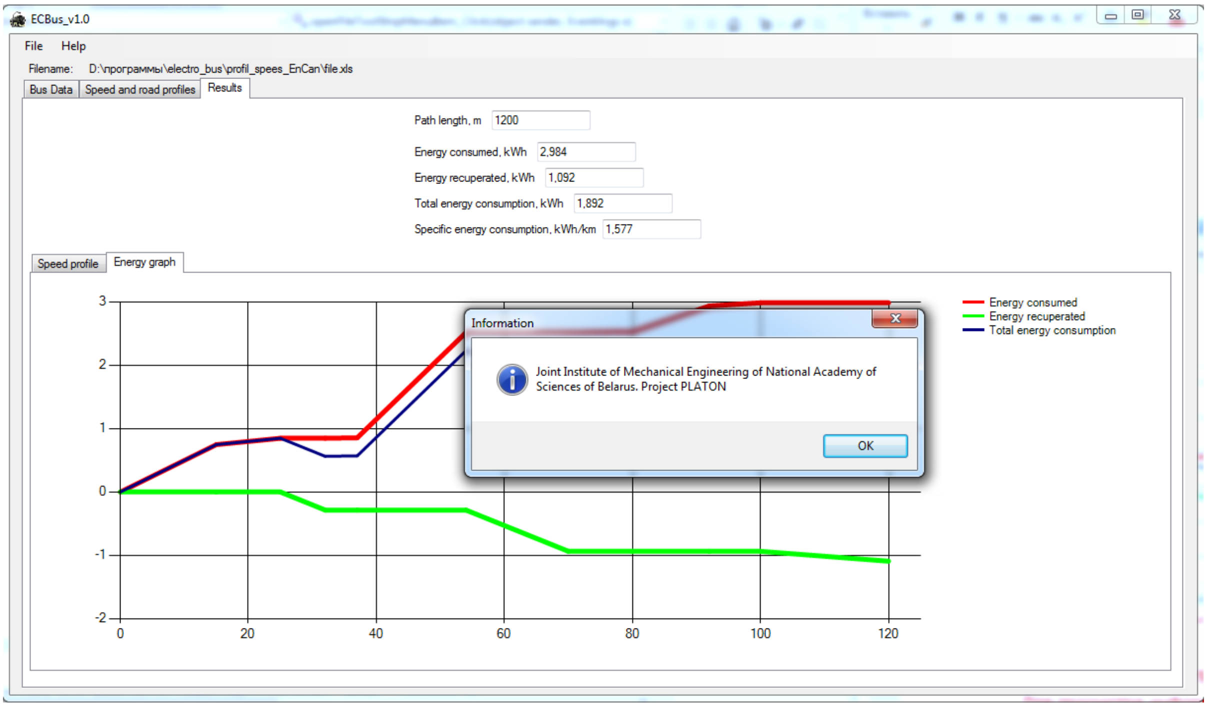


Figure B8 Program Information

9 Annex C. Example of methodology application on calculation of bus energy consumption

Electric bus data

To demonstrate the developed methodology, computational studies of energy consumption by the E420 model electric bus produced by JSC "Belkommunmash" were carried out. The section between two stops is considered. The initial data are given in Table C1.

Table C1 Initial data for electric bus energy consumption calculation

Parameter	Value
Electric bus weight m_A, kg	15000
Rolling resistance coefficient f	0.008
Slope angle of the road α	0
Rotational inertia coefficient δ	1.05
Coefficient of air resistance k_W, N·s^2/m^4	0.4
Frontal area of electric bus A_W, m^2	6.6
Average efficiency of the invertor η_{PE}	0.98
Average efficiency of the motor η_m	0.95
Average efficiency of the transmission η_t	0.95

Regeneration (recuperation) factor r_{reg}	0.6

Calculation results for a given speed profile of the route

The dependence of electric bus movement speed on time (speed profile) is given in Table C2 and Fig. C1.

Table C2 Speed of electric bus vs. time

i	0	1	2	3	4	5	6	7	8	9
t, s	0	16	20	30	33	42	54	70	76	81
v, km/h	0	50	50	12	12	35	0	0	20	0

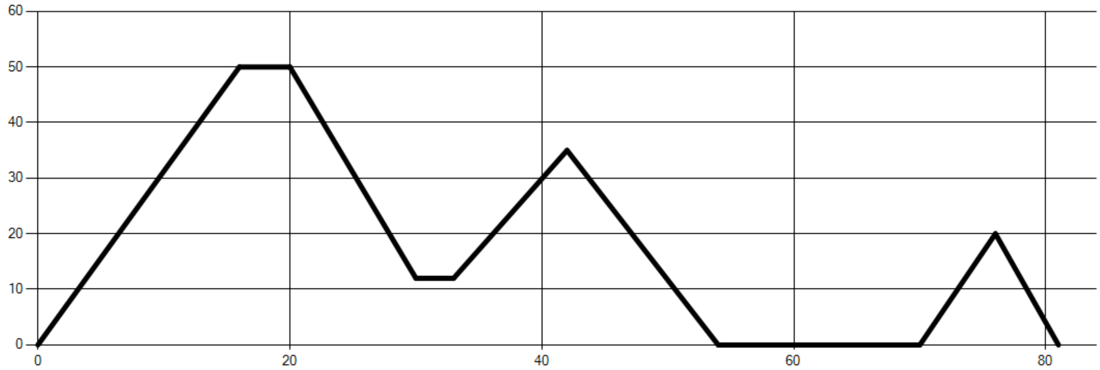


Figure C1 Electric bus speed profile

The calculation results are presented in Table C3. The values of consumed, recuperated energies and total energy consumption at time moments t_i are shown graphically in Fig. C2.

Table C3 Kinematic, force and energy characteristics of electric bus movement

Parameter	i = 1	i = 2	i = 3	i = 4	i = 5	i = 6	i = 7	i = 8	i = 9
j_i, m/s^2	0.868	0.0	–1.056	0.0	0.71	–0.81	0.0	0.926	–1.111
$S_{i,i+1}$, m	111.11	55.56	86.11	10.0	58.75	58.33	0.0	16.67	13.89
S, m	410.42								
$F_{f,i}$, N	1177.2								
$F_{\alpha,i}$, N	0.0								
$F_{j,i}$, N	13671.9	0.0	–16625.0	0.0	11180.6	–12760.4	0.0	14583.3	–17500.0
$F_{W,i}$, N	0.0	509.3	509.3	29.3	29.3	249.5	0.0	0.0	81.5	0.0
$F_{Wekv,i}$, N	254.6	–	269.3	–	139.4	124.8	–	40.7	40.7
$F_{ERight,i}$, N	14849.1	1686.5	–14938.5	1206.5	12387.1	–11333.7	1177.2	15760.5	–16241.3
$F_{ELeft,i+1}$, N	15358.3	1686.5	–15418.5	1206.5	12607.3	–11583.2	1177.2	15842.0	–16322.8
$A_{Ff,i}$, kJ	130.8	65.4	101.37	11.77	69.16	68.67	0.0	19.62	16.35

$A_{F\alpha,i}$, kJ	0.0								
$A_{Fj,i}$, kJ	1519.1	0.0	–1431.6	0.0	656.86	–744.36	0.0	243.06	–243.06
$A_{FW,i}$, kJ	28.29	28.29	23.19	0.29	8.19	7.28	0.0	0.68	0.57
A_i, kJ	1678.19	93.69	–1307.04	120.65	734.21	–668.41	0.0	263.35	–226.14
$E_{ECcons,i}$, W·h	527.07	29.43	0.0	3.79	230.59	0.0	0.0	82.71	0.0
$E_{ECreg,i}$, W·h	0.0	0.0	192.67	0.0	0.0	98.53	0.0	0.0	33.33
E_{ECcons}, W·h	873.58								
E_{ECreg}, W·h	324.53								
$E_{ECtotal}$, W·h	549.05								
E_{ECspec}, kW·h/km	1.338								

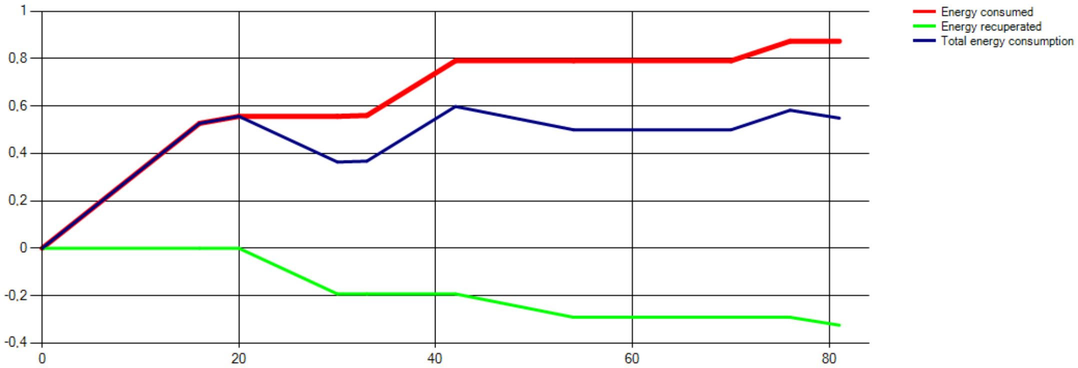


Figure C2 Change in time of consumed, recuperated energies and total energy consumption (kWh)

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