



PLATON –

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

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Software ECBus v4

Calculation of energy consumption by an electric and diesel buses on the route

Description and user's manual

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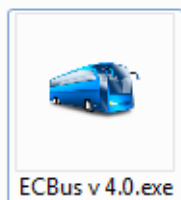
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Software ECBus v4.0

Calculation of energy consumption by an electric and diesel buses on the route



1 Introduction

The software ECBus v 4.0 is designed to calculate the energy consumption of electric and diesel buses on the route.

ECBus v 4.0 is also used to estimate energy and fuel consumption as well as pollutant emissions of a diesel bus.

Even if the user does not specify the corresponding data for the electric or diesel bus, the calculation is performed with the data specified in the program by default.

ECBus v 4.0 can be used to evaluate the following parameters:

1. Energy consumption of the electric and diesel bus on the route
for electric buses
2. Electric energy costs per day, month, year
3. Bus battery capacity for a specific set of routes
4. Distance that a bus with a known battery capacity can travel by a given route after charging (to determine the location for the next charger)
for diesel buses
5. Fuel consumption
6. Pollutant emissions

Note. In the European Union, emissions of nitrogen oxides (NO_x), total hydrocarbon (THC), non-methane hydrocarbons (NMHC), carbon monoxide (CO) and particulate matter (PM) are regulated for most vehicle types, including cars, trucks (lorries), locomotives, tractors and similar machinery, barges, but excluding seagoing ships and airplanes. For each vehicle type, different standards apply. Emissions data for heavy-duty diesel engines of lorries and buses are presented in Table 1. This table is used to estimate emissions depending on the energy consumption of a bus diesel engine on a route.

Table 1 Emission standards for heavy-duty diesel engines of lorries and buses, g/kWh (based on European emission standards: https://en.wikipedia.org/wiki/European_emission_standards)

Standard	Carbon monoxide (CO)	Hydrocarbons (HC)	Nitrogen oxides (NO _x)	Particulate matter (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

Approach peculiarities. The ECBus v 4.0 program has the following features in calculating energy consumption during bus movement [1].

1. The speed profile is described with horizontal and inclined lines (sections). The bus movement is considered as a set of elementary modes with constant accelerations during time interval (t_i, t_{i+1}) for each section.

When moving with constant acceleration / deceleration, the work of the air resistance forces can be determined using the equivalent resistance force for the considered section of the speed profile. So, all the forces are simple to calculate and determine the traction force F_E . In this case, the energy for each section of the velocity profile is calculated as: *Energy=Work=Force • Distance*.

2. When using any numerical methods, the calculation is reduced to the consideration of time periods for which it is assumed that the accelerations for them are constant. In this case, a situation may arise when at the boundary points 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. What is why, the program includes a special procedure that control the sign of traction force.

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

2 System requirements of the ECBus

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

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

3 Objective of the ECBus

Objective of ECBus v 4.0 is calculate the energy consumption for a bus on a route when a speed profile, bus data and road data are given. Some additional results are provided: graphs of energy consumption and traction over time, as well as distribution of bus speeds and accelerations.

4 Input data for the software ECBus

The input to the program are:

- Calculation identifier;
- Route description (Infrastructure):
 - Identifier of the route in question;
 - Route length, m;

- Number N of route segments;
- Segments lengths, m (Segment numbers and Segment lengths);
- Altitudes at the stopping points, m (Stopping points and Altitudes at the stopping points);
- Bus data:
 - Identifier of the bus in question;
 - Bus weight without passengers, kg;
 - Max number of passengers;
 - One passenger weight, kg (default is 70 kg);
 - Cross section area, m² (default is 6.6 m²);
 - Coefficient of air resistance, Ns²/m⁴ (default is 0.4 Ns²/m⁴);
 - Rotation inertia factor (default is 1.05);
 - Rolling resistance (for planned types of bus tires and road surfaces) (default is 0.008 in summer);
 - Maximum electrical power of auxiliary system or its subsystems with battery energy consumption, kW;
 - Average efficiency of the inverter (default is 0.98);
 - Average efficiency of the motor (default is 0.95);
 - Average efficiency of the transmission (default is 0.95);
 - Regeneration (recuperation) factor (default is 0.6);
 - Effective efficiency of the diesel (default is 0.33);
 - Transmission efficiency (default is 0.90);
 - Coefficient taking into account the diesel power consumption for equipment drive (by default 1.05);
 - Calorific value of diesel fuel, MJ/l (default is 43.12 MJ/l);
 - Diesel emission standard, EURO;
- Trip data:
 - Identifier of the trip in question;
 - Passenger loads by segments (Segment numbers and % of passenger load per segment);
- Fuel consumption and Ecology;
- Profile speed.

5 The core of the ECBus

Start

After starting the program ECBus v 4.0, the tab “Source information” opens (Figure 1).

ECBus v 4.0

File Help

Filename:

Source information Speed profile

1. Road data

Identifier of the route in question

Route length, m

Number N of route segments

Segments lengths, m

Altitudes at the stopping points, m

2. Bus data

Identifier of the bus in question

Bus weight without passengers, kg

Max number of passengers

One passenger weight, kg (default is 70 kg)

Cross section area (default is 6.6 m²)

Coefficient of air resistance (default is 0.4 Ns²/m⁴)

Rotation inertia factor (default is 1.05)

Rolling resistance (for planned types of bus tires and road surfaces)
(default is 0.008 in summer)

Electric

Average efficiency of the inverter (default is 0.98)

Average efficiency of the motor (default is 0.95)

Average efficiency of the transmission (default is 0.95)

Regeneration (recuperation) factor (default is 0.6)

Maximum electrical power of auxiliary system or its subsystems with battery energy consumption, kW

Diesel

Effective efficiency of the diesel (default is 0.33)

Transmission efficiency (default is 0.90)

Coefficient taking into account the diesel power consumption for equipment drive (by default 1.05)

Caloric value of diesel fuel, MJ/l (default is 43.12 MJ/l)

Diesel emission standard, EURO (default 5)

3. Trip data

Identifier of the trip in question

Passenger loads % by segments

Bus weight calculation type
☒ Fixed weight ☐ Depends on workload

Save edit

Figure 1 Window after starting the program

Download data on the road, bus and route

To download the data on the road, bus and route it is necessary to press “File” -> “Open” (Figure 2). In the window that appears, select the file and press “Open” (Figure 3).

Downloadable Excel-file with the extension *.xls, must be filled in according to the template, an example of which is shown in Figures 4–7.

ECBus v 4.0

File Help

Open

Open file containing speed profile

1. Road data

Identifier of the route in question

Route length, m

Number N of route segments

Segments lengths, m

Altitudes at the stopping points, m

2. Bus data

Identifier of the bus in question

Bus weight without passengers, kg

Max number of passengers

One passenger weight, kg (default is 70 kg)

Cross section area (default is 6.6 m²)

Coefficient of air resistance (default is 0.4 Ns²/m⁴)

Rotation inertia factor (default is 1.05)

Rolling resistance (for planned types of bus tires and road surfaces)
(default is 0.008 in summer)

Electric

Average efficiency of the inverter (default is 0.98)

Average efficiency of the motor (default is 0.95)

Average efficiency of the transmission (default is 0.95)

Regeneration (recuperation) factor (default is 0.6)

Maximum electrical power of auxiliary system or its subsystems with battery energy consumption, kW

Diesel

Effective efficiency of the diesel (default is 0.33)

Transmission efficiency (default is 0.90)

Coefficient taking into account the diesel power consumption for equipment drive (by default 1.05)

Calorific value of diesel fuel, MJ/l (default is 43.12 MJ/l)

Diesel emission standard, EURO (default 5)

3. Trip data

Identifier of the trip in question

Passenger loads % by segments

Bus weight calculation type

☒ Fixed weight ☐ Depends on workload

Save edit

Figure 2 Opening the program file

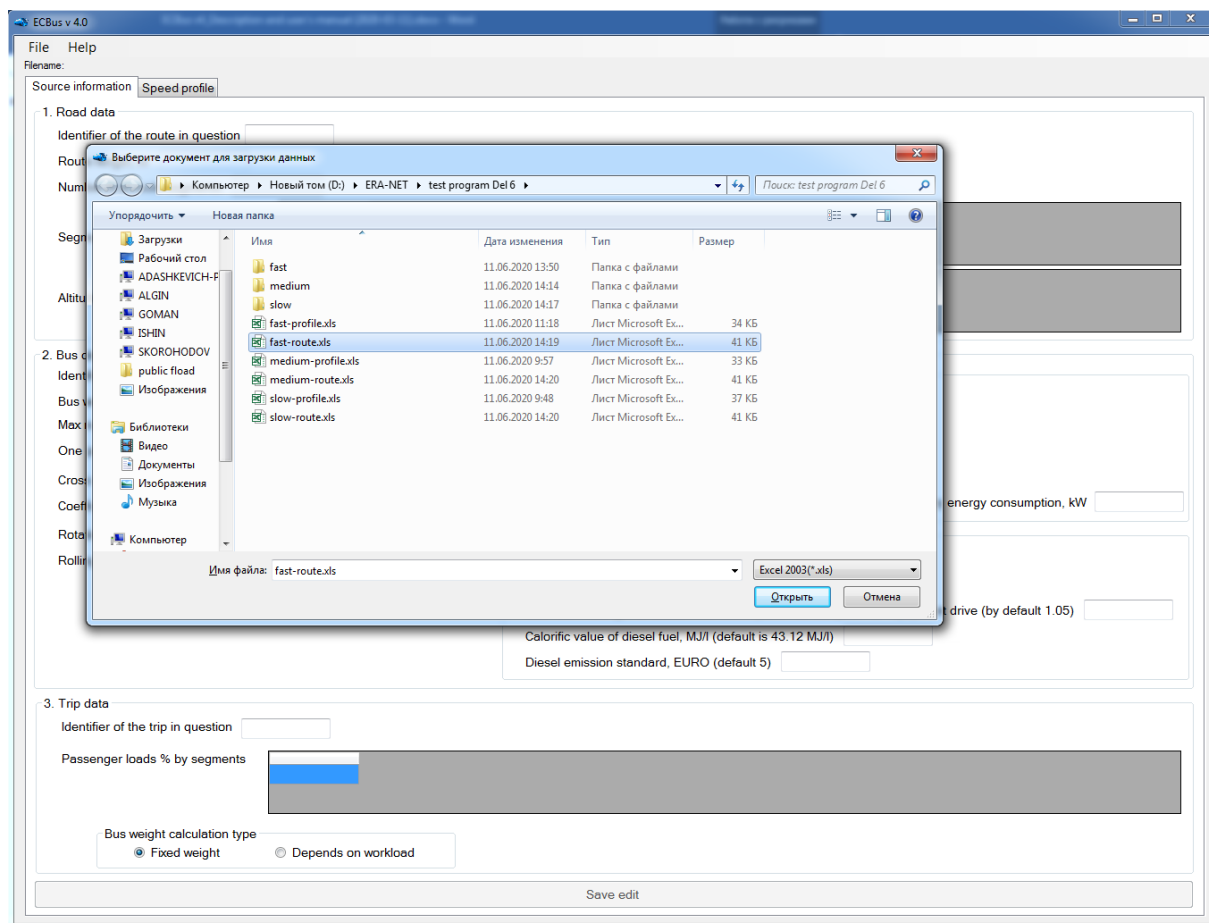


Figure 3 Selecting an openable file with a description of the road, bus and route

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Calculation identifier	1													
2															
3	1. Route description (Infrastructure)														
4	Road data														
5	Identifier of the route in question	1													
6	Route length, m	8232,5													
7	Number N of route segments	13													
8	Segments lengths														
9	Segment numbers 1, 2, ..., N	1	2	3	4	5	6	7	8	9	10	11	12	13	
10	Segment lengths s(1), s(2), ..., s(N), m	1095,8	515,5	1034,7	667,7	522,8	483,2	129,6	356,1	561,5	434,2	866,7	608,3	956,4	
11	Altitudes at the stopping points														
12	Stopping points 1, 2, ..., N+1	1	2	3	4	5	6	7	8	9	10	11	12	13	14
13	Altitudes at the stopping points h(1), h(2), ..., h(N+1), m	224	223	222	212	210	198	194	193	199	206	211	211	222	224
14															

Figure 4 An example of filling out the "Route description" template

	A	B	C
15	2. Bus data		
16	Identifier of the bus in question	1	
17	Bus weight without passengers, kg	15000	
18	Max number of passengers	80	
19	One passenger weight, kg (default is 70 kg)	70	
20	Cross section area (default is 6.6 m ²)	6,6	
21	Coefficient of air resistance (default is 0.4 Ns ² /m ⁴)	0,4	
22	Rotation inertia factor (default is 1.05)	1,05	
23	Rolling resistance (for planned types of bus tires and road surfaces) (default is 0.008 in summer)	0,012	
24	Electric		
25	Maximum electrical power of auxiliary system or its subsystems with battery energy consumption, kW	0	
26	Average efficiency of the inverter (default is 0.98)	0,98	
27	Average efficiency of the motor (default is 0.95)	0,95	
28	Average efficiency of the transmission (default is 0.95)	0,95	
29	Regeneration (recuperation) factor (default is 0.6)	0,85	
30	Diesel		
31	Effective efficiency of the diesel (default is 0.33)	0,33	
32	Transmission efficiency (default is 0.90)	0,9	
33	Coefficient taking into account the diesel power consumption for equipment drive (by default 1.05)	1,05	
34	Calorific value of diesel fuel, MJ/l (default is 43.12 MJ/l)	43,12	
35	Diesel emission standard, EURO	4	
36			

Figure 5 An example of filling out the “Bus data” template

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
37	3. Trip data													
38	Identifier of the trip in question	1												
39	Passenger loads by segments													
40	Segment numbers 1, 2, ... N	1	2	3	4	5	6	7	8	9	10	11	12	13
41	% of passenger load per segment	100	50	25	40	30	80	20	40	90	75	60	30	100

Figure 6 An example of filling out the “Trip data” template

	A	B	C	D	E
43	4. Fuel consumption and Ecology				
44	Standard	Carbon monoxide (CO)	Hydrocarbons (HC)	Nitrogen oxides (NO _x)	Particulate matter (PM)
45	Euro I	4,5	1,1	8	0,36
46	Euro II	4	1,1	7	0,15
47	Euro III	2,1	0,66	5	0,1
48	Euro IV	1,5	0,46	3,5	0,02
49	Euro V	1,5	0,46	2	0,02
50	Euro VI	1,5	0,13	0,4	0,01
51					

Figure 7 An example of filling out the “Fuel consumption and Ecology” template

The first section “Trip data” must be filled in the downloaded file, other values can be accepted by default.

Figure 8 shows the result of loading data from the file.

ECBus v 4.0

File Help

Filename: D:\ERA-NET\для теста энерг затрат по маршруту\test_program_ECBus_v4.0.xls

Source information Speed profile

1. Road data

Identifier of the route in question 1

Route length, m 8232.5

Number N of route segments 13

1	2	3	4	5	6	7	8	9	10
1095.8	515.5	1034.7	867.7	522.8	483.2	129.6	356.1	561.5	434.2

Segments lengths, m

1	2	3	4	5	6	7	8	9	10	11
224	223	222	212	210	198	194	193	199	206	211

Altitudes at the stopping points, m

2. Bus data

Identifier of the bus in question 1

Bus weight without passengers, kg 15000

Max number of passengers 80

One passenger weight, kg (default is 70 kg) 70

Cross section area (default is 6.6 m²) 6.6

Coefficient of air resistance (default is 0.4 Ns²/m⁴) 0.4

Rotation inertia factor (default is 1.05) 1.05

Rolling resistance (for planned types of bus tires and road surfaces) (default is 0.008 in summer) 0.012

Electric

Average efficiency of the inverter (default is 0.98) 0.98

Average efficiency of the motor (default is 0.95) 0.95

Average efficiency of the transmission (default is 0.95) 0.95

Regeneration (recuperation) factor (default is 0.6) 0.85

Maximum electrical power of auxiliary system or its subsystems with battery energy consumption, kW 0

Diesel

Effective efficiency of the diesel (default is 0.33) 0.33

Transmission efficiency (default is 0.90) 0.9

Coefficient taking into account the diesel power consumption for equipment drive (by default 1.05) 1.05

Calorific value of diesel fuel, MJ/l (default is 43.12 MJ/l) 43.12

Diesel emission standard, EURO (default 5) 4

3. Trip data

Identifier of the trip in question 1

Passenger loads % by segments

1	2	3	4	5	6	7	8	9	10	11
100	50	25	40	30	80	20	40	90	75	60

Bus weight calculation type

☒ Fixed weight ☐ Depends on workload

Save edit

Figure 8 Downloaded data

If there is a need to make changes to the data displayed in Figure 8, you must perform the following steps:

- 1) edit the necessary data;
- 2) click the "Save edit" button.

After that, updated data will be used for calculation, which will also be saved in the file.

Downloading a file containing a speed profile

To download a file containing a speed profile, click "File" -> "Open file containing speed profile" (Figure 9), then select the required file and click "Open" (Figure 10).

A file containing data describing the speed profile must be created in Excel and have the extension *.xls. Figure 11 shows an example of filling a file with a speed profile: values of time (s), and speeds (km per hour), corresponding to time values.

ECBus v 4.0

File Help

Open

Open file containing speed profile

test_program_ECBus_v4.0.xls

1. Road data

Identifier of the route in question 1

Route length, m 8232.5

Number N of route segments 13

1	2	3	4	5	6	7	8	9	10
1095.8	515.5	1034.7	667.7	522.8	483.2	129.6	356.1	561.5	434.2

Segments lengths, m

1	2	3	4	5	6	7	8	9	10	11
224	223	222	212	210	198	194	193	199	206	211

Altitudes at the stopping points, m

2. Bus data

Identifier of the bus in question 1

Bus weight without passengers, kg 15000

Max number of passengers 80

One passenger weight, kg (default is 70 kg) 70

Cross section area (default is 6.6 m²) 6.6

Coefficient of air resistance (default is 0.4 Ns²/m⁴) 0.4

Rotation inertia factor (default is 1.05) 1.05

Rolling resistance (for planned types of bus tires and road surfaces)
(default is 0.008 in summer) 0.012

Electric

Average efficiency of the inverter (default is 0.98) 0.98

Average efficiency of the motor (default is 0.95) 0.95

Average efficiency of the transmission (default is 0.95) 0.95

Regeneration (recuperation) factor (default is 0.6) 0.85

Maximum electrical power of auxiliary system or its subsystems with battery energy consumption, kW 0

Diesel

Effective efficiency of the diesel (default is 0.33) 0.33

Transmission efficiency (default is 0.90) 0.9

Coefficient taking into account the diesel power consumption for equipment drive (by default 1.05) 1.05

Caloric value of diesel fuel, MJ/l (default is 43.12 MJ/l) 43.12

Diesel emission standard, EURO (default 5) 4

3. Trip data

Identifier of the trip in question 1

Passenger loads % by segments

1	2	3	4	5	6	7	8	9	10	11
100	50	25	40	30	80	20	40	90	75	60

Bus weight calculation type

☒ Fixed weight ☐ Depends on workload

Save edit

Figure 9 Opening the file with the speed profile using the menu

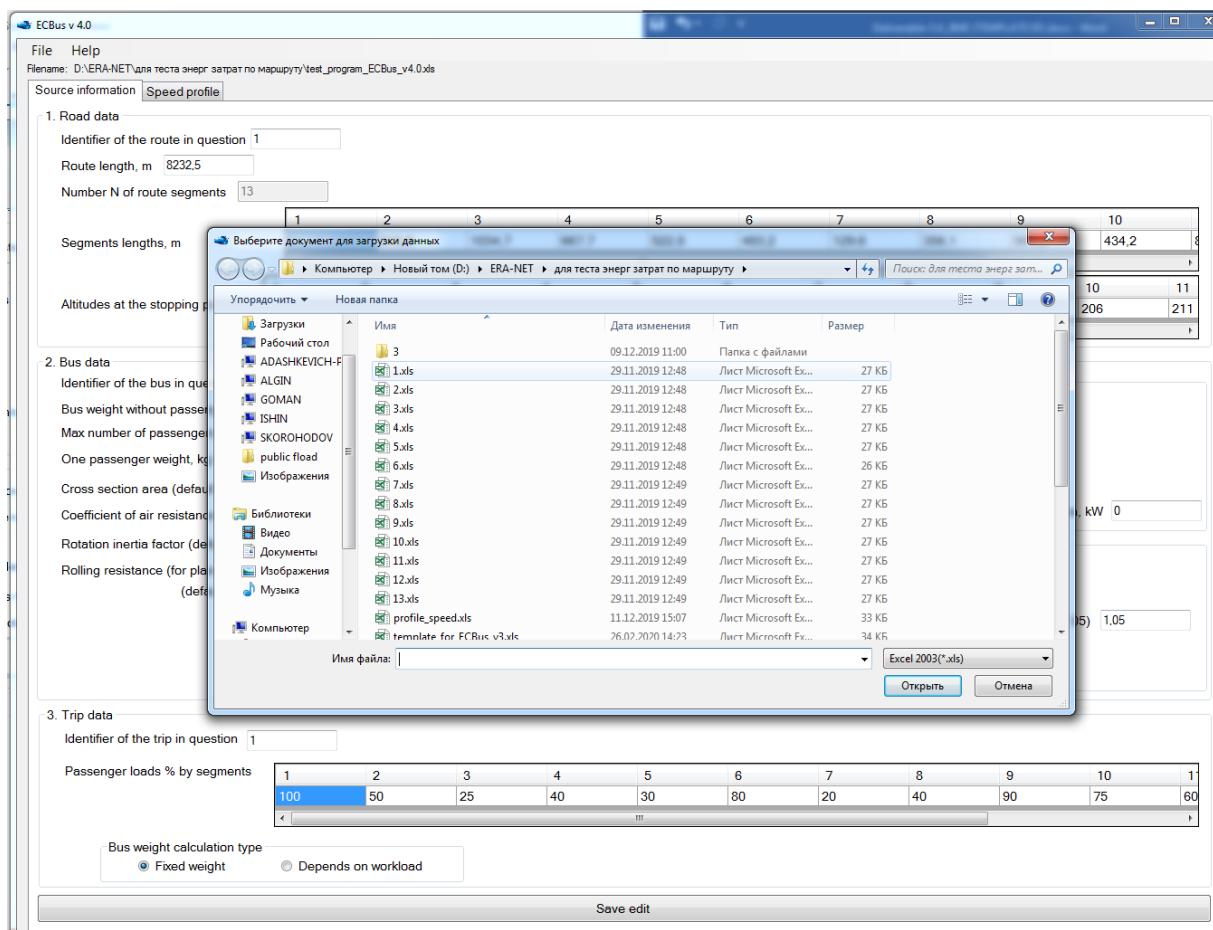


Figure 10 Selecting a file containing a speed profile

	A	B	C	D	E	F	G	H	I	J
1	t, s	v, km/h								
2	0,00	0,0								
3	5,00	21,9								
4	10,30	17,2								
5	21,64	42,2								
6	42,49	0,0								
7	58,42	0,0								
8	64,12	20,2								
9	69,92	6,3								
10	86,49	37,0								
11	99,07	8,2								
12	111,56	38,7								
13	124,12	8,6								
14	137,85	43,5								
15	140,95	17,2								

	A	B	C	D	E	F	G	H	I	J
1	t, s	0,00	5,00	10,30	21,64	42,49	58,42	64,12	69,92	
2	v, km/h	0,0	21,9	17,2	42,2	0,0	0,0	20,2	6,3	

Figure 11 Views of Excel-files with speed profiles: vertical or horizontal tables

Switching the user to the tab “Speed profile”

After loading the speed profile and switching the user to the tab “Speed profile”, a graphical representation of the speed profile from the downloaded file is displayed on the tab “Speed profile of the chart” (Figure 12).

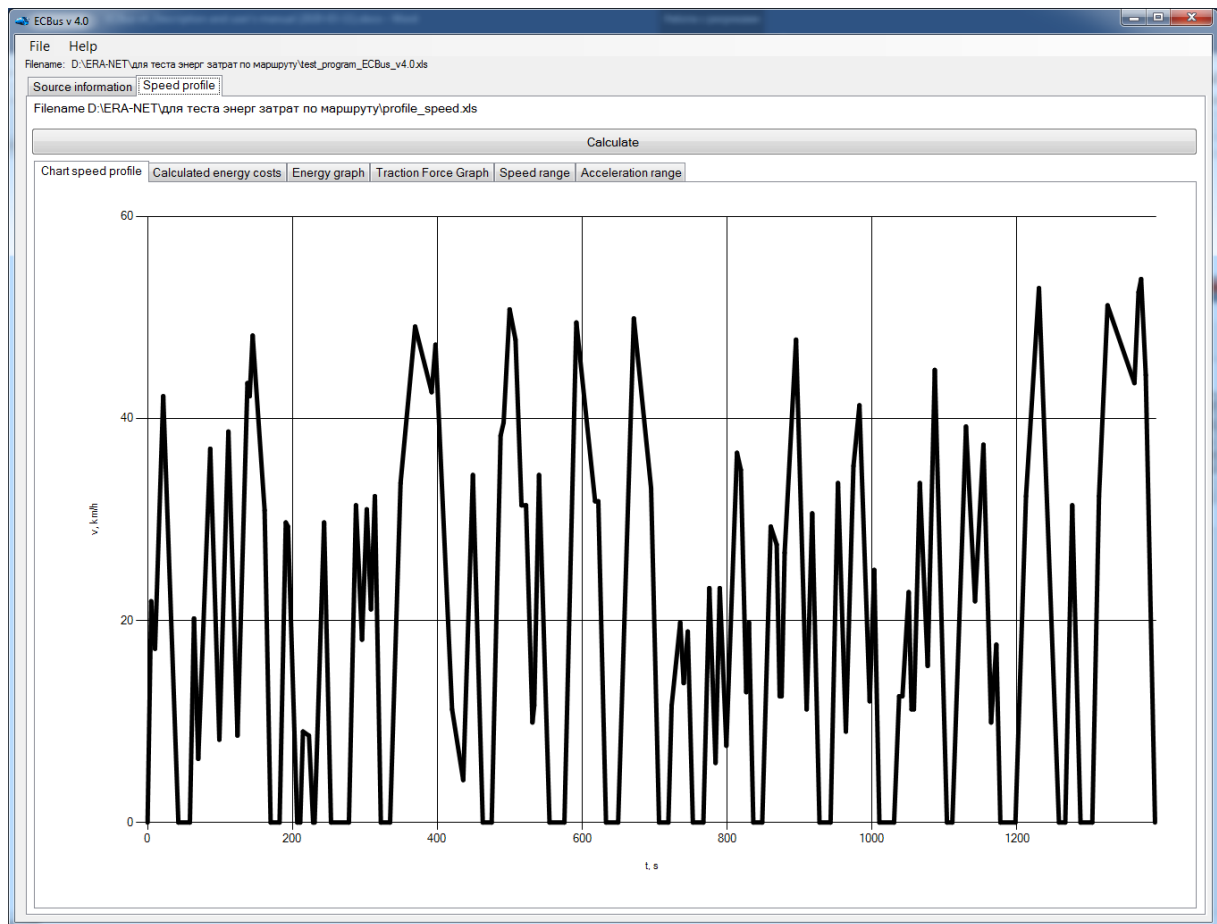


Figure 12 Speed profile and its graphical representation

Calculating

Before clicking on the “Calculate” button, it is necessary to select the method of weight accounting: fixed weight or changing weight on each segment depending on the passenger load (%). A button for the choice of weight is located on the tab “Source information”.

To calculate energy costs when driving a bus on the route, you must click “Calculate”.

6 The outputs of the ECBus

After calculating and switching to the tab “Calculated energy costs”, the following data are displayed: path length, calculated according to the speed profile, energy expended for movement, recuperated energy, total energy consumption for movement, specific consumption, energy consumption for heating / cooling the bus compartment and driver’s cabin, energy costs for heating / cooling and movement, the total energy taking into account heating / cooling as well as the specific energy consumption in this case, diesel energy consumption (kWh), fuel consumption (liters per route), fuel consumption (liters per 100 km), pollutant emission (g) for the route: CO, HC, NO_x, PM. The results of the calculations of these parameters are presented in Figure 13.

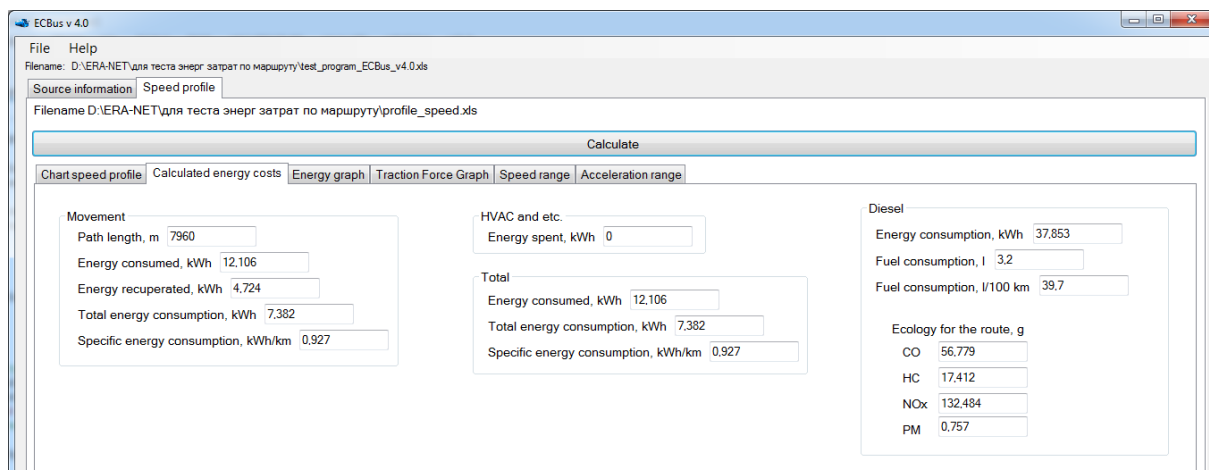


Figure 13 Results of energy calculations

Energy graphs

After switching to the tab “Energy graph”, the graphs of changes in the consumed, recovered, total (resulting) energies for electric and diesel energy consumption are displayed (Figure 14).

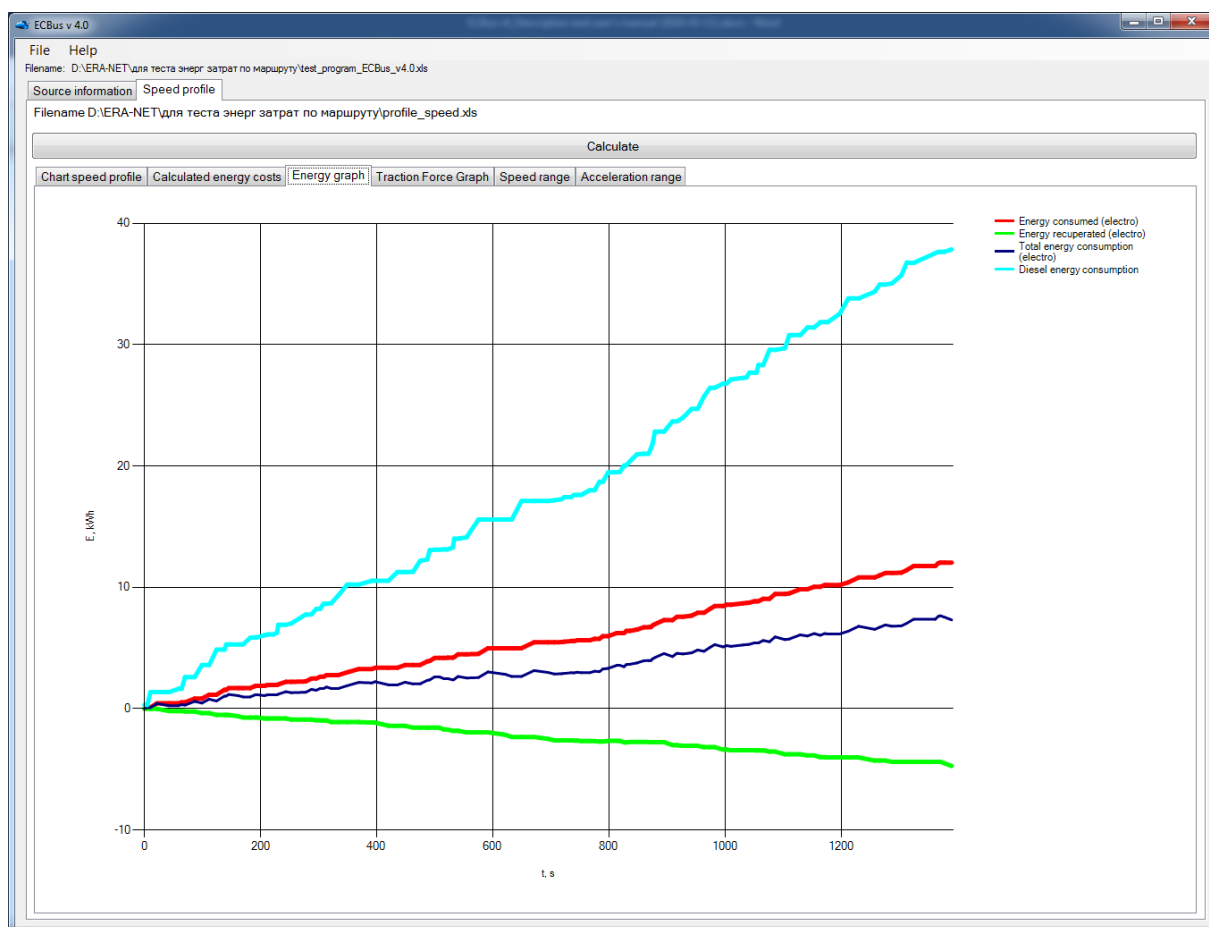


Figure 14 Graphs of energy changes

Traction force graph

To view the graph of change in the traction force, you must go to the tab “Traction Force Graph” (Figure 15).

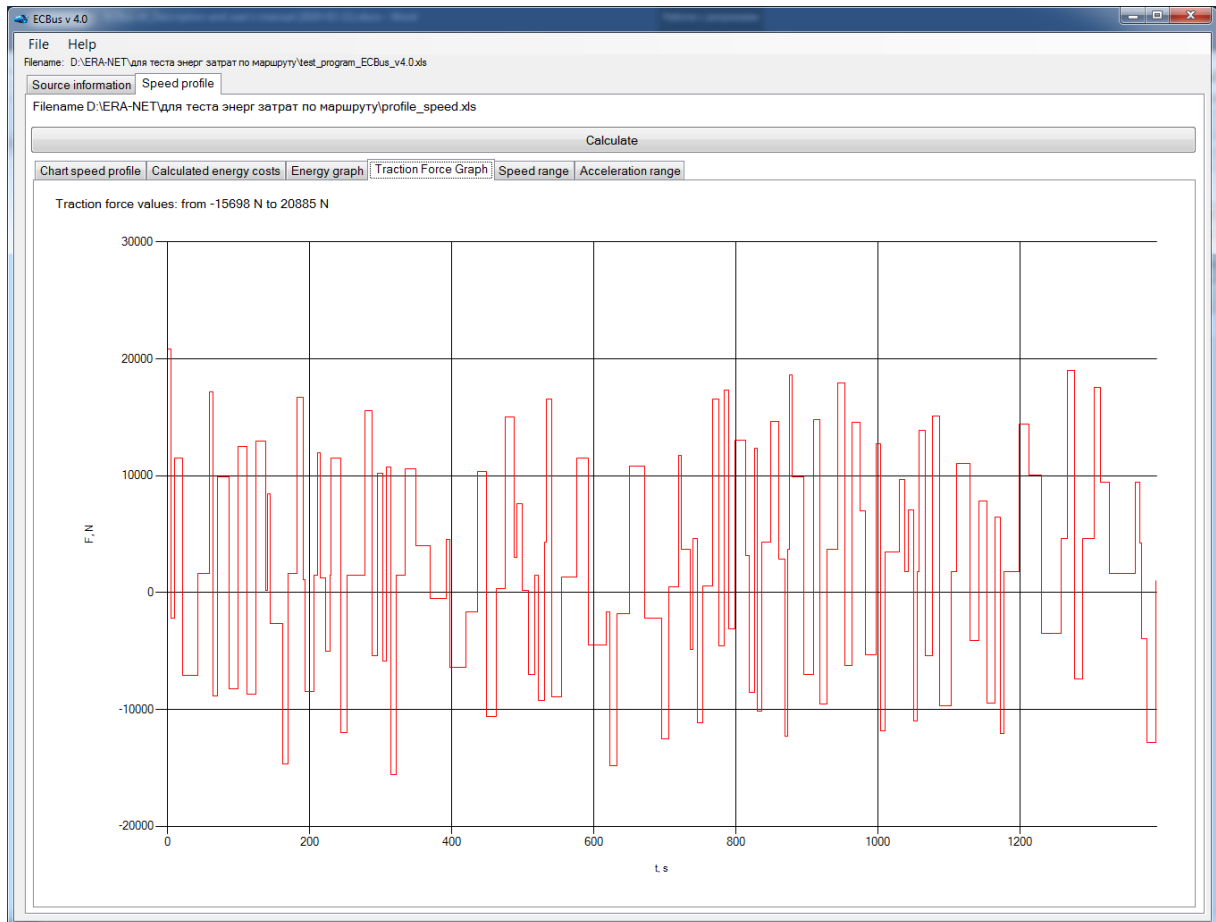


Figure 15 Graph of change in traction force

Histogram of the speed distribution

A histogram of the speed distribution is displayed after the switching to the tab «Speed range» (Figure 16).

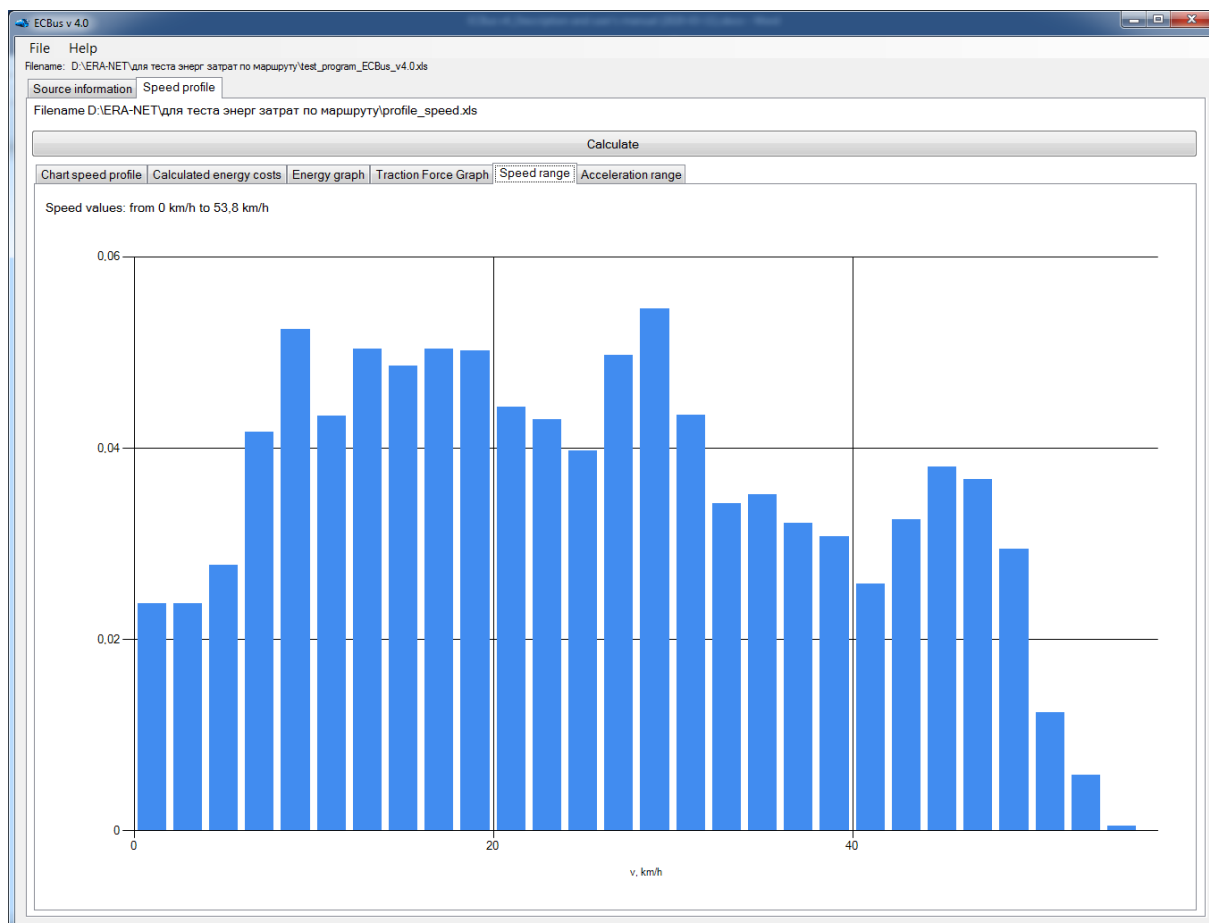


Figure 16 Histogram of the speed distribution

Accelerations distribution

After switching to the tab “Acceleration range”, a histogram of the distribution of accelerations is displayed (Figure 17).

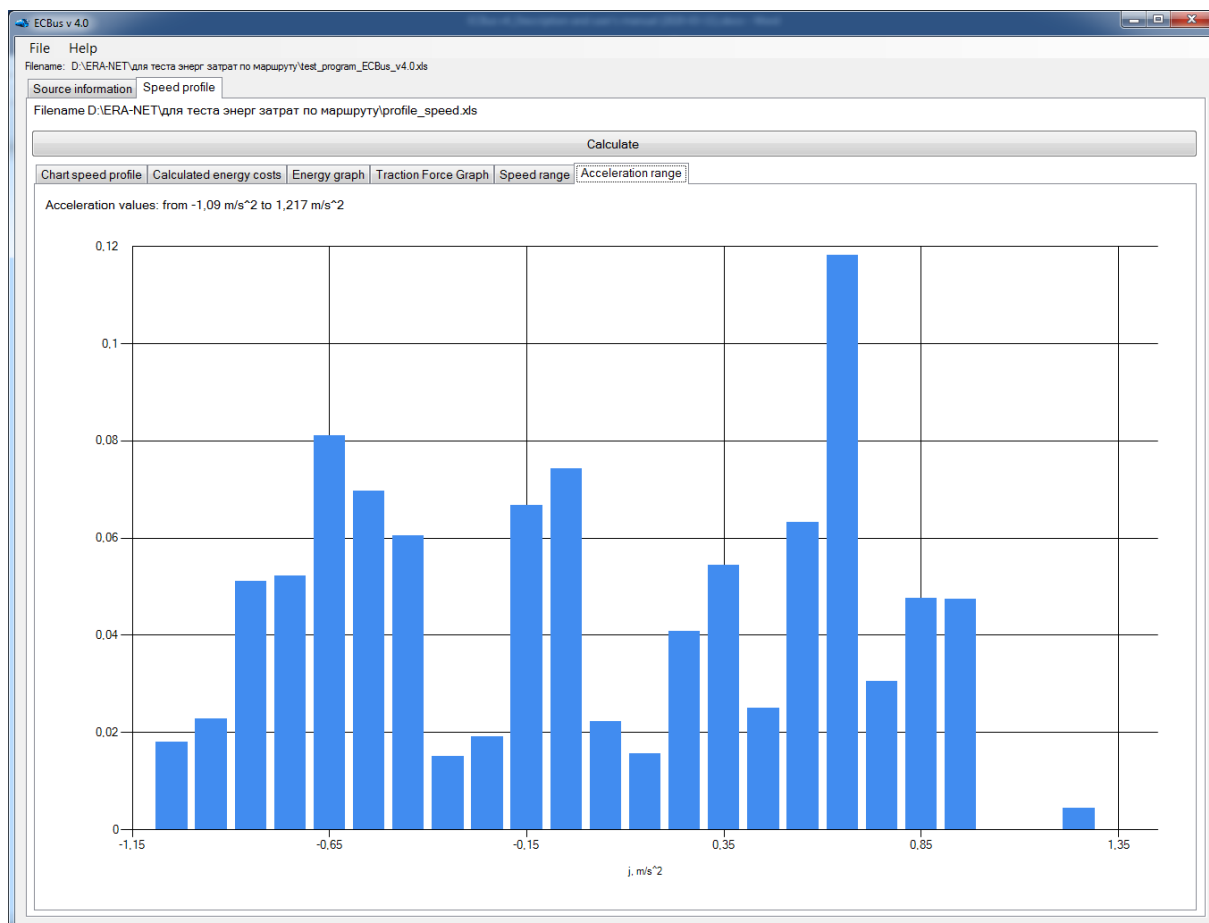


Figure 17 Histogram of the accelerations distribution

7 Information about the organization-developer

After switching “Help” -> “About”, information about the organization-developer of the program will be displayed (Figure 18).

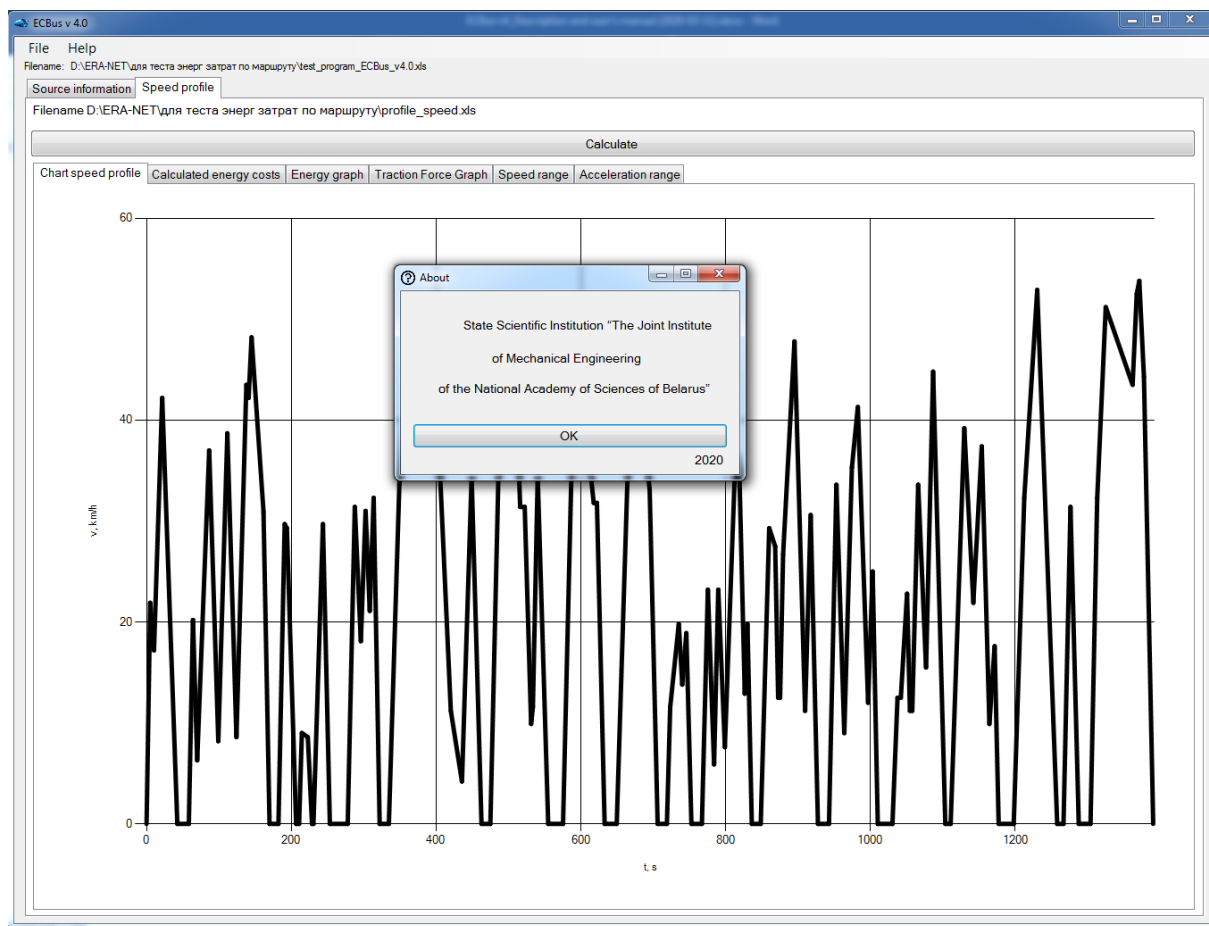


Figure 18 Organization-developer

References

1. Algin V., Goman A., Skorokhodov A. (2019) *Main Operational Factors Determining the Energy Consumption of the Urban Electric Bus: Schematization and Modelling*. In: *Topical issues of mechanical engineering: Collection of scientific papers*, Minsk, iss. 8, pp. 185-194. DOI: 10.13140/RG.2.2.32154.80328, 2019.