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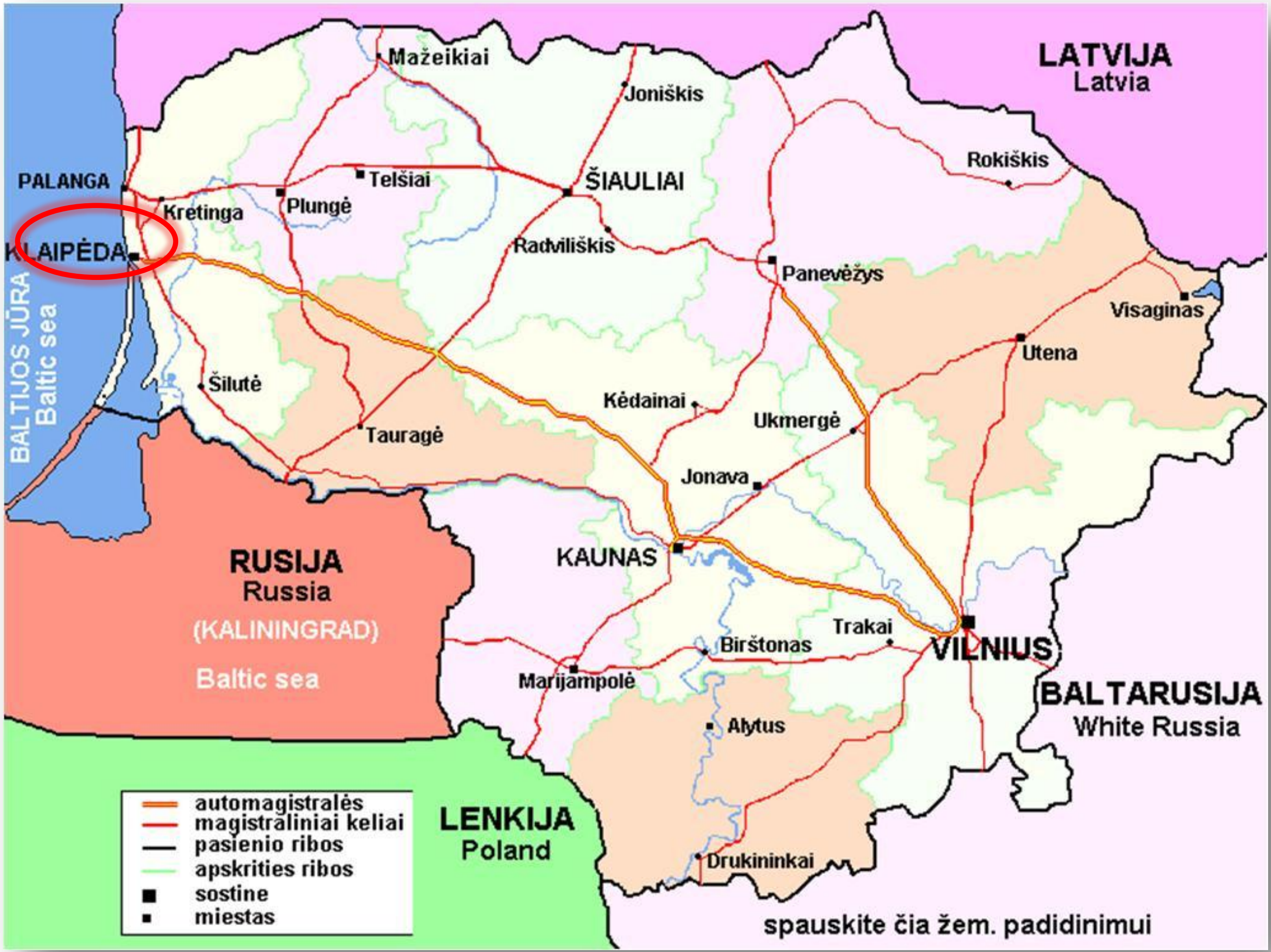
RESEARCH ON E-BUS ENERGY CONSUMPTION AND MOBILE POWER SOURCE CAPACITY OPTIMIZATION EVALUATING REGENERATIVE ENERGY

Klaipeda university

(JSC “Vėjo projektai”)

Prof. dr. Eleonora Guseinoviene


LATVIJA
Latvia
Mažeikiai
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PALANGA
Telšiai
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Kretinga
Plungė
KLAIPĖDA
Radviliškis
Panevėžys
Visaginas
BALTIJOS JŪRA
Baltic sea
Utena
Šilutė
Kėdainai
Ukmergė
Tauragė
Jonava
KAUNAS
RUSIJA
Russia
(KALININGRAD)
Baltic sea
Trakai
Birštonas
VILNIUS
Marijampolė
BALTARUSIJA
White Russia
Alytus
LENKIJA
Poland
Drukininkai
automagistralės
magistraliniai keliai
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sostine
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Klaipeda is the third city in Lithuania after Vilnius and Kaunas in terms of size and population. Square 98 km2, population 180 400 (2011)

Klaipeda university

(faculties are situated in the main campus and a few different parts of the city)

Content

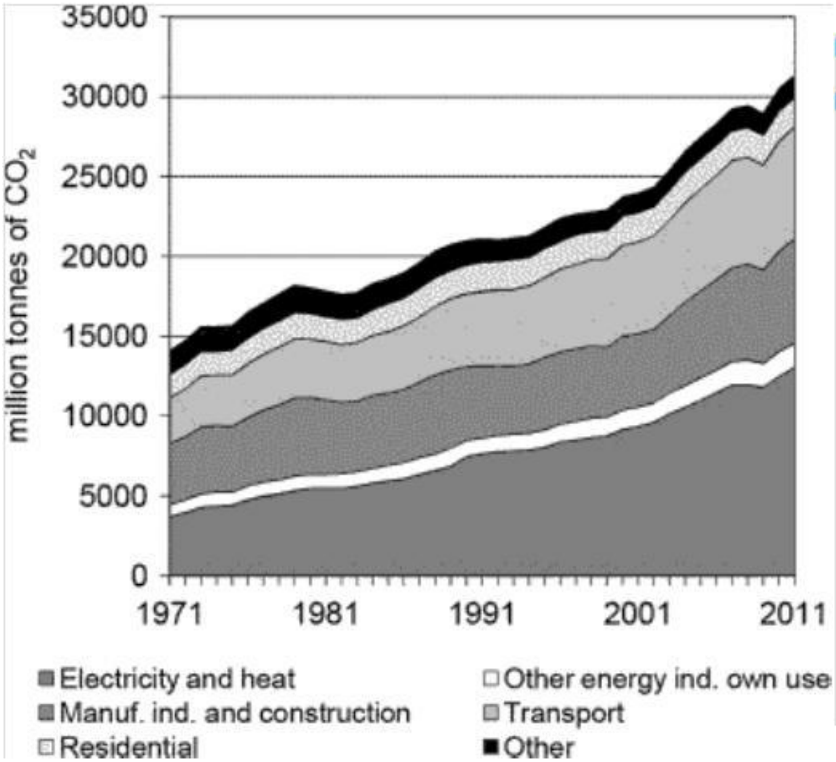
The world moves towards the reduction of CO2 gas emissions and creation of alternative means of transport primary energy forms. One of the forms of energy - electric, may be effectively transferred to mechanical energy using electric motors. This work provides public transport buses of category M3 energy consumption analysis and compares with electricity powered the same category vehicles energy consumption. Compared to the internal combustion engine, electric motor can switch to generator operating mode, which allows the vehicles kinetic energy regeneration and to store in mobile electric energy storage.

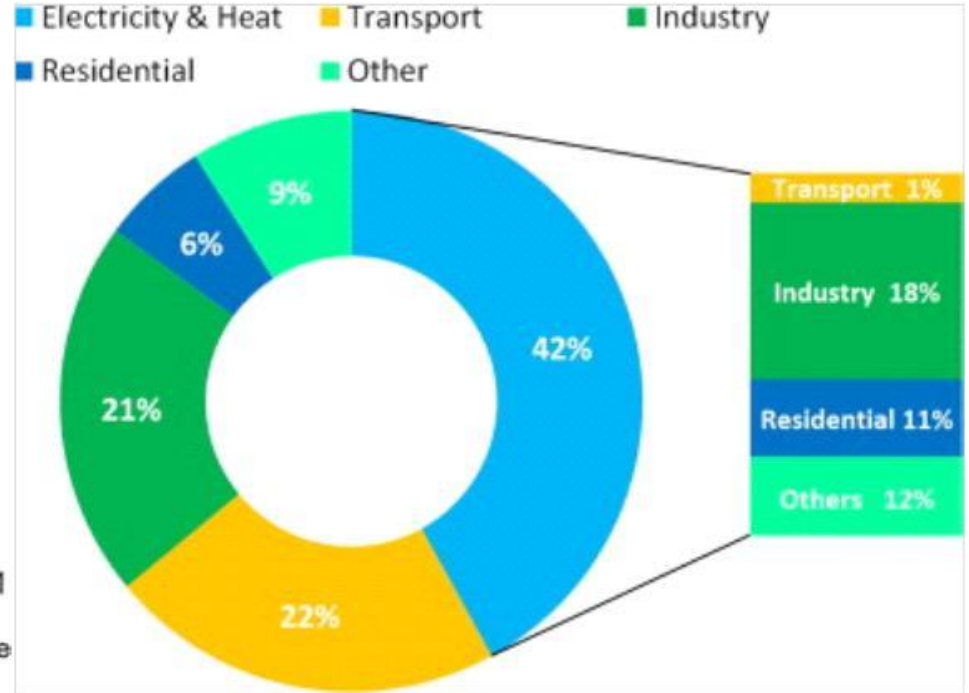
Performed e-bus driving tests in Klaipeda city, while working devices' data is collected and later analyzed, perform calculations of energy costs. An optimization was performed of the battery capacity for specified route and estimation of consumption impact.

Abbreviations

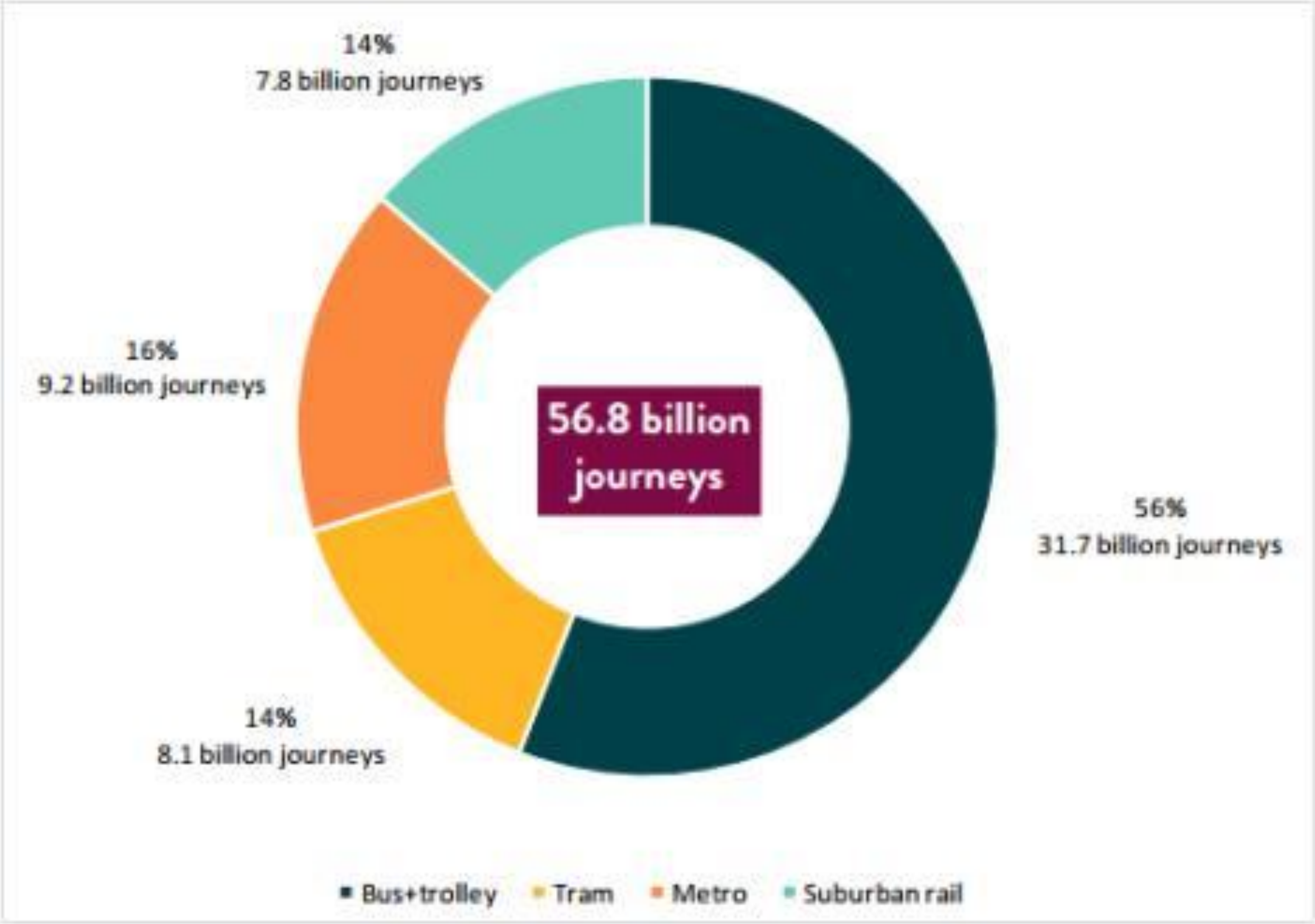
APD – Automatic gear box (automatinė pavarų dėžė)
BMS – Battery management system
CAN – Controller area network
DC – Direct current
DI – Digital input
DO – Digital output
ES – European Union (Europos sąjunga)
FCS – Fuel cell system
GHG – Greenhouse gas
I/O – Input/Output
USB – Universal serial bus
VDV – Internal combustion engine (Vidaus degimo variklis)

Introduction

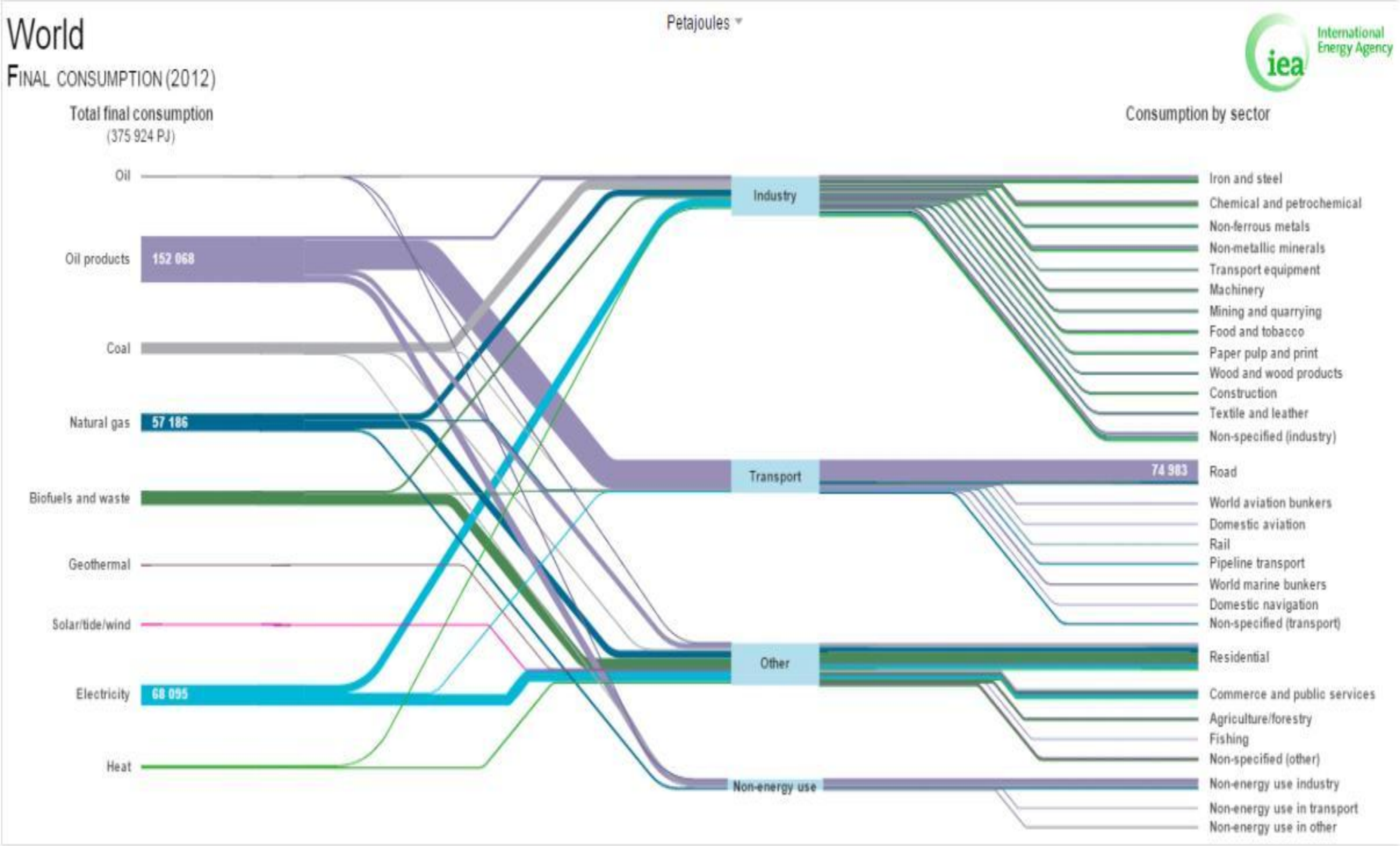




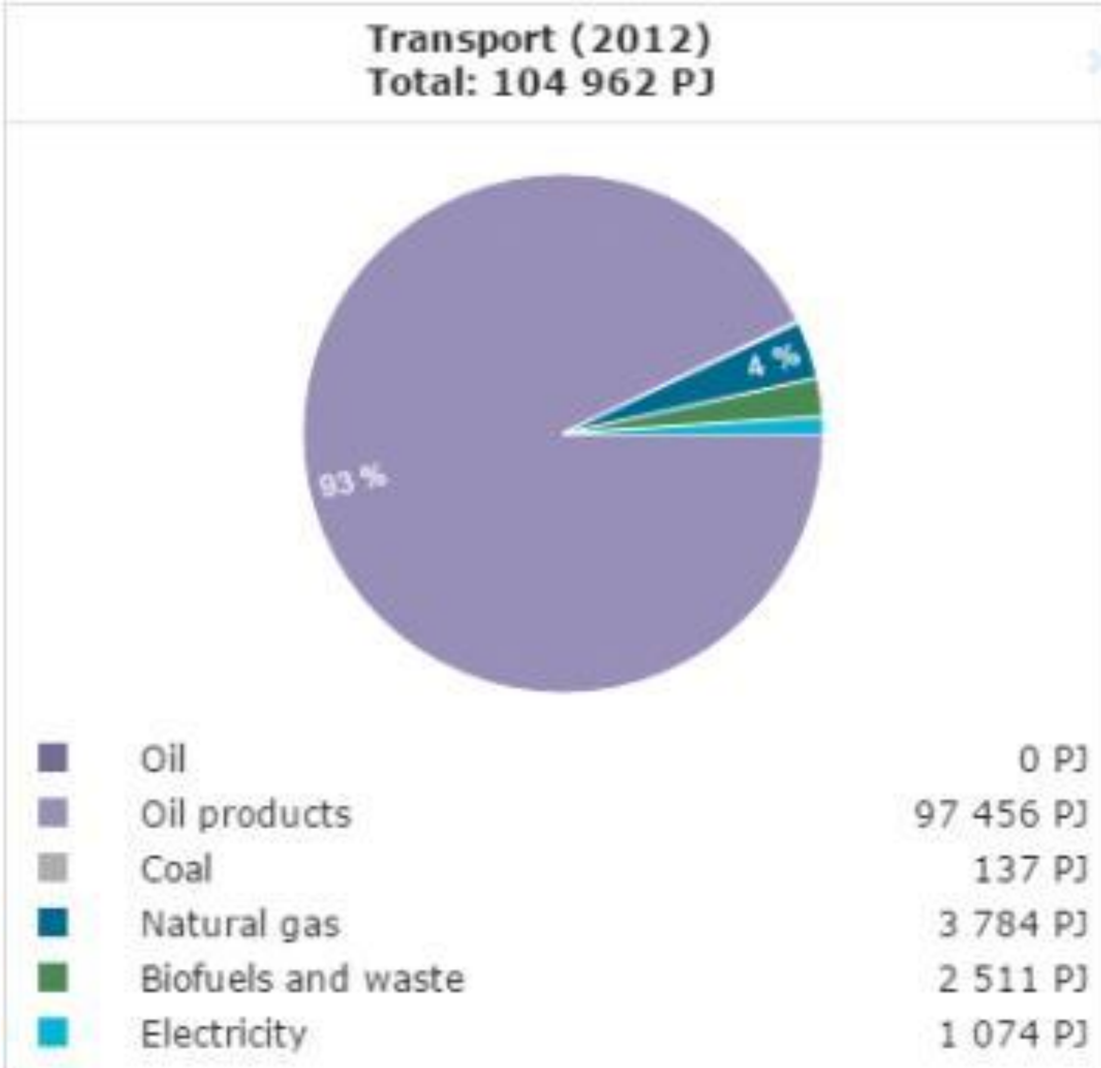
CO2 emission world tendencies up to 2011 and after 2011. According to statistics, energy consumption and CO2 emission is increasing and the main users are industry and transport



Distribution of public transport (ES, 2012)



Consumption by sector (2012)



Distribution of energy type used in transport in the world (2012)

Object of investigation

M3 category electro bus, typeTR14M, re-designed from Škoda TR14 trolley (made in1983) in Klaipeda by JSC „Vėjo projektai“; the drive motors having the structure, which consists of mobile electrical storage system – battery with LiFePO4 chemical cells, DC/AC converter and one synchronous electrical motor with permanent magnets that is connected mechanically to rear axle differential

The main parameters of trolley TR14 and designed prototype TR14M

Characteristics	***TR14***	***TR14M***
Nominal power of electrical motor, kW	100	130
Max torque, Nm	-	500 (1150)
Tires	205/80 R22,5	205/80 R22,5
Weight without load, kg	10 300	9 000
Max load, kg	7 220	8 220
Max weight with load, kg	17 520	17 520
Front axle load, kg	4 500	4 000
Max front axle load, kg	6 500	6 500
Rear axle load, kg	5 800	5 300
Max rear axle load, kg	11 020	11 020
Length, mm	11 340	11 380
Width, mm	2 500	2 560
Height, mm	3 410	3 410

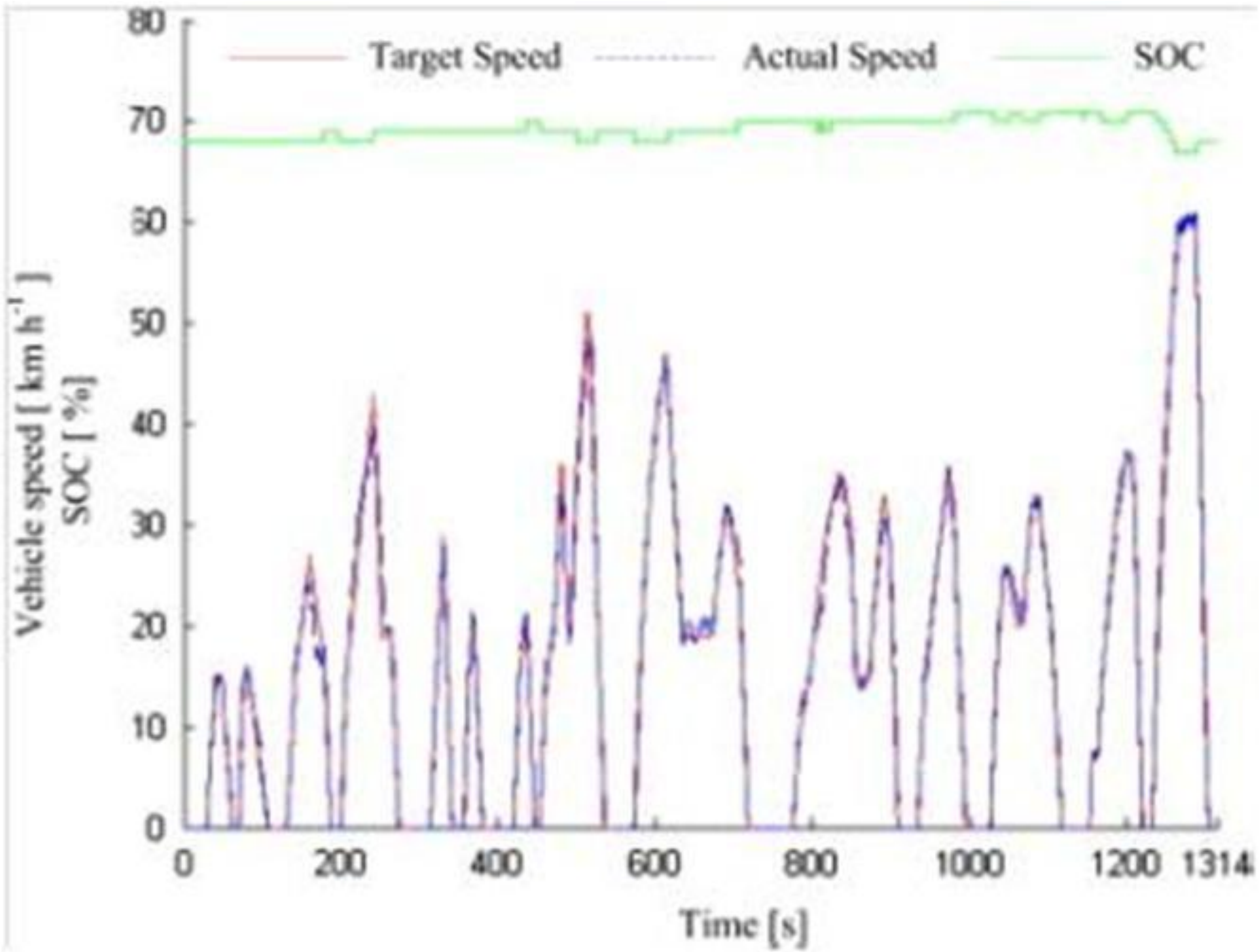
The main aim was:
To make a research on e-bus energy consumption and mobile power source capacity optimization evaluating regenerative energy (public transport buses of category M3)

Tasks:
Analysis of current situation and solutions
Methodics
Real experimental
Analysis of the results and recomendations

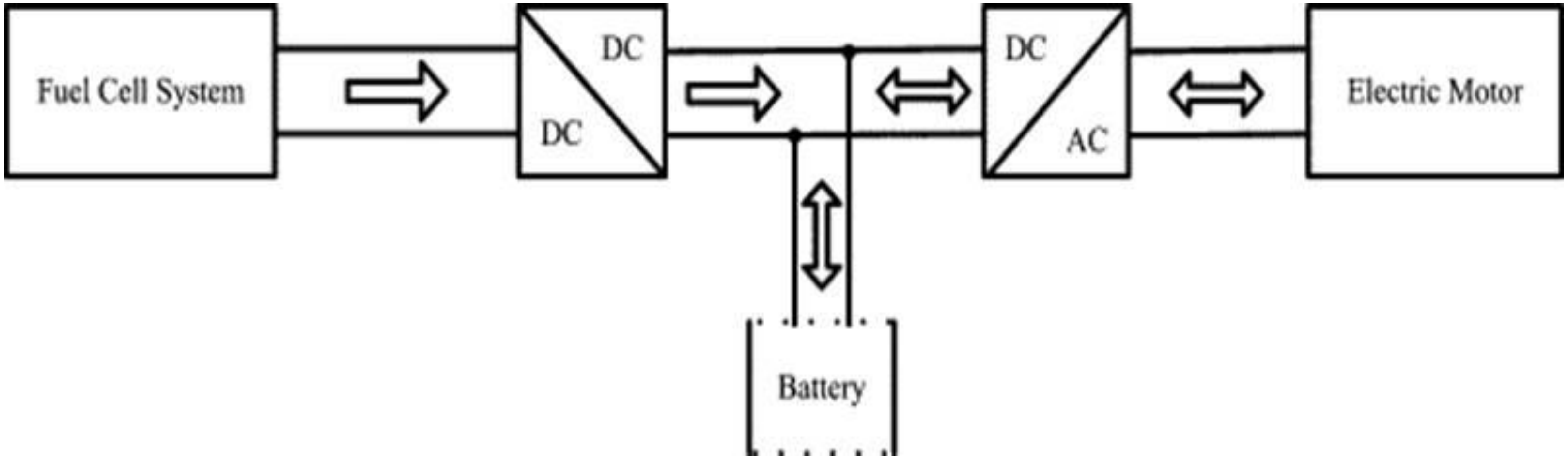
Methods:
Experimental investigation in three different routes
Data mining using CAN bus, DL1 with GPS and dynamic acceleration sensor
„MathWorks MATLAB“ and „Microsoft EXCEL“ software

Analysis of current situation

shows, that economy of hydrogen was researched by scientists from Tsinghua universitety in China. They made investigation on hydrogen economy in fuel cells of hybrid electro bus when using created algorithm for braking mode with energy regenerative function. Energy cannot be transferred to the fuel cell system, so mobile electrical storage system (batteries or super capacitors) is connected in parallel in order to store regenerative energy when braking mode. FCS and motor are separated using converters



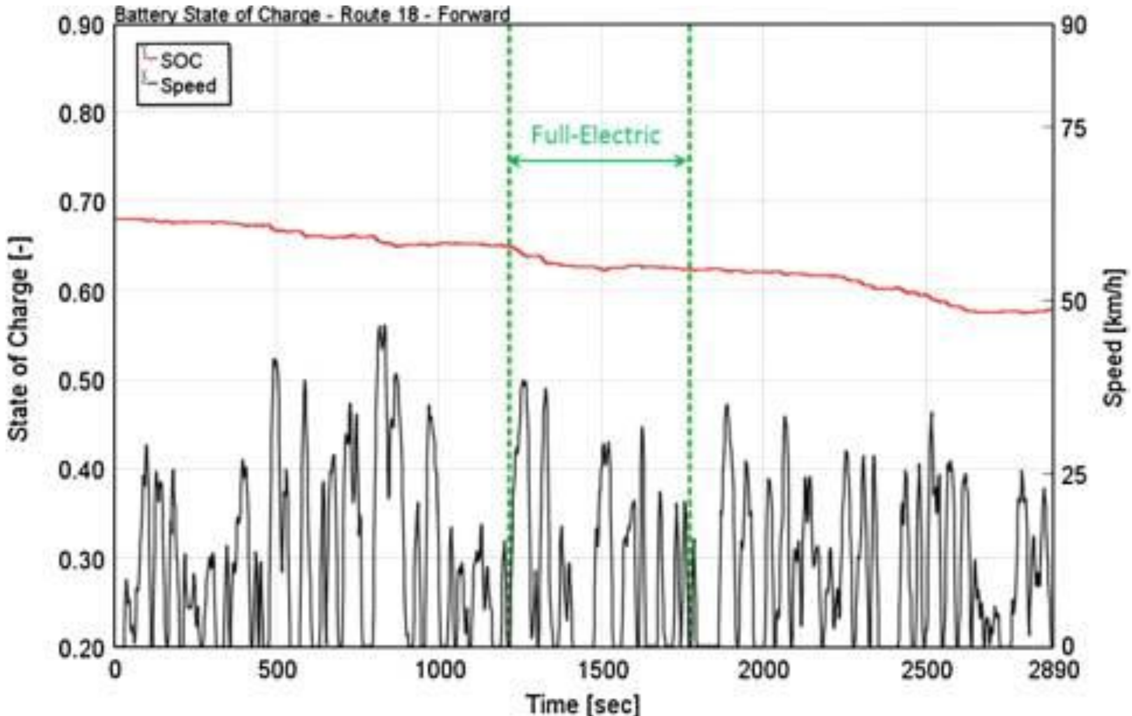
Typical buses driving cycle in the cities in China



Configuration of FCSB system and energy flows

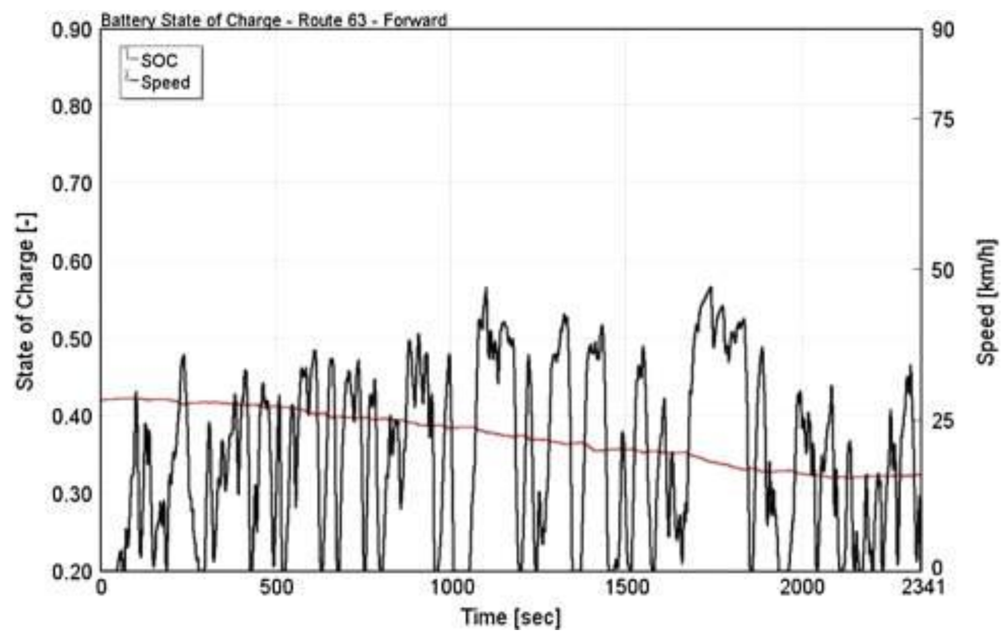
Study shows that consumption of hydrogen decreased by 16% (when coordinating control algorithm for the brake pedal), and 9% (when parallel regenerative braking algorithm)

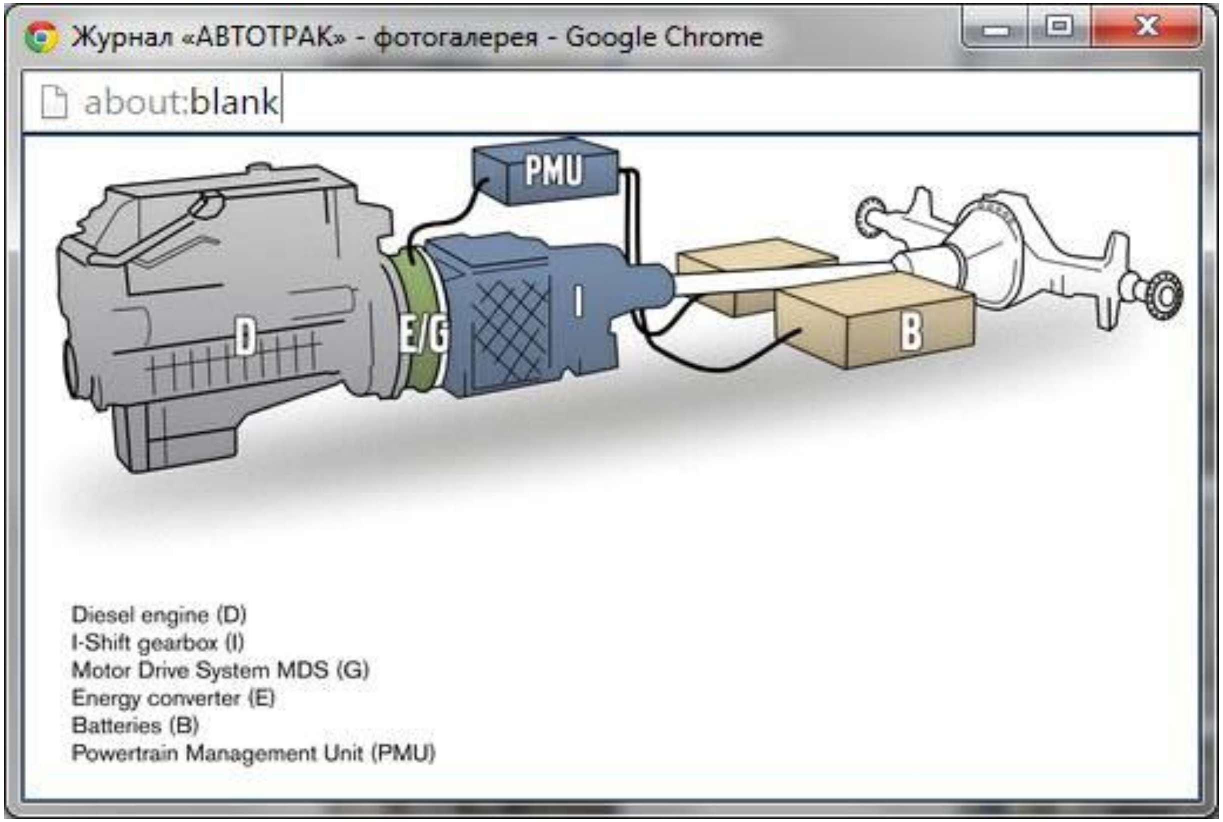
Different types of batteries were used as well: Li batteries have more advantages in comparison with Ni-Mh (Nickel–metal hydride) batteries, so hydrogen economy increased by 11,5% due to decreasing losses in batteries. Weight was not taken into account



Scientists from Turino together with company “Pininfarina” made an experiment in Genua, Italy and calculated economy of diesel fuel in hybrid prototype in comparison with typical bus

Data: The route Nr.18, average speed 11 km/h, length 9,4 km, hillside ±5%, 3,5 stops/km. Hybrid prototype system allows to save 27–45% fuel consumption in comparison with typical bus. Experiment was repeated with the route Nr.63)





Parallel type hybrid drive (combination of internal combustion engine with an electrical motor/generator) has an advantage when decreasing fuel consumption; implementation of such a system gives 25–50% economy.
Many companies: VOLVO (Sweden), IVECO (Italy), DAF (Netherlands), RENAULT (France), MERCEDES-BENZ , MAN (Germany), MITSUBISHI , HINO, ISUZU (Japan), PETERBILT (USA) have been working on different systems in order to decrease fuel consumption, to increase energy saving etc.

Experiment was realized using:

- feedback rotational speed, pressure, current (Hall sensors), voltage, temperature sensors, vibration acceleration sensors
- Speed measurement encoder RM44
- Hall sensors installed in the battery BMS
- Temperature sensors mounted in electric motor (PT100) inverters, batteries
- GPS and accelerometer data logger “Race Technology DL1 MK2“
- Protocol converter DIGA “CRUSB” and its software CANstudio3 Pro (from CAN to USB interface)
- „Race technology analysis software – v8.5”
- Devices for measuring temperature, pressure, voltage, current
- Etc.

Mobile power supply – 600V-cell LiFePO4 battery with BMS's proprietary monitoring system and the climate control, internal temperature, current and voltage sensors, contactors and fuses. CAN communication CANopen 401 protocol is attached

Parameter	Value	Notes
System		
Model	EBattery™ 690	
Type	23s8s3p	
Total cell count	552	
Cell chemistry	LiFePO4	
Module		
Model	EBattery30	
Type	8s3p	
Dimensions (W x H x L)	170 x 317 x 428	
Weight	32 kg	

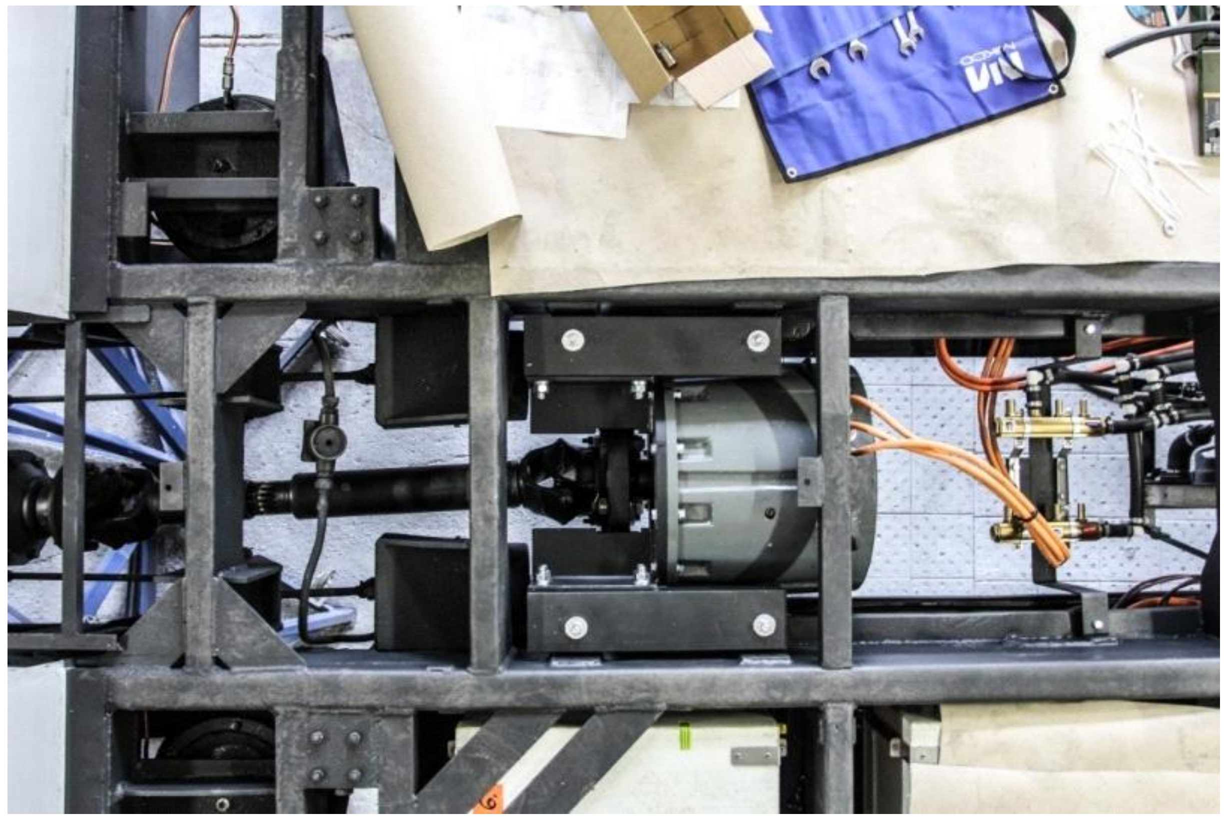
Electrical specification		
Cell voltage:		
Nominal	3,20 V	@ C/5 discharge
Maximum charge	3,55 V	
Minimum discharge	2,50 V	
Battery voltage:		
Nominal	588,8 V	@ C/5 discharge
Maximum charge	653,2 V	
Minimum discharge	460,0 V	
Battery capacity (@ C/5 discharge)	126 Ah	IEC 62660-1 (7.2)
Charge current:		
Nominal	14 A	Charger max. 14 A
Maximum	14 A	32 A charger fuse
Max. regenerative current	126 A	Cell max. Voltage limit
Discharge current:		
Recommended	126 A	
Maximum continuous	235 A	
Maximum (1 s pulse)	350 A	350 A main fuse
Battery energy capacity	75,4 kWh	
Balancing capacity	0.9 % / h	
Insulation resistance	TBD	Between cooling fins an terminals @ TBD V

Environment		
Operating temperature: Charge Discharge	 0° to +60° C -20° to +60° C	Inside module. Non-con noncorrosive humidity.
Storage temperature Continuous Temporary (48 h)	 -30° to +45° C -40° to +60° C	Non-condensing, nonco humidity.

24V I/O signal module

Liquid cooled power converter
"PowerMASTER"

VISEDO „PowerDRUM XS-frame“ motor



Motor was mounted on the frame

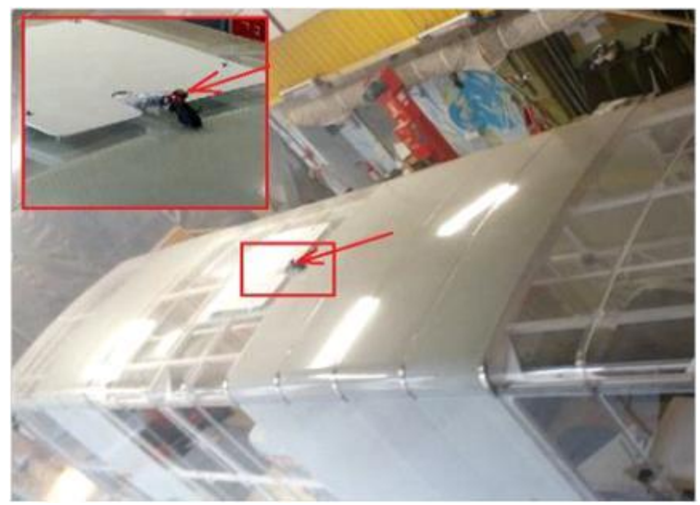
SPECIFICATIONS	Nominal Speed	Nominal Torque	Nominal Power	Nominal Current	Maximum torque	Nominal Frequency
MODEL						
PDR-XS-2700-T470	2650	470	130	160	1150	265

Mechanical		**Temperature rating**	
Weight	160 kg	Insulation class (IEC 60034-1)	F
Moment of inertia	0.44 kgm^2	Temperature rise (IEC 60034-1)	80°C
Maximum torque on the shaft	2000 Nm	**(At nominal ambient temperature)**	
Maximum allowed speed	4000 rpm	Temperature sensors	1 x PT100 stator win
General electrical properties			
Nominal voltage (line to line)	500 V	Nominal ambient temperature (IEC 60034-1)	+40°C

CAN bus data analyzer „DIGA CRUSB v1”

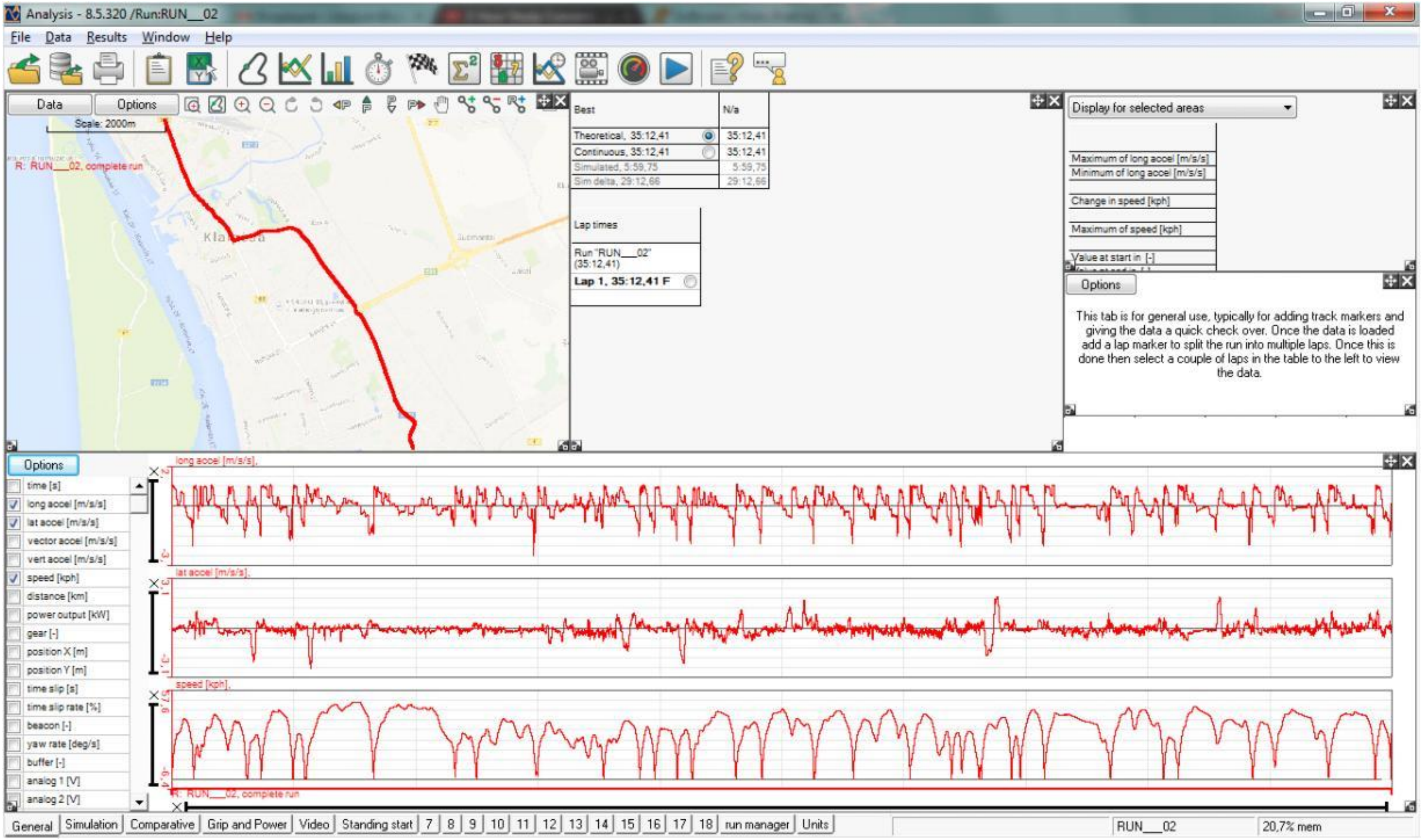
The scheme of normal operating of DL1 data logger

DL1–MK2 data logger (Race Technology)



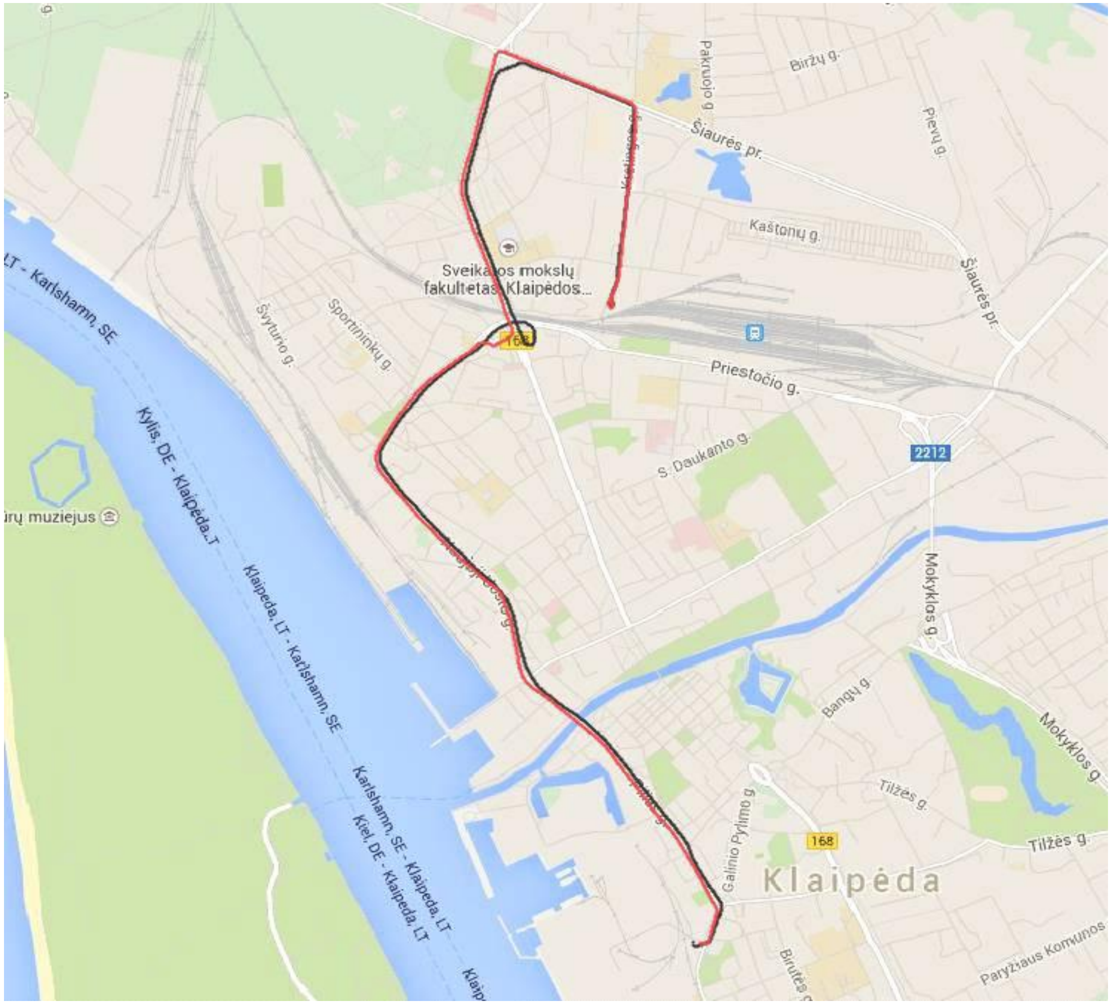
GPS mounting place

View of software "CANstudio3 Pro”



View of Race Technology Analysis V8.5 software

Route Nr.1 of electrobus in closed territory of “West Baltic Ship building” company

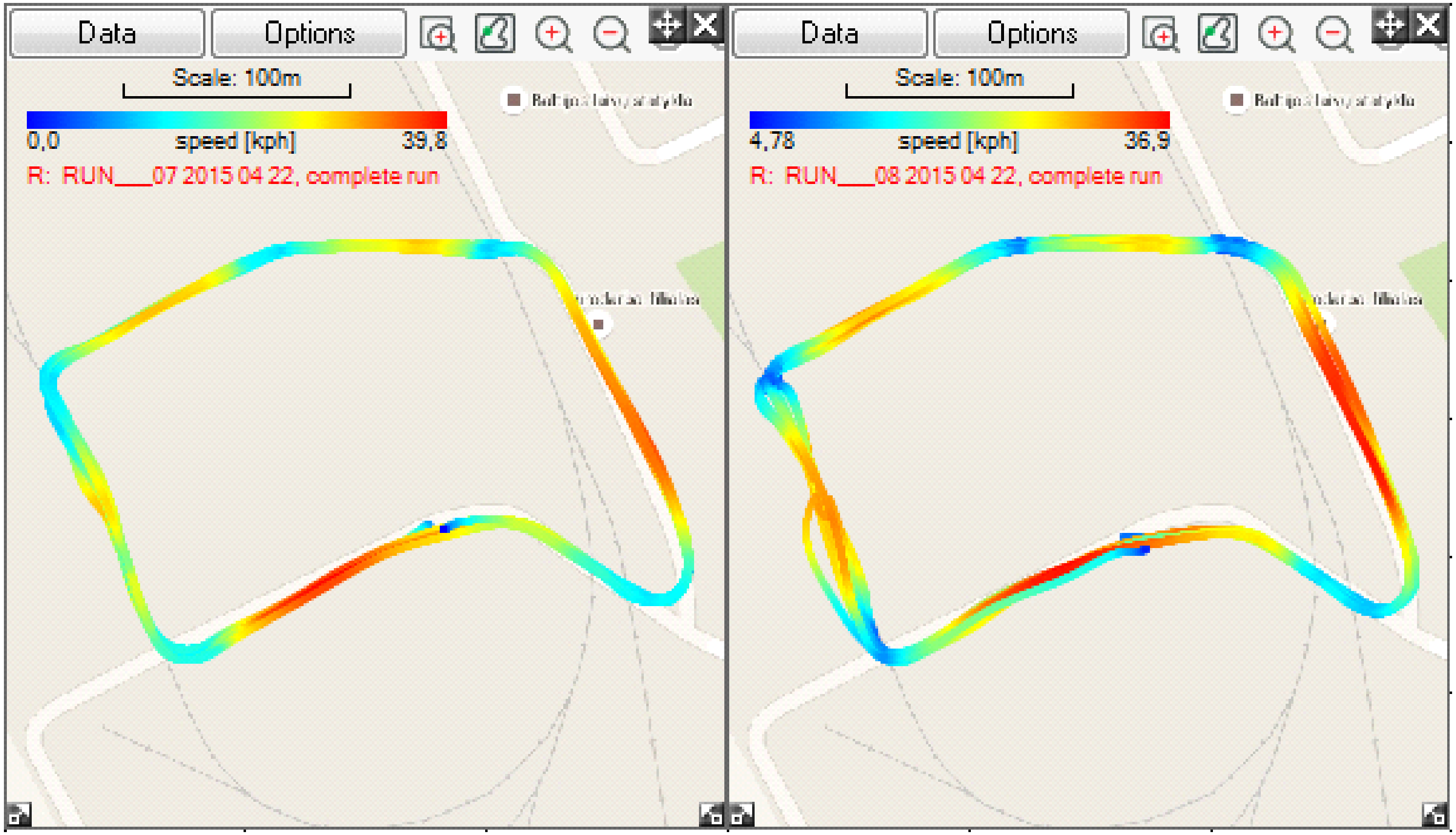


Route Nr.2 of electrobus in Klaipeda; Streets: Minijos, Pilies, Naujoji Uosto, J.Janonio, Dariaus ir Girėno, H.Manto, Šiaurės pr., Kretingos are included to the route. Length of the route is 11 km; 15 traffic lights, experiment time from 8.30 a.m. to 12 a.m.

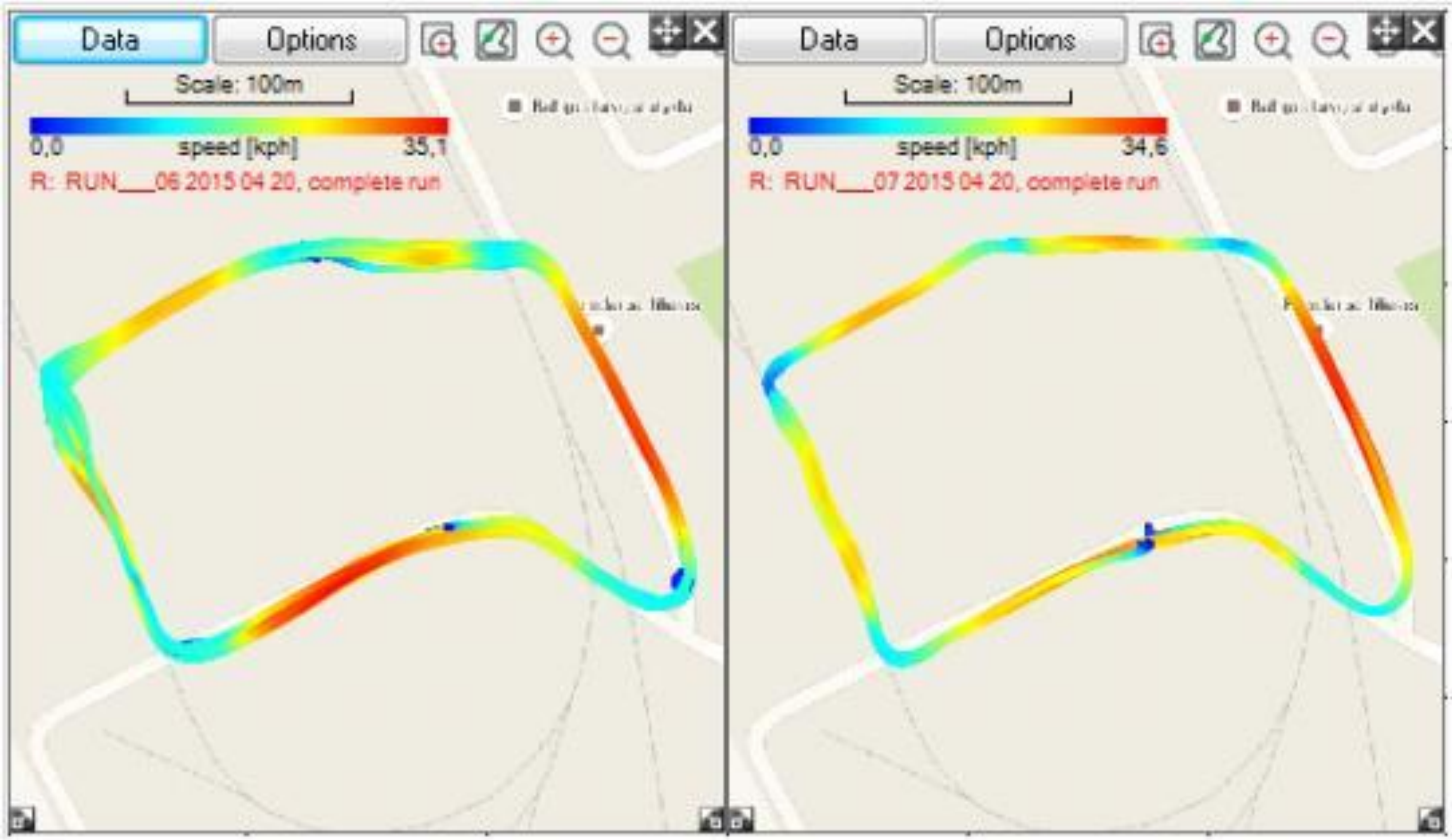
Route Nr.3 of electrobus in Klaipeda (route the same as bus Nr.5)

During experiments a lot of data collected, modeling was done as well:

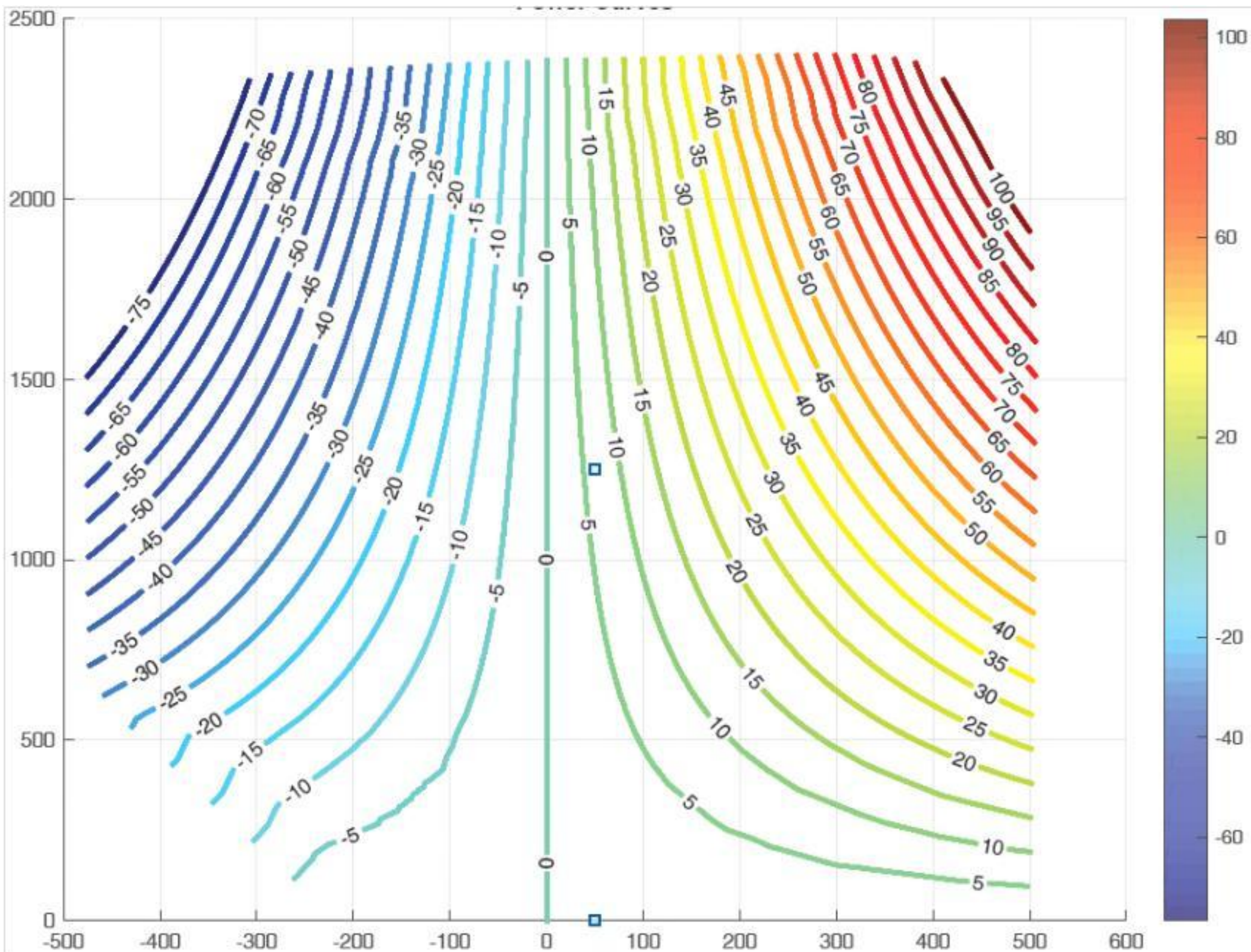
Route
Time
Consumption
Taken energy
Returned energy
Speed
Acceleration
Temperature
Humidity
Total length
Etc.



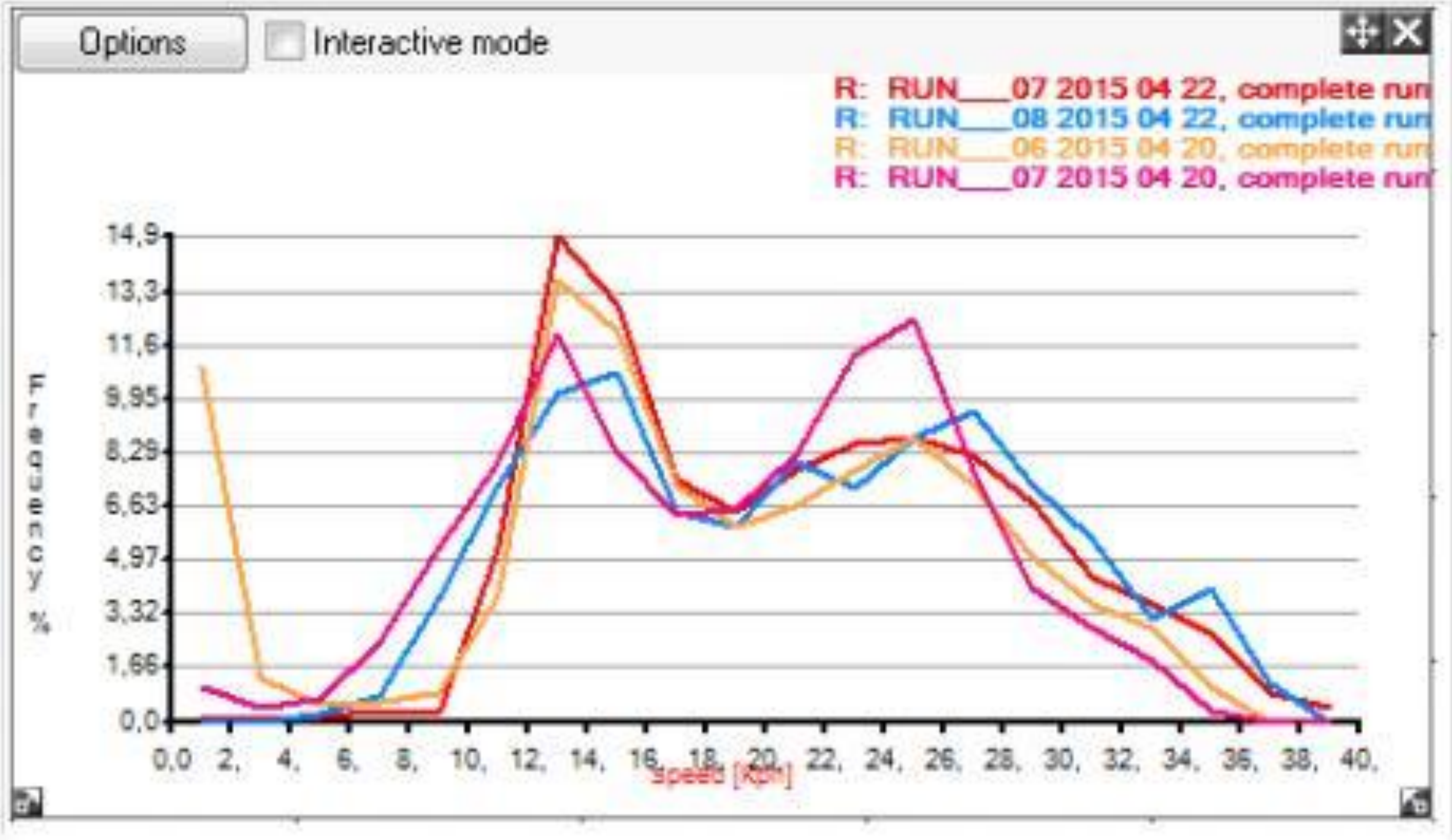
Modeling of the first route:
left side – clockwise, speed 39,8 km/h
right side – counterclockwise, speed 36,9 km/h
It can be seen that the number of acceleration and braking cycles is 41, batteries SOC decreased 6% (in both cases). **Electrobus was not loaded**



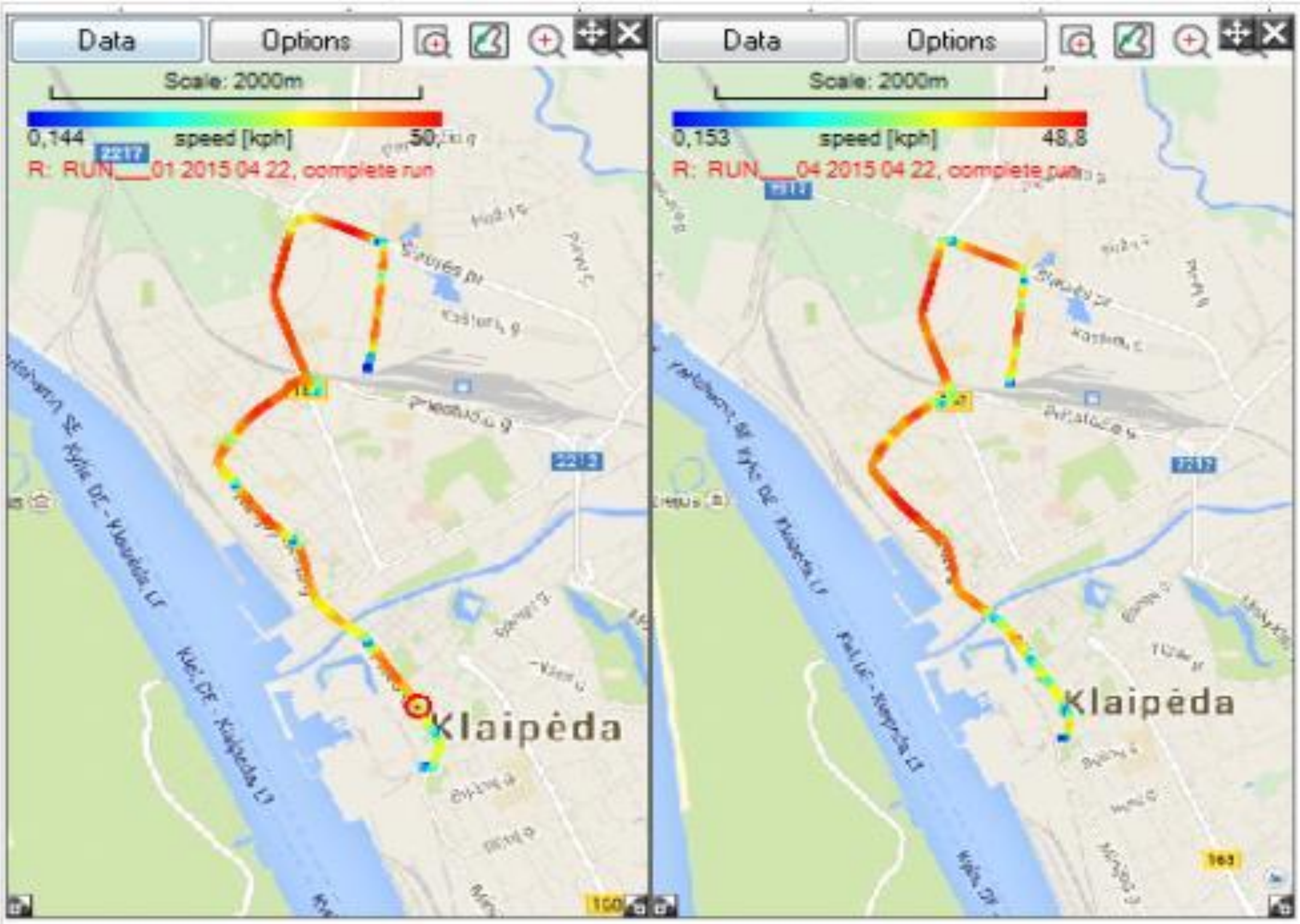
Modeling of the first route:
left side – clockwise, speed 35,1 km/h
right side – counterclockwise, speed 36,9 km/h
batteries SOC decreased 16% (in both cases). **Electrobus was loaded**



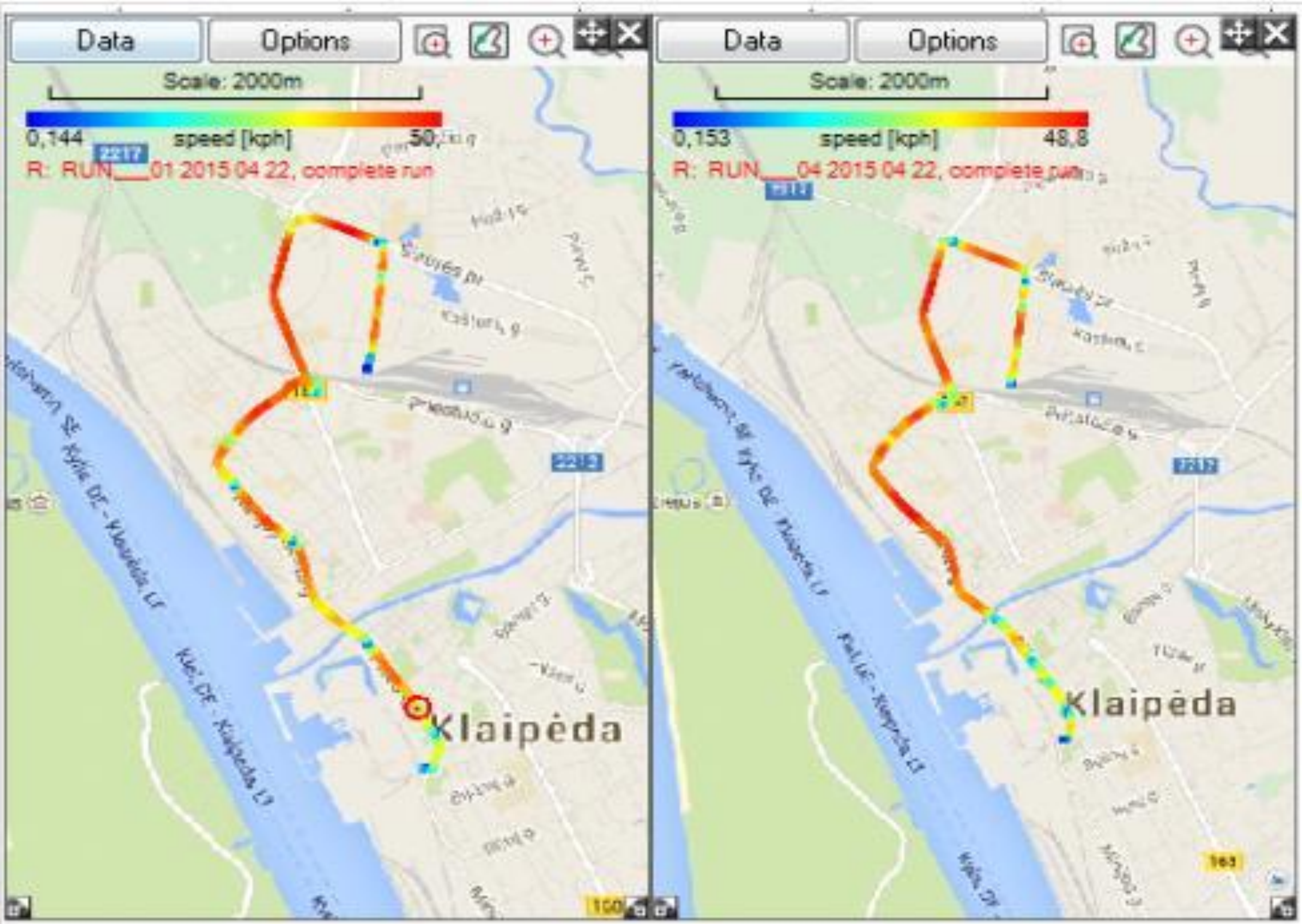
Speed dependence on torque, when **electrobus was loaded**



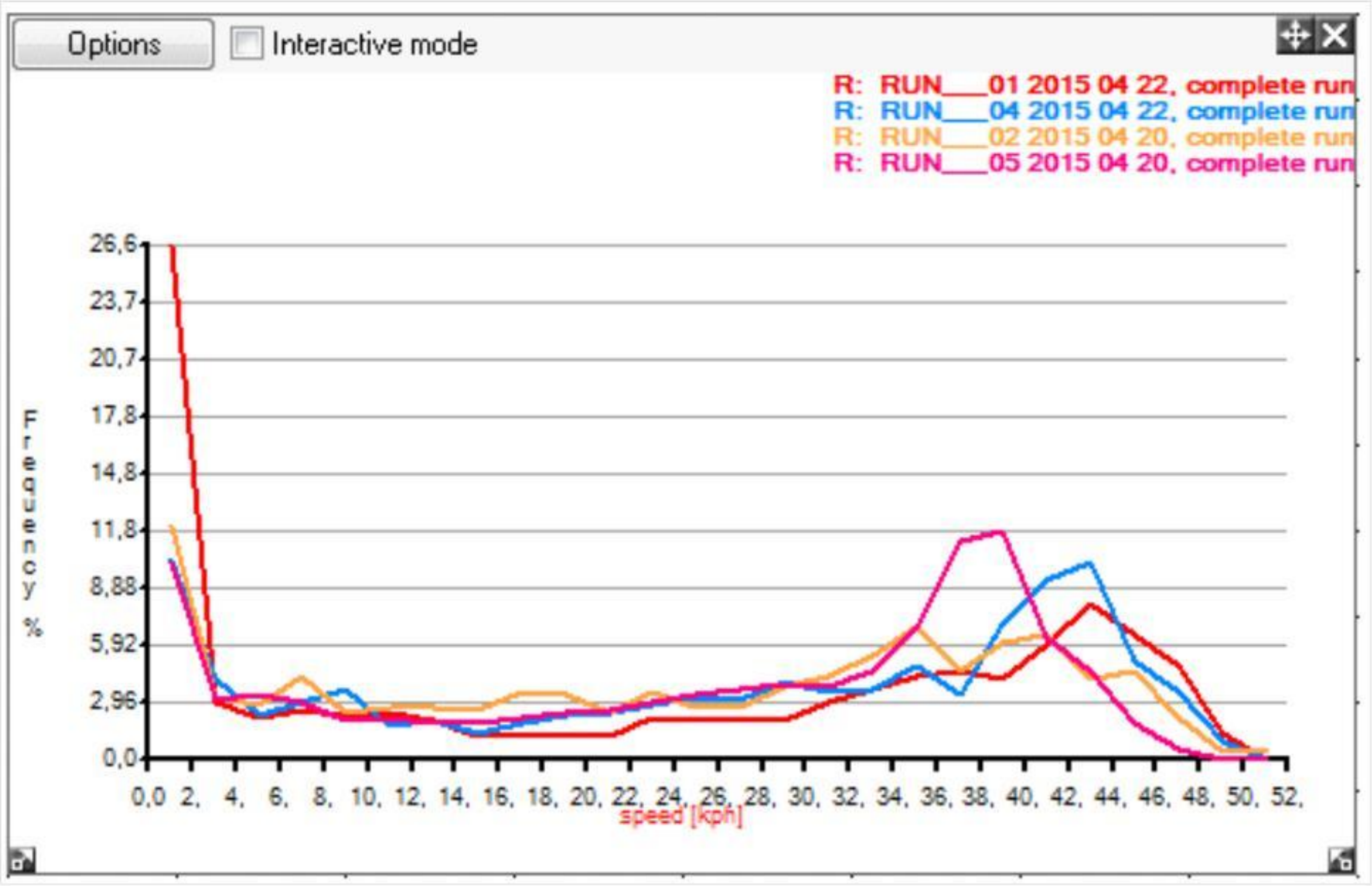
Frequency dependence on the speed, when **electrobus was loaded**



Modeling of the route Nr.2:
left side – clockwise, speed 50 km/h
right side – counterclockwise, speed 48,8 km/h
Batteries decreased 6%. 7 times braking happens due to traffic lights
Electrobus was not loaded



Modeling of the route Nr.2:
left side – clockwise, speed 50,9 km/h
right side – counterclockwise, speed 47,1 km/h
Batteries decreased 4%. 6 times braking happens due to traffic lights
Electrobus was loaded



Frequency dependence on the speed; red line, when **electrobus was not loaded, speed is 40-46 km/h, 27% time stops; orange line – 11,8% electrobus stops, speed 34-42 km/h, electrobus was loaded**

Data was collected during all experiments:

Weight (number of passengers);
Time;
600V ir 24V charging;
Weather conditions outside and inside.
DL1 device registered data:
Investigation time on real time;
Acceleration;
CANStudio registered data:
Motors' rotor:
Number of rotation, RPM;
Torque, Nm;
Temperature of the motor, 0C.
DC\AC invertors:
Current, A;
Voltage, U;
….

Maršruto Nr.	Tyrimo data	Važiavimui		600V baterijai)		Judėjimui (Inverteriu		
		Energija				Energija		
		Sunaudota	Paimta	Grąžinta	Santykinė	Sunaudota	Paimta	Grąžinta
		kWh	kWh	kWh	%	kWh	kWh	kWh
1.1	2015-04-20	11,65	15,00	3,35	22,32%	9,12	13,10	3,98
1.2	2015-04-20	5,14	6,68	1,54	23,08%	4,05	5,83	1,78
1.1	2015-04-22	4,26	6,01	1,75	29,08%	3,09	5,18	2,09
1.2	2015-04-22	4,31	6,21	1,90	30,54%	3,16	5,38	2,21

Experimental data: in Klaipeda city streets (route Nr.1). Results show that even in case when electrobus moves, consumption are 27% and 21,5% less without evaluation of all additional systems

Maršruto N r.	Tyrimo data	Vidutinis greitis	Didžiausias pagreitis		Vidutinė galia	Energija pagal DL1		
			įsibėgėjant	stabdant		Sunaudota	Paimta	Grąžinta
		km/h	m/s^2	m/s^2	kW	kWh	kWh	kWh
1.1	2015-04-20	17,93	1,14	-2,77	13,76	9,09	14,53	5,43
1.2	2015-04-20	19,21	1,10	-2,23	14,55	4,19	6,84	2,65
1.1	2015-04-22	21,13	1,34	-2,30	12,00	3,55	5,54	2,00
1.2	2015-04-22	21,16	1,20	-2,10	12,00	3,59	5,68	2,09

Experimental data: in Klaipėda city streets (route Nr.1). Results show that even in case when electrobus moves, consumption are 27% and 21,5% less without evaluation of all additional systems

Lentelė 36. Lyginamųjų energijos sąnaudų suvestinė.

		Energijos sąnaudos vienam kilometrui			Energijos sąnaudos vienam ki priklausiamai nuo mas		
Maršruto Nr.	Tyrimo data	600V baterijos	Inverterio	Pagal DL1	600V baterijos	Inverterio	P
		kWh/km	kWh/km	kWh/km	Wh/(kg*km)	Wh/(kg*km)	W
1.1	2015-04-20	0,98	0,77	0,77	0,066	0,052	
1.2	2015-04-20	0,93	0,73	0,76	0,063	0,049	
1.1	2015-04-22	0,68	0,49	0,57	0,074	0,054	
1.2	2015-04-22	0,68	0,50	0,57	0,074	0,054	

Comparison of consumption
When increasing the weight of electrobus, consumption will increase by 40,4% (weight increased by 60,7%)

Maršruto Nr.	Tyrimo data	Važiavimui		600V baterijai		Judėjimui (Inverteriu		
		Energija				Energija		
		Sunaudota	Paimta	Grąžinta	Santykinė	Sunaudota	Paimta	Grąžinta
		kWh	kWh	kWh	%	kWh	kWh	kWh
2.1	2015-04-20	6,44	7,33	0,90	12,24%	5,55	6,58	1,03
2.2	2015-04-20	4,58	5,44	0,86	15,82%	3,71	4,71	1,00
2.1	2015-04-22	4,54	5,33	0,79	14,86%	3,87	4,78	0,91
2.2	2015-04-22	3,24	4,15	0,90	21,75%	2,55	3,58	1,03

Results of route Nr 2.1 show that regenerative energy is12,2% ir 14,9% (fully loaded) and 15,8% and 21,8% (not loaded), respectively, in comparison to route Nr.2.2; if all other additional systems were not taken into account it is achieved 13,8% and 5,3% (loaded), 19,0% and 21,3% (not loaded), routes Nr.2.1 and Nr.2.2.

Electrobus Škoda TR14M in Klaipėda city streets when experiment
(photo made by Eglė Šerbinskaitė)

Photos © eglė ščerbinskaitė

A lighter electric city bus through the use of composite materials, integration of new technological materials into the public transportation, creation a new generation of city buses, a visionary approach to the automotive industry that seeks to integrate into the public transportation sphere the original concepts used in bus design with new technological materials and wind power usage;

Interior of the bus, while engineers test and monitor it (photo made by Eglė Šerbinskaitė)

MARINE VALLEY OPEN ACCESS RESEARCH INFRASTRUCTURE

IN KLAIPĖDA UNIVERSITY

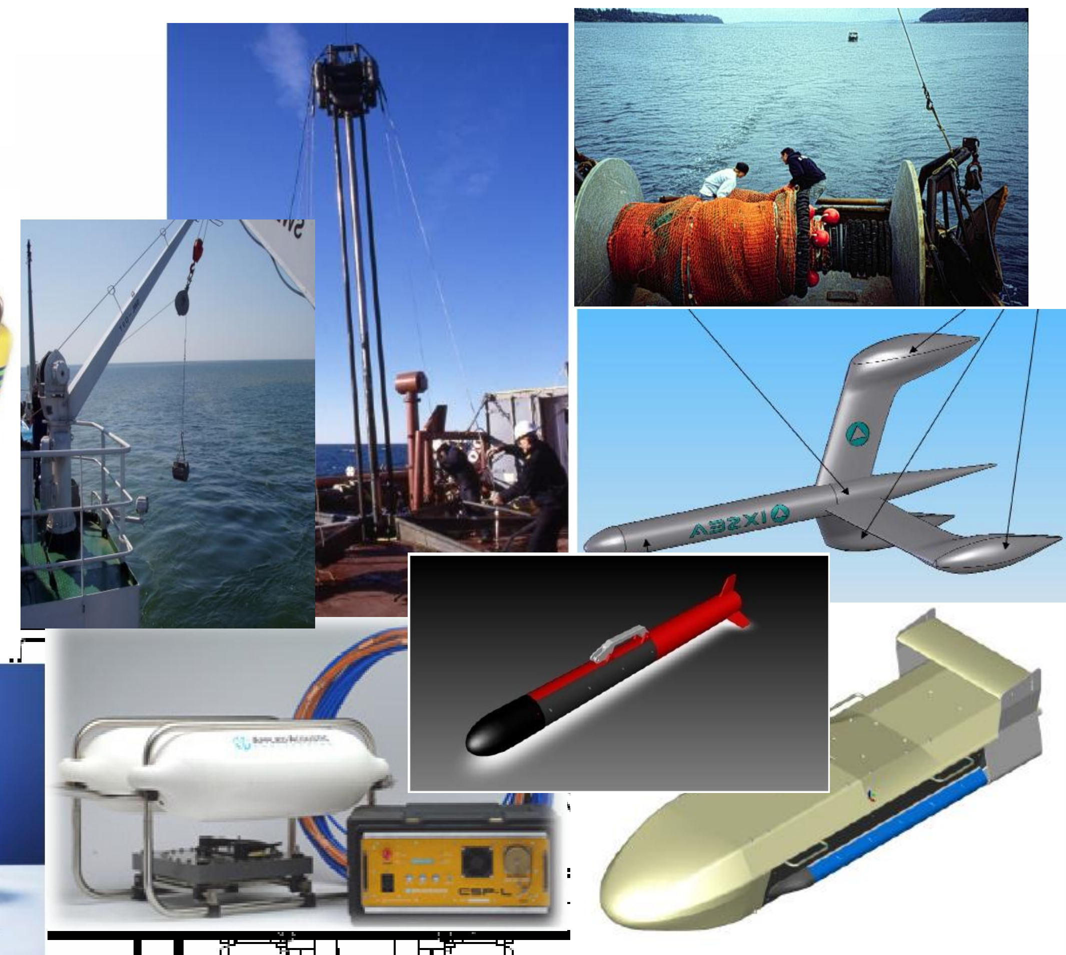
RESEARCH VESSEL

CONSTRUCTION COST ESTIMATION
COST IN EU, TAXES & OFFICIAL FEES NOT INCLUDED
DESIGN AS PER DRAWING BO-0/9339.000.10

Main Particulars:

1. LENGHT OVER ALL	Loa = 42,50 m	
2. BEAM	B = 12,00 m	
3. DEPTH	H = 3,80 m	
4. DRAFT (design)	T =2,20 m	
5. POWER INSTALLED	TOTAL	1360kWe

MODERN EQUIPMENT



Thank You for Attention