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BOOK OF PROCEEDINGS

INTERNATIONAL CONFERENCE

SUSTAINABLE MOBILITY

5-6 MARCH

2026

The INTEC International Conference brings together academics, researchers, policymakers and industry experts to discuss innovative approaches and collaborative solutions for a sustainable future in engineering and mobility. The conference will be hosted by POLIS University in Tirana, Albania, and co-organized by partners from across the EU as part of the Erasmus+ CBHE Project 101081873-ERASMUS-EDU-2022-CBHE-STRAND-2.

INTEC International Engineering Competence Centres to push sustainable mobility development in Albania and Montenegro
Project Reference: 101081873-ERASMUS-EDU-2022-CBHE-STRAND-2

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Project Partners:

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TABLE OF CONTENTS

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12

DESIGN AND DEVELOPMENT OF A CONSTANT-VOLUME COMBUSTION CHAMBER FOR OPTICAL INVESTIGATION OF HYDROGEN AND WATER INJECTION UNDER ENGINE-LIKE CONDITIONS

DOI: 10.37199/c41001012

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Abstract

Hydrogen-fuelled combustion engines with water-injection, or dual-fuel combustion provide an alternative to fossil fuels in the heavy-duty vehicle sector. However, the complex interplay between injection, mixture formation, ignition delay, and combustion under high-pressure, high-temperature conditions remains insufficiently understood to consistently realize high engine efficiencies. Conventional engine test benches limit optical access and cannot provide controlled conditions to understand spray and combustion processes. To address this gap, this work presents the systematic development of a constant-volume combustion chamber (CVCC) capable of reproducing engine-relevant conditions for fundamental studies on. The chamber design followed a structured engineering approach starting with a functional analysis and a morphological design matrix to identify feasible concepts for pressure containment, thermal conditioning, optical diagnostics, injector integration, and safety systems. Design requirements include peak pressures exceeding 200 bar, gas temperatures above 800 K, and compatibility with gaseous fuels. Finite element (FE) analyses were conducted to evaluate structural integrity, thermal stresses, and deformation of the pressure vessel and optical window assemblies under combined pressure and temperature loading. The FE results informed material selection, wall thickness dimensioning, sealing concepts, and window mounting geometry. Optical access is provided via high-strength quartz windows enabling Schlieren and shadowgraph visualization. Thermodynamic calculations were used to define target pre-combustion states, while the measurement concept includes high-speed pressure transducers, thermocouples, and synchronized injector triggering. The resulting CVCC represents a purely conceptual and simulation-based test rig design capable of generating reproducible, isochoric pressure–temperature states with peak pressures exceeding 200 bar. FE simulations indicate

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sufficient structural safety margins and acceptable thermo-mechanical deformation within the intended operating envelope. The modular injector interface concept supports the integration of one or two injectors and enables theoretical investigations of different injection strategies, including hydrogen injection, combined hydrogen–water injection, and dual-fuel injectors. At this stage, no experimental implementation or commissioning has been performed; all findings are based exclusively on analytical considerations and numerical simulations. The developed CVCC constitutes a versatile platform for repeatable investigation of hydrogen injection under engine-like conditions. The results of system design and FEA-Analysis support the realization of the CVCC for manufacturing and subsequent experimental investigations.

Keywords: hydrogen combustion, constant-volume combustion chamber, optical diagnostics, spray and ignition, sustainable mobility

I. INTRODUCTION

The decarbonization of the transport sector represents a central challenge for achieving national and European climate targets. In particular, heavy-duty transport contributes disproportionately to CO_2 emissions while offering only limited potential for full electrification based on battery systems. Consequently, hydrogen is increasingly regarded as a key energy carrier for climate-neutral mobility pathways (Schrank et al., 2021).

In addition to fuel cell systems, hydrogen internal combustion engines are discussed as a technologically viable option, especially for applications requiring high power density, long operating times and robust system behavior (AVL & ZSW, 2021). Hydrogen exhibits favorable combustion properties such as a high gravimetric heating value, wide flammability limits and high laminar flame speed. At the same time, these properties impose significant challenges regarding mixture formation, injection control, ignition behavior and safety, while NO_x emissions remain a critical issue at high temperatures (Klell et al., 2018).

A detailed understanding of hydrogen injection and combustion processes under engine-like conditions is therefore essential. Experimental investigations in real engines, however, are limited by restricted optical accessibility, complex coupled phenomena and limited reproducibility of boundary conditions (van Basshuysen & Schäfer, 2015). Constant Volume Combustion Chambers (CVC/CVCC) provide an attractive alternative, as they allow well-defined initial pressure and temperature conditions, optical access to the combustion process and the decoupled investigation of individual physical and chemical mechanisms (Truong et al., 2024).

Nevertheless, many existing CVCC designs are tailored to specific applications and lack geometric flexibility, particularly with respect to chamber volume and injector integration (Caricato et al.,

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2023). This paper addresses this gap by presenting the development, design and numerical validation of a modular and optically accessible CVCC specifically intended for hydrogen injection and combustion studies under engine-like conditions. The paper is structured as follows: Section 2 presents the design requirements and applied methods, Section 3 summarizes the numerical results, and Section 4 discusses the findings and provides conclusions and outlook.

II. METHODS

II.1 Requirements and functional analysis

The development of the CVCC is based on a structured requirement definition derived from the intended experimental use. The most relevant requirements can be summarized as follows:

- Maximum operating pressure approximately 280 bar.
- Operating temperature up to approximately 900 K.
- Adjustable combustion chamber volume in the range of approximately 0.1–0.5 L.
- Two opposing optical windows enabling Schlieren, Shadowgraph and related optical diagnostic techniques.
- Interfaces for various injector types (passenger car and heavy-duty injectors, potentially dual-fuel configurations).

From a system perspective, the CVCC setup can be described as a black box with material inputs (air, hydrogen, alternative fuels, water, inert gas), energy input (electrical power), and control signals, while outputs consist of exhaust gases and measurement data (Verein Deutscher Ingenieure). The functional structure derived from this analysis includes the functions of media storage, conditioning (pressure and temperature control), transport, injection, ignition, measurement and purging. These functions are distributed between two main subsystems: the conditioning unit and the CVCC itself. A simplified functional overview of the CVCC system is shown in Figure 1.

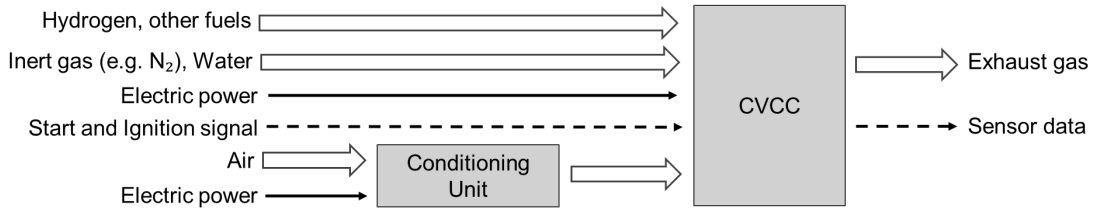

Figure 1. Functional overview of the CVCC system including conditioning unit, media supply, and measurement signals.

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2. Concepts variants and selection

Based on the functional analysis, three principal design variants were developed (Bender & Gericke, 2021):

- **Variant 1:** Cylindrical reaction chamber with continuously adjustable volume, two circular opposing windows, modular injector adapters and conventional media supply.
- **Variant 2:** Cylindrical chamber with discrete volume adjustment using inserts, simpler single-injector integration and reduced flexibility.
- **Variant 3:** Spherical-segment chamber with highly configurable geometry, coaxial injector arrangement and advanced ignition concepts, but significantly increased complexity.

The concepts were evaluated using weighted criteria derived from the requirement list. The criteria included structural integrity, safety, optical accessibility, variability, measurement capability, maintainability, cost and development time. Weighting was performed using a dominance matrix, with safety and mechanical integrity receiving the highest priority (Verein Deutscher Ingenieure, 1998). The evaluation followed the VDI 2225 scoring approach on a scale from 0 to 4.

Variant 1 achieved the highest weighted score and approximately 96% fulfillment of the defined objectives. It was therefore selected for further development and detailed design.

3. Thermodynamic sizing and construction

The thermodynamic dimensioning of the CVCC was derived from typical pressure and temperature conditions encountered in gasoline and diesel engines as well as reported hydrogen engine studies (AVL, 2022) and a heavy duty diesel reference engine OM471 (Daimler Truck AG, 2022). Target combustion pressures in the range of approximately 200–300 bar were defined (van Basshuysen & Schäfer, 2015). Based on stoichiometric requirements and typical injected fuel masses, the required reaction volumes for different fuels were estimated, resulting in the selection of a variable volume range between 0.1 and 0.5 L. The thermodynamic sizing is based on simplified zero-dimensional considerations. Local in-chamber temperature gradients, transient wall heat transfer, and detailed chemical kinetics are not explicitly resolved at this conceptual design stage.

The chamber body material was selected as quenched and tempered 42CrMo4 steel due to its high strength, good machinability and compatibility with hydrogen environments. Quartz glass was chosen for the optical windows owing to its high temperature resistance and favorable optical transmission. The mechanical layout consists of a cylindrical chamber body with an attached volume tube, a removable cover incorporating the window seats, a large adjustment screw (M42) for volume control, and interchangeable injector adapters. A simplified sectional representation of the chamber design is shown in Figure 2.

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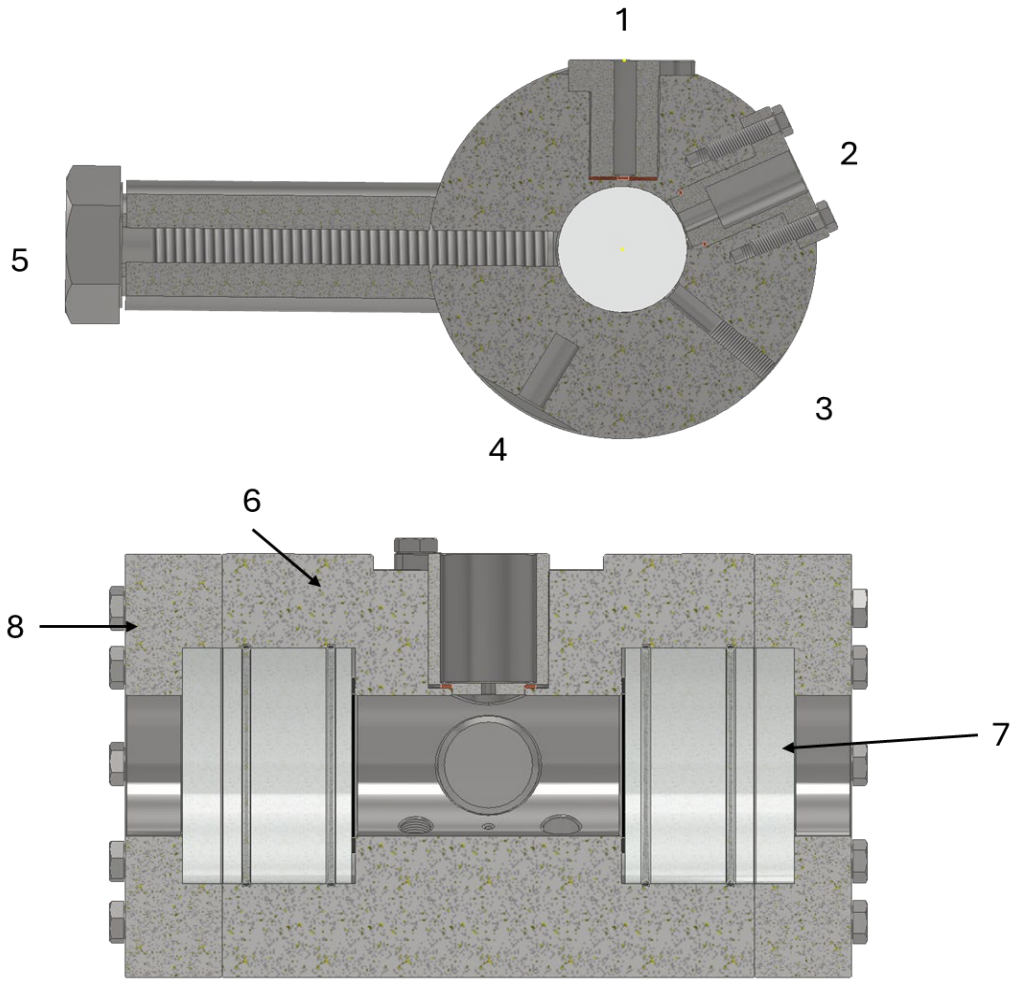

Figure 2. Sectional views of the CVCC design: (a) Detail of injector interfaces and volume adjustment; (b) Overall assembly showing optical windows and chamber cover. 1 – Large injector adapter, 2 – Spark plug & inert gas injector adapter, 3 – Sensor mounting, 4 – Air & inert gas inlet, 5 – Volume adjusting screw, 6 – Chamber body, 7 – Optical windows, 8 – Bolted cover. Manufacturing considerations include conventional turning and milling operations, defined surface quality requirements at sealing interfaces, and an appropriate welding and heat treatment sequence for the assembled pressure components.

III. RESULTS

The mechanical feasibility of the design was assessed using Altair Hyperworks (2026 Altair Engineering Inc) for the finite element analysis. The numerical model was created as a three-dimensional section model and discretized using tetrahedral elements with local mesh refinement in critical regions such as window seats and threaded connections. Material models included elastic

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properties and thermal expansion coefficients for both steel and quartz glass, and contact interactions between glass and steel components were considered. The analyses assume linear-elastic material behavior and idealized boundary conditions. Manufacturing tolerances, local notch effects beyond the modeled geometry, dynamic pressure oscillations during combustion, and transient thermal gradients are not considered.

Three primary load cases were analyzed:

- Internal pressure load of 280 bar.
- Thermal load corresponding to an inner wall temperature increase up to approximately 830 K (ΔT ≈ 570 K).
- Combined pressure and thermal loading.

Under pure pressure loading, the maximum von Mises stresses occurred at geometrical stress concentrators but remained clearly below the admissible material limits. Thermal and combined loading resulted in higher stresses due to thermal expansion effects; however, all evaluated stresses remained within acceptable limits for the selected materials. The predicted global deformations were below 0.1 mm and did not indicate any critical deformation behavior in the window or cover regions. Representative stress and deformation distributions are illustrated in Figure 3 and 4.

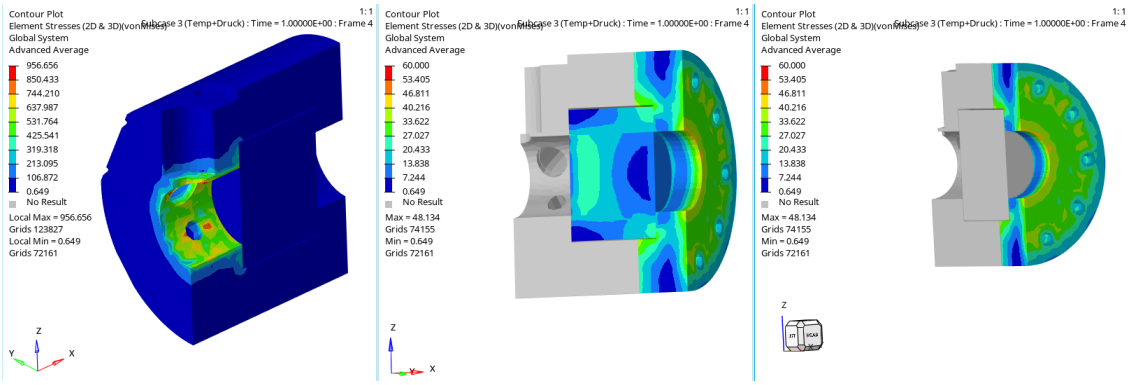

Figure 3. FEA results for the CVCC under combined pressure (280 bar) and thermal loading (ΔT ≈ 570 K) von Mises stress distribution.

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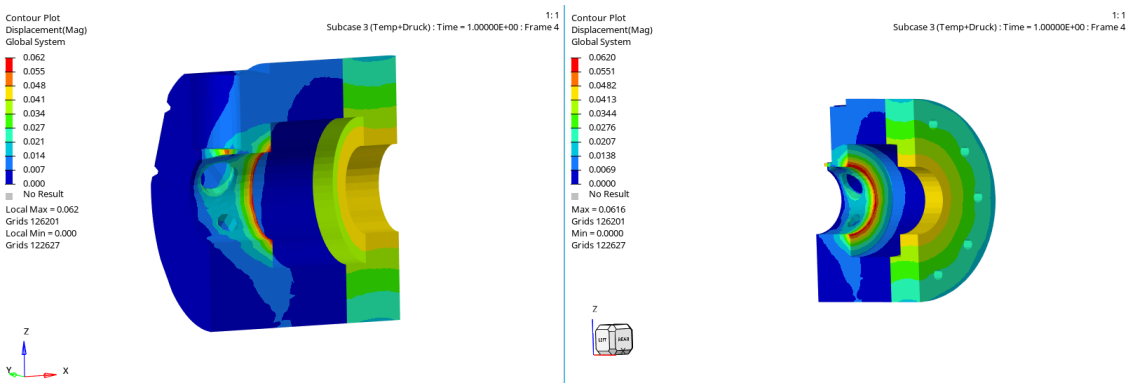

Figure 4. FEA results for the CVCC under combined pressure (280 bar) and thermal loading (ΔT ≈ 570 K): total deformation.

Overall, the numerical results indicate the structural feasibility of the proposed CVCC design under the considered operating conditions, within the limits of the applied modeling assumptions.

IV. CONCLUSION

The presented CVCC concept fulfills key requirements for hydrogen injection and combustion studies under engine-like conditions, including pressure and temperature capability, optical accessibility, geometric variability and structural integrity (Chau et al., 2023, 2023; Haq et al., 2022, 2022; Truong et al., 2024, 2024; Zhang et al., 2010, 2010). The adjustable chamber geometry enables systematic investigations of different fuels and operating points without the need for multiple dedicated chamber designs.

Compared to many existing CVC/CVCC systems reported in literature, the proposed design emphasizes modularity with respect to injector integration and operating media while maintaining a strong focus on optical accessibility and mechanically validated window integration. This combination supports both qualitative and quantitative optical diagnostics for hydrogen and liquid fuels.

The main limitations of the present work lie in the absence of experimental validation. The thermodynamic sizing and numerical analyses rely on simplified assumptions, including idealized temperature distributions and neglect of local notch effects. These aspects should be refined in future development stages.

In conclusion, the conceptual development of a flexible, optically accessible CVCC for hydrogen injection and combustion studies was successfully achieved, and the structural integrity was

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demonstrated numerically for relevant load cases. Future work will focus on prototype manufacturing, integration of the complete media and safety system, and stepwise experimental validation of the design assumptions. This includes inert gas pressure testing, hydrogen compatibility testing, and first optical injection and combustion experiments to validate the numerical thermo-mechanical predictions and window-sealing integrity.

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International conference on sustainable mobility

Agenda

Project title: International Engineering Competence Centres to push Sustainable Mobility Development in Albania and Montenegro
Acronym: INTEC

Work package	
WP11	**International conference**
TASK	
11.4	Coummunity Building Events

Dates	05.03.-06.03.2026
City	Tirana
Meeting venue	POLIS University Entrance Hall
Address	Rr. Bylis 12, Kodi Postar 1051, Kutia Postare 2995, Tirana, Albania

05.03.2026	
Entrance Hall, POLIS University	
8:30 – 9:00	**Registration**
9:00 – 9:30	**Opening Performance**
Welcome session – Auditorium A5 (Ground floor)	
9:30 – 10:00	**Opening Remarks** **Dr. Elona Karafili** (Vice Rector, POLIS University) **Dr. Flora Krasniqi** (Head of Office of Projects and Internationalization, POLIS University) **DI Daniela Wenzl** (INTEC Project Coordinator)
Auditorium A5 (Ground floor)	
10:00 –11:00	**Keynote speakers** **DI Horst Pflügl AVL** Collaborative Research for sustainable Mobility **DPSHTRR Representative** – (General Directorate of Road Transport Services in Albania)
11:15 – 11:30	**Coffee break (Moving into parallel sessions)**

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11:30	SESSION 1: POLITICAL AND REGULATORY FRAMEWORK AULA B1	SESSION 2: TECHNOLOGICAL INNOVATION AULA B4
11:30 – 11:45	**Opening Session:** Prof. Emeritus dr Nataša Gospić (FSKL)	**Opening Session:** Associate Prof. Ivan Tolj (US)
11:45 – 12:00	**Integrating Event Data Recorder (EDR) Technology into Sustainable Road Safety Frameworks within the European Green Deal** Eriselda Alimeti, Parid Milo, Mentor Çejku, Anis Sulejmani, Odhisea Koça	**Empirical Comparative Study of Structural CFRP Sandwich Structure Inserts for Out-of-Plane loads** Imre Kovács
12:00 – 12:15	**Infrastructure Readiness for Sustainable Mobility: EU Frameworks and the Case of Albania** Ervin Kalemaj, Parid Milo, Mentor Çejku, Anis Sulejmani, Odhisea Koça	**The Role of Intermodal Transportation for the Sustainable Mobility** Márton Kovács
12:15 – 12:30	**Review of the Evolution of International Ship Energy Efficiency Regulations and the Albanian context** Dr. Blenard Xhaferaj, Doklejda Hodaj	**Impact of Heat Pump Systems on Winter Energy Use and Driving Range in Battery Electric Vehicles** Luis Henrique Pereira Martins
12:30 – 12:45	**Renewable Energy Procurement (CPPA) and Transport Electrification: European Perspectives and Albanian Challenge** Antonio Ndoci, Anis Sulejmani, Odhisea Koça, Mentor Çejku, Parid Milo	**Liquid Cooling Systems for Electric Vehicle Batteries: Improving Safety, Performance and Sustainability** João Miguel de Almeida Ribeiro Silva
12:45 – 13:00	**The Current Status of Autonomous Vehicle**	**Analysis of Battery Charging and Discharging Behavior for Electric Vehicle Applications** Leona Markic, Luka Filipović

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	Technology Adoption in the Balkan Region Darjana Lopičić, Oliver Popović, Miloš Ilić, Bojan Kocić	
13:00 – 14:00	**Lunch**	
14:00 – 14:15	**Reviewing the European Green Deal in Energy, Mobility and Industry** Veselinka Calasan, Ivana Ognjanovic	**Automotive Cooling Systems Sustainability: A Focus on the Expansion Tank** Ana Inês Barbeiro Casimiro
14:15 – 14:30	**The European Green Deal and its National Implementation: From Strategy to Practice** Blerina Bektashi, Andi Bektashi	**Design and Development of a Constant-Volume Combustion Chamber for Optical Investigation of Hydrogen and Water Injection Under Engine-like Conditions** Julius Hollerith, Prof. Dr. Bhavin Kapadia
14:30 – 14:45	**From Prediction to Regulation: Evidence Production Approaches in Autonomous Mobility Research and Their Policy Implications** Sadmira Malaj	**Emission Reduction of Marine Propulsion Systems in SECA Zones Through the Integration of Hydrogen Technologies** Motalleb Miri, Ivan Radaš, Marija Mandić, Ivan Tolj
14:45 – 15:00	**Questions and Discussion**	**A Comprehensive Analysis of Ventilation System for Enhanced Energy Efficiency in Marine Propulsion Applications** Sara Blašković, Gojmir Radica, Jakov Šimunović

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15:00 – 15:15		**Design and Topology Optimization of a Lightweight Chain Sprocket for Electric Motorcycle Applications** Teo Čolović, Ivo Marinić-Kragić
15:15 – 15:30	**SESSION 3: ECONOMIC AND BUSINESS PRESPECTIVES + CASE STUDIES AND GOOD PRACTICES** Aula B1	**Questions and Discussion**
	Opening Session: Dr. Anis Sulejmani (PUT)	
15:30 – 15:45	**Managing Renewable Energy Resources as a Foundation for Sustainable Mobility Transitions** Deivi Sinanaliaj, Martin Bektashi	
15:45 – 16:00	**Feasibility of Electric Bus deployment in Montenegro: A Case Study of Budva (Erasmus+ INTEC / IECC Context)** Anastasija Mrkajic, Vinko Nikic.	
16:00 -16:15	**Children Paths as an Urban Regeneration Strategy: Naim Frasheri Study Case** Dejvi Dauti	
16:15 – 16:45	**Questions and Discussion**	

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International conference on sustainable mobility

Agenda

Project title: International Engineering Competence Centres to push Sustainable Mobility Development in Albania and Montenegro
Acronym: INTEC

Work package	
WP11	International conference
TASK	
11.4	Coummunity Building Events

Dates	05.03.-06.03.2026
City	Tirana
Meeting venue	POLIS University Entrance Hall
Address	Rr. Bylis 12, Kodi Postar 1051, Kutia Postare 2995, Tirana, Albania

06.03.2026		
First Floor Hall, POLIS University		
8:30 – 9:00	Registration	
9:00– 9:15	**SESSION 4: SOCIAL AND ENVIRONMENTAL IMPACT** AULA B1	**SESSION 5: FUTURE SCENARIOS** AULA B4
9:00 – 9:15	**Opening Session:** Prof. Dr. Bhavin Kapadia (FHF)	**Opening Session:** MA Adrian Millward-Sadler (FHJ)
9:15 – 9:30	**Comparison of Lifecycle Emissions of a SUV with Fuel Cell and Battery Electric Powertrains** - Bhavin Kapadia, Alper Sayin, Sandra Eisenträger	**GENAI Literacy as a Transversal Skill for Emerging Professionals: Implications for Sustainability-Critical Knowledge Work** – Adrian Millward-Sadler
9:30 – 9:45	**Smart Mobility Technologies and their Impact on Urban Sustainability: Insights from**	**Effects of Technical Traffic Calming Measures** – Filip Perović

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	European and Western Balkan Cities – Alma Gjonaj, Vjola Ziu	
9:45 – 10:00	**The Disappearing Squares: Social and Environmental Impacts of Urban Mobility Planning in Durres –** Arjola Sava	**Cybersecurity Vulnerabilities in Electric Vehicle Operating Systems: A Global Awareness Analysis -** Aleksa Radević
10:00 – 10:15	**The City that Demands Continuous Movement: The Disappearance of the Right not to Move within the Framework of Sustainable Mobility –** Avrili Meshi	**Development of a risk assessment model for the transport of hazardous materials using ALOHA and GIS software tools –** Marko Radetić
10:15 – 10:30	**Between Rhetoric and Reality: Discursive Framings, Greenwashing and Outcomes in Sustainable Mobility –** Kejsi Veselagu	**Mapping Distance and Time Leveraging Isochrone Intelligence in Emerging Cities** - Andia Vllamasi, Erjon Cobani
10:30 – 10:45	**Reimagining the City Through Green Mobility Strategies: The Case of Tirana** - Vjola Ziu, Alma Gjonaj	**Can AI develop its Own "Taste" Automotive Design?** - Gregor Andoni, Kristjana Meço
	Coffee Break	
11:00 – 11:15	**Linking Morphology, Perceived Safety, and Sustainable Mobility in Post-Socialist Urban Contexts-** Sindi Doce	**Optimizing Public Transport Corridors Using AI-Based Scenario Modelling: A case Study on Tirana's Ring Road** - Erjon Çobani, Julian Beqiri, Merita Guri
11:15 – 11:30	**Towards Sustainable Transport: A Comparative Analysis of Electric Vehicle Adoption in Montenegro and Albania -** Radmila Milić	**Threat Landscape and Multi-Layered Protection Mechanisms for Autonomous and Electric Vehicle Systems** - Marko Asanovic, Oliver Popović, Zoran Avramović, Nataša Gospić

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11:30 – 11:45	Questions and Discussion	**Cybersecurity Challenges in Modern Vehicular Communication Networks** - Aleksandar Grgurević, Nataša Gospić, Oliver Popović
11:45 – 12:00		**Green Transition in Albania: Challenges and Future Actions** - Erik Kushta, Andi Hyka, Enea Nasto
12:00 – 12:15	**SESSION 6: CONTROVERSIES AND CHALLENGES** Aula B1 **Opening Session:** Prof. Kristofor Lapa (UV)	**Use of AI in the Process of Green Transformation and Impact on Public Health** - Esmeralda Hamiti, Federika Alliaj, Kristi Metushi
12:15-12:30	**The Adoption of Electric Vehicles in Albania: A Comparative Study with Other Western Balkan Countries** - Doklejda Hodaj, Andrea Lapa	**Development of an Automatic Traffic Sign Detection System Using YOLOv8** - Valentina Vojinović, Luka Filipović
12:30-12:45	**Application of Quality Tools in the Analysis of Factors Influencing the Development of Electromobility in Montenegro** - Jelena Šaković Jovanović, Draško Jovanović, Mirjana Grdinić Rakonjac, Marko Lučić, Miloš Perović, Aleksandar Vujović, Gordana Radulović	**The Historical Development of Artificial Intelligence and Its Influence on the job market in Automotive Engineering** - David Josef Pilgram
12:45 – 13:45	**Questions and Discussion**	**Questions and Discussion**
13:45	**Lunch**	

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