

ABSTRACT

The present habilitation thesis, “*RESEARCH IN THE FIELD OF POLLUTION, THE USE OF RENEWABLE ENERGY SOURCES, AND EDUCATION*”, synthesizes the research and academic activities carried out by the author in the field of mechanical engineering during the period 2008–2024, following the public defense in 2008 of the doctoral thesis entitled “*Contributions to the Study and Research of the Behavior of Flexicoil-Type Springs Used in CFR 060-EA Electric Locomotives of 5100 kW*”.

The thesis is structured into three main parts. The first part provides a synthesis of the author’s scientific, academic, and professional achievements. The second part presents in detail the author’s scientific results, while the third part outlines plans for career development and future evolution. The habilitation thesis concludes with the list of bibliographic references associated with the three parts.

In the first part of the habilitation thesis (Chapter 1), the main scientific, academic, and professional achievements obtained throughout the author’s entire period of activity are presented. The research carried out during these years can be grouped into three major fields:

- environmental pollution, particularly pollution generated by transportation systems;
- renewable energy resources;
- education.

The study of environmental pollution, especially pollution generated by transport systems, primarily results from research conducted within research projects that started in 2001 and have continued to the present. The second field, renewable energy, began to be developed in 2009 through the EPOC project, was further consolidated after the completion of the Master’s program in Renewable Energy Systems Engineering in 2013, and has continued to the present. The third field, education, started with the writing and implementation of the first European-funded project in 2010 and has continued to the present, representing one of the author’s main areas of interest. In addition to these fields, research activities have also been carried out in the following areas: economics and finance, IT, ergonomics, and marketing. The research results are presented in the form of scientific papers, a patent application, published books, and research contracts. From an academic perspective, the teaching and professional training activities conducted during this period are also presented. The professional prestige of the author is validated by the national and international impact of the published specialized books, contractual research results, and scientific publications. This prestige is further supported by membership in national and international professional organizations, roles as reviewer for national and international conferences and as editor, as well as collaborations with universities in Romania and abroad.

The second part (Chapter 2) presents the most important research results of the author. This part is structured into three subchapters, as follows.

Chapter 2.1 – Research on Environmental Pollution addresses aspects related to environmental quality and pollution.

Subchapter 2.1.1 presents research on monitoring CO₂ concentration in indoor environments, aimed at assessing indoor air quality and its impact on occupants’ health. In this context, an experimental CO₂ sensor (INO-SEN CO₂) was developed and tested within a spin-off project, and its performance was compared with two commercial analyzers based on

the NDIR principle: Sensors Europe AGM50 (considered the reference instrument) and Greisinger EBG-CO₂-1R.

Comparative measurements were carried out between 2021 and 2024 in several indoor locations at Politehnica University of Timișoara (laboratories and offices), using extensive datasets and hourly averages of CO₂ concentration. The measured values fell within ranges compatible with ASHRAE recommendations for indoor spaces, showing only minor differences between the instruments.

Statistical analysis of the results was performed in accordance with SR EN ISO/IEC 17043 and ISO 13528 standards, using proficiency testing methods such as the Cochran test, ANOVA (F-test), SAP, ABSV, Z-score, and En-score. The results indicated good data homogeneity, satisfactory repeatability, and small deviations from reference values. For all analyzed locations, Z-scores (<2) and En-scores (<1) confirmed satisfactory performance of the INO-SEN CO₂ sensor, comparable to that of the commercial analyzer.

Subchapter 2.1.2 presents research results on outdoor air pollution, conducted since 2008, with a focus on monitoring urban air quality in the city of Timișoara. The study addresses modern methods for assessing atmospheric pollution, including passive and active sampling, automated techniques, and optical analyzers used to determine the concentrations of major atmospheric pollutants (SO₂, NO_x, CO, O₃, PM₁₀, VOCs).

Experimental campaigns were carried out over more than 50 days in several representative locations (industrial areas, road intersections, central and residential zones), using a semi-mobile monitoring station calibrated in accordance with European standards. Data were collected continuously and analyzed as 30-minute and 24-hour averages to capture variations and pollution peaks.

The results indicate that, in most locations, pollutant concentrations were within the limits imposed by European legislation, with notable exceptions for nitrogen oxides (NO_x) in areas with intense road traffic and for volatile organic compounds (VOCs) near industrial zones. The analysis identifies road traffic and industrial activities as the main sources of urban pollution.

The general conclusion of the study is that, although air quality in Timișoara largely complies with current regulations, there are specific areas and episodes with exceedances of admissible limits, highlighting the need for stricter emission control, especially for NO_x and VOCs, as well as the use of mobile laboratories for detailed local investigations.

Subchapter 2.1.3 presents a coherent set of studies on the environmental impact of railway traffic, focusing on soil, air, and water pollution, as well as particulate emissions generated by rolling stock operation. Although railway transport is considered more environmentally friendly than other modes of transport, the study highlights its significant contribution to diffuse pollution through emissions of metallic particles, gaseous compounds (NO_x, SO_x, VOCs), and soil contamination with heavy metals.

Experimental research conducted in the Banat region, along railway main line no. 900, included in situ measurements of suspended particles generated by wear of braking and rolling systems, using aerosol spectrometers and laser photometers, as well as laboratory analyses of water, soil, and plant samples. The results indicated a predominance of particles rich in iron, copper, zinc, and other metals, originating mainly from brake pads, wheels, and rails, with variations depending on operating conditions and material characteristics.

Chemical analyses of soils collected from railway junction areas revealed the presence of heavy metals (Cr, Fe, Pb, Mn, Ni, Zn), generally at moderate concentrations, but with locally high values, especially in railway stations, indicating the direct influence of railway traffic. At the same time, air quality studies showed relevant concentrations of NO_x, SO₂, ozone, and volatile organic compounds, correlated with both diesel locomotive activity and adjacent industrial sources.

The impact of diesel locomotive modernization on emission reduction is also analyzed by comparing old and modernized engines, demonstrating significant reductions in NO_x and CO emissions due to improved combustion processes and the introduction of electronic control. Finally, technical solutions for pollution mitigation are discussed, such as the use of exhaust gas after-treatment systems (SNCR, SCR, particulate filters), emphasizing the need for continued research for a comprehensive and integrated assessment of the environmental impact of railway transport.

Chapter 2.2 addresses aspects related to the research, development, and valorization of renewable energy resources, with a focus on biomass and biogas, through experimental laboratory and pilot-scale studies aimed at evaluating energy potential, conversion behavior, and technical solutions for increasing the efficiency of energy systems.

Subchapter 2.2.1 presents experimental research on the valorization of biomass as a renewable energy resource, structured into three complementary case studies. The first study focuses on the physico-chemical and thermal characterization of two types of plant biomass—Jerusalem artichoke and Romanian hemp—to evaluate their energy potential for combustion processes. Laboratory analyses revealed relatively low ash, sulfur, and chlorine contents, as well as high calorific values, indicating favorable combustion behavior and a reduced risk of equipment corrosion. Thermogravimetric analysis showed that chemical decomposition occurs between 200–500 °C, with differences between air and nitrogen atmospheres, the residual mass being below 5% in air and approximately 20% in an inert atmosphere. Jerusalem artichoke exhibited a higher flow temperature than hemp, suggesting superior thermal stability during combustion.

The second case study analyzes the combustion of several types of biomass in a pilot heating installation, evaluating energy performance and flue gas emissions. The results highlighted the influence of fuel type and moisture content on boiler efficiency, CO and NO_x emissions, and energy losses. The pilot installation demonstrated constructive and functional advantages, as well as limitations related to autonomy and high exhaust gas temperatures.

The third case study presents the development of an automatic complete biomass combustion installation, for which a patent application was submitted. The proposed system integrates an innovative superheater and multiple heat exchangers, ensuring increased energy efficiency, complete biomass combustion, reduced deposits, and automated operation. Overall, the research confirms the high potential of biomass as a renewable energy source and provides concrete technical solutions for improving the efficiency of combustion installations.

Subchapter 2.2.2 presents experimental research on the production and valorization of biogas as a renewable energy source, structured into three case studies conducted at pilot and laboratory scales. The first case study describes the development and operation of a patented pilot installation for biogas production from biodegradable municipal waste, within

the EPOC project. The installation includes an anaerobic digester of approximately 30 m³, biogas filtration systems, and automatic control loops for temperature, pH, and pressure. Experiments conducted over periods of 70–75 days highlighted the significant influence of thermal regime and pH on the onset and evolution of the anaerobic fermentation process. The produced biogas had a methane content of 55–70 vol.%, a calorific value of 20–25 MJ/m³, and an energy potential comparable to conventional sources, confirming its feasibility for combustion and co-combustion processes.

The second case study analyzes biogas production from wastewater and mixtures of stabilized sludge and whey, using small-scale installations. The results showed that not all substrates are suitable for anaerobic fermentation, with the best performance obtained for wastewater from the brewing industry, which generated methane concentrations of up to 69% and higher biogas volumes. High ash and sulfur contents in some mixtures were identified as limiting factors for subsequent energy use, highlighting the importance of raw material selection and pretreatment.

The third case study, conducted at laboratory scale, investigates the anaerobic co-digestion of wastewater and animal manure, focusing on the influence of the C/N ratio, thermophilic temperature, and pH control. The results highlighted the high sensitivity of the process to pH variations, with inhibition of biogas production correlated with excessive pH increases. pH correction by acetic acid addition led to significant increases in biogas production and improved composition, with methane concentrations of up to 70% and H₂S levels below admissible thresholds for energy use.

Overall, the research confirms the high potential of biogas as a renewable energy resource, highlighting the critical role of operational parameters (temperature, pH, substrate composition) in optimizing anaerobic digestion processes and ensuring adequate biogas quality for energy applications.

Chapter 2.3 analyzes research carried out in the field of higher education, with a focus on:

- a. correlating engineering education with labor market requirements, in the context of transformations generated by globalization, digitalization, and technological progress;
- b. integrating digital technologies, gamification, and Agile approaches into the educational process, as well as the impact of face-to-face, online, and hybrid educational systems on students and pupils.

Research on aligning engineering education with labor market requirements was initiated and developed within European-funded projects (PRACTICOR, PRACTICOR EURO-REGIO, CONPRACTIS), with the main objective of increasing graduate employability through the integration of practical training, career counseling and guidance, and the use of online educational resources.

The results highlight the central role of practical training in reducing the gap between competencies acquired in academia and those required by employers, as well as the importance of developing social, entrepreneurial, and transferable skills among future engineers. Case studies show that the involvement of the economic environment in organizing internships, the existence of dedicated tutors, and the personalization of practical activities significantly contribute to increased student motivation and more efficient professional integration.

Quantitative analyses based on surveys conducted on a sample of over 300 respondents confirm students' positive perception of the usefulness of internships, study visits, and career counseling, as well as the need for specialized institutional structures to coordinate these activities. The results also emphasize the importance of multidisciplinary and international collaboration in education and research, as well as the need for a systemic and sustainable approach to professional training.

Overall, the research demonstrates that the coherent integration of practical training, counseling, and digital resources in higher education represents a key factor in developing students' professional and social competencies, facilitating their transition from academia to the labor market, and contributing to the increased competitiveness of higher education institutions.

The first study analyzed in the field of education, focused on integrating digital technology, gamification, and Agile approaches into the educational process (2018), highlights the role of internet resources and gamification in increasing learning efficiency among high school students, considered "digital natives." The use of the Kahoot! platform demonstrated a significant increase in the rate of correct answers, average scores, and reaction speed, confirming the effectiveness of integrating educational games, mobile applications, and social networks into teaching.

Another case study focuses on the implementation of Agile methodology, particularly Scrum, in engineering higher education through game-based activities and project-based learning. The results show that the Agile approach fosters iterative learning, collaboration, student accountability, and continuous improvement, leading to increased engagement, higher quality deliverables, and improved learning outcomes. Performance indicators (KPIs) highlight a constant positive evolution throughout the Sprints.

Studies dedicated to hybrid and online education, conducted in the context of the COVID-19 pandemic, show that first-year students prefer face-to-face activities for better understanding, socialization, and a sense of belonging, while online education is associated with flexibility and time savings, but also with difficulties in concentration and motivation. The hybrid approach is identified as an effective transitional solution, contributing to reducing university dropout rates and increasing motivation for learning.

Overall, the research confirms that the intelligent use of digital technologies, gamification, and Agile methodologies, combined with face-to-face activities, leads to a more efficient, adaptable, and student-centered educational process, capable of meeting the requirements of modern education.

Chapter 3 presents the author's plans for career development and future evolution, within the global context of significant and up-to-date scientific achievements in the field, through which the candidate aims to further develop the capacity to coordinate research teams and to organize and manage teaching, explanation, and facilitation activities related to learning and research.

At the end of the thesis, the main bibliographic references underlying the elaboration of the habilitation thesis are presented.