UDC 378.091.214:621.791:330.33-024.81

Tutlys Vidmantas
Ph.D., Professor, Centre for Vocational Education and Research at Vytautas Magnus University, Kaunas, Lithuania, vidmantas.tutlys@vdu.lt
ORCID ID: https://orcid.org/0000-0003-2000-8862

Genute Gedviliene
Ph.D., Professor, Vytautas Magnus University, Kaunas, Lithuania, genute.gedviliene@vdu.lt
ORCID ID: https://orcid.org/0000-0002-1797-8924

Daiva Bukantaite
Ph.D., Assoc. Prof., Music academy of the Vytautas Magnus University, Kaunas, Lithuania, daiva.bukantaite@vdu.lt
ORCID ID: https://orcid.org/0000-0003-4590-9173

Algimanta Ščiglinskienė
Ph.D., Alytus Business Advisory Center, Alytus, Lithuania, direktore@avkc.lt
ORCID ID: https://orcid.org/0000-0002-3042-1231

Aida Baranauskaitė
Alytus Business Advisory Center, Alytus, Lithuania, buhalterija@avkc.lt
ORCID ID: https://orcid.org/0000-0002-9416-0333

Rolanadas Urbanavičius
Alytus Business Advisory Center, Alytus, Lithuania, konsultantas@avkc.lt
ORCID ID: https://orcid.org/0000-0002-3781-1582

Christine Schmidt
IBBF Berlin, Berlin, Germany, christine.schmidt@ibbf.berlin
ORCID ID: https://orcid.org/0000-0002-4635-4563

Jose Ramón Natal Toribio
«MetaIndustry 4», Gijón, Spain, jrnatal@metaindustry4.com
ORCID ID: https://orcid.org/0000-0002-0557-5650

Silvia Jiménez Garcia
«MetaIndustry 4», Gijón, Spain, cluster@metaindustry4.com
ORCID ID: https://orcid.org/0000-0003-3504-4380

ADJUSTING VET CURRICULA FOR WELDERS TO THE REQUIREMENTS OF THE PRINCIPLES OF CIRCULAR ECONOMY[1]

Abstract. *Vocational education is important for training competent specialists considering recent changes in the work processes and their related re-design due to the development of circular economy in the different sectors, especially in the industry. At the same time, the issue of the framework for the VET (vocational education and training) curricula for welders of different levels prepared to perform on a sustainable level remains extremely challenging. The aim of the article is to identify the ways to adjust the VET curricula to include the application of the principles of circular economy in the work process of welding. The article considers the main approaches to determining the components of the work process for*

[1] Co-authors of the study: Volha Zinouvyeva (IBBF Berlin, Berlin, Germany), Janusz Poulakowski (Innovation Development and Promotion Center, Bialystok, Poland), Martyna Przedlacka (Innovation Development and Promotion Center, Bialystok, Poland), Ilaria Massari («Reindustria Innovazione», Cremona, Italy), Rita Longari («Reindustria Innovazione», Cremona, Italy).

welding and the specialists needed to perform it efficiently and sustainably. To achieve our goal, we used two different approaches, meaning the Daughnut model of social and planetary boundaries to establish the goal for the changes in the VET curricula, and the Work and Learning Station Analysis (WLSA) to create a roadmap of changes to the VET curricula. A structured seminar for target groups was organized, during which a survey of experienced workers, as well as teachers and trainers, was conducted. The survey included 8 areas of research, covering both the organization of the work process and the training curricula for welders and the necessary changes to it. A detailed analysis of the welding work process, as well as the necessary procedures for its implementation, allowed us to determine the basic skills and abilities that welders must have. This made it possible to determine the basic competencies that should be acquired by specialists in the process of vocational training. Six areas of competence were identified and the objectives of the curriculum for each of them were set. The analysis of the best practices of designing the welding wok process was carried out, the basic skills which are used by the welders are defined. It is established that the proper design of the work process requires the welders to perform efficiently and sustainably. It is determined that the use of the principles of the circular economy requires a significant adjustment to the VET curriculum for welders. The key factor in the successful implementation of the necessary changes was the legislative support.

Keywords: *vocational education and training curriculum, competence, circular economy, welding processes, saving of materials, reduction of emissions, optimization of work processes.*

JEL classification: I20, I29.

DOI: 10.32987/2617-8532-2022-1-91-112.

Introduction. Recently, the circular economy and its principles become more widespread, leading to a change in the work processes and their related re-design that requires a new approach to education and training of the specialists. They are among the important factors that define the development of circular economy in the different sectors, especially in the industry.

Production and consumption are among the key sources and areas of impact on the environment and society. Dealing with the environmental challenges and related socio-economic implications also involves a significant change in the design of the work processes, especially technological, ergonomic, anthropological, organizational – managerial dimensions of the production cycle [1; 2]. Implementation and development of the principles of the circular economy require a pro-active and constructive approach to the work process including critical analysis and adjustment of the different parameters of the work process, such as technologies, production organization, objects of production process (products and services), requirements to work processes imposed by the enterprises, consumers, public authorities, attitudes of the employees, communication at work and others. As a result, new requirements for competence emerged that have to be considered while designing the vocational curricula for the initial and continuing vocational education. Besides, the implementation of the principles of circular economy in the work processes can take different forms so should be considered an open and very diverse phenomenon. The reasons for the implementation of the circular economy principles vary from the legislative requirements and government regulations of economic activities to the different financial and fiscal incentives initiated by the public authorities (top-down), or to the corporate social responsibility initiatives of the enterprise, as well as by the personal initiatives of the employees (bottom-up). There can also exist different hidden or tacit work practices, which «fit» the principles of a circular economy but are not recognized as such by the enterprise or employee [3]. For example, the usage of such principles of circular manufacturing, like modularity, open standards of design, open-source of design, open data and transparency are applied by following economic or marketing goals and are not recognized as valuable work practices with a positive impact on the environment and society. Disclosing such practices and making them explicit could serve as a source of know-how and inspiration for the improvement and development of the work process design. This leads to the necessity of the changes in the curricula for education and training of the specialists knowledgeable in new principles of the work process.

As a result, the main goal of this study is to identify the ways to adjust the VET curricula to include the application of the principles of circular economy in the work process of welding. To achieve this goal we propose the following tasks:

1. Disclosing the existing practices of the re-design or improvement of the welding work process, which follow the principles of the circular economy.

2. Identifying the skills/competences needed as a result of the application of the principles and practices of the circular economy.

3. Drafting of the related competence profile which should serve as a source for design and adjustment of the VET curricula (both for initial and continuing VET).

Literature review and theoretical framework. The source of the changes of the VET curricula to train welding specialists is the introduction of the circular economy principles to the work process. As a result, the circularity and sustainability of welding processes attract the attention of researchers and experts. To create the best background, the main focus of research in this field is on the technological, ergonomic, economic and environmental aspects of the sustainability of welding processes, whereas the implications for skill formation and training or the impact of these processes for vocational training are much less explored.

K. P. Mehta distinguishes the components of sustainable welding processes by taking into consideration the aspects of energy saving, material waste, resources and parameters, environmental benefits and cost-saving capabilities in the different categories of welding and processing [4]. A. Kapil and A. Sharma provide a detailed overview of the environmental advantages of magnetic pulse welding by using electromagnetic forces by outlining the clean and multi-material operation, non-melting weld interface, avoiding the generation of hazardous emissions in form of heat, fume, and spatters [5].

R. Chiou, M. Mauk, C. Husanu, T. Tseng, S. Sowmithran and T. Nguyen present the technological possibilities and positive environmental impacts of the application of virtual reality laboratories for the training of welders in the different welding processes [6; 7]. K. Vimal, S. Vinodh and A. Raja outline the possibilities of deployment of the sustainable manufacturing strategies in the shielded metal arc welding (SMAW) process by analyzing the implications of these strategies for the training of welders and waste minimization and disposal [8].

M. Saad, B. Darras and M. Nazzal suggest and experiment with a comprehensive framework for sustainability assessment of the selected welding processes, such as friction stir welding (FSW), gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), and shielded metal arc welding (SMAW) and find out that FSW is the most sustainable welding process for their study [9]. D. Rivas, R. Quiza, M. Rivas and R. Haber develop a formalized framework for optimizing the sustainability of manufacturing processes which combines a methodology for selecting the sustainability indicators and a multi-objective optimization for improving the economy, environment, and society [10]. There is an example provided of the usage of this framework based on optimization of a submerged arc welding process, which indicates, that the computed optimal welding solution outperforms the economic and environmental sustainability while keeping equal the social impact.

Each working process requires several different specialists with different levels of competence that require specific training. The work process of welding is defined as a complex work process that involves all occupations, jobs and qualifications related to welding in the metalworking and engineering industry, such as skilled welder (EQF level 3), highly skilled welder/welding operator (EQF level 4), highly skilled and specialist welder or welding operator, e.g., operator of automatic and robotized welding (EQF level 5), welding technicians and engineers (EQF levels 6 and 7). On this basis we suggest the following structure of the work processes of welding followed in this analysis (Figure 1).

Research methodology. The methods used in this article are two-folds. The goal for the changes in the VET curricula is based on the «Daughnut model of social and planetary boundaries» suggested by the Oxford University economist K. Raworth [11]. This model creates a

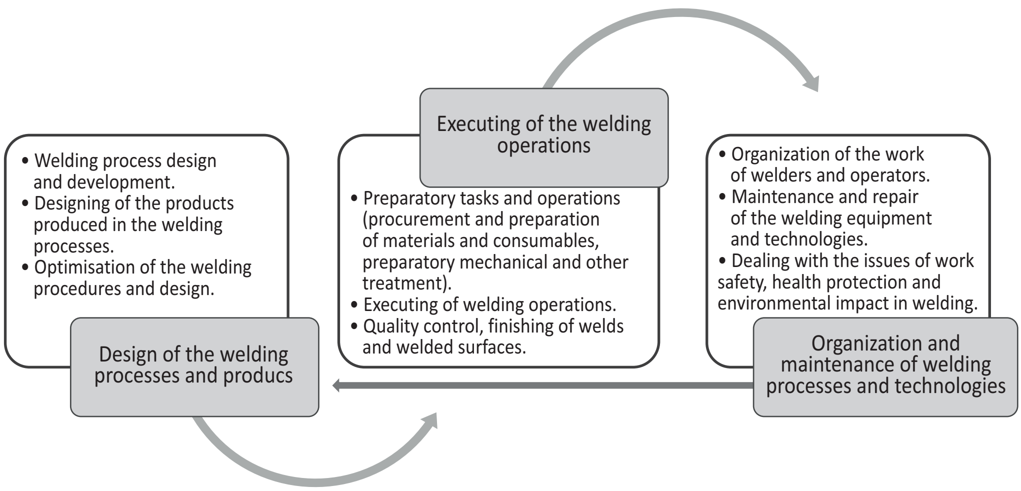

Figure 1. **Structure of the work processes of welding**

Created by the authors.

framework for the challenge of balancing between meeting life's essential needs (shortfalls) on one side and dealing with the collective overshooting of the pressure of economic activities on the fundamental Earth's life-supporting systems, such as stable climate, fertile soils, biodiversity, etc. This model claims, that it is necessary to re-adjust the economic and social activities and systems in order to fit them in the space between the social boundaries defined by the minimum social standards, or social foundation from the one side, and the environmental ceiling consisting of key planetary boundaries. To what extent and how this model is suitable for the analysis of the industrial work processes? The Daughnut model can serve as a reference for the exploration of the balancing between the social foundations (shortfalls) and ecological ceiling at the level of the work process. In this regard, the safe and sustainable design of the work process should satisfy the social foundations of work related to objective human needs, such as access to occupation, employment safety, remuneration, work safety and health protection, and subjective needs like the dignity of work, meaningfulness of work, contribution of work to personal development and self-realization. The sustainable design of work should also counteract the overshooting of the ecological ceiling of the work process by coping with pollution of the environment, eliminating of reducing the effects of work which contribute to reducing biodiversity, wasting and depleting non-renewable resources, irresponsible and wasteful consumption of products produced in the work process, unsustainable work culture (Figure 2).

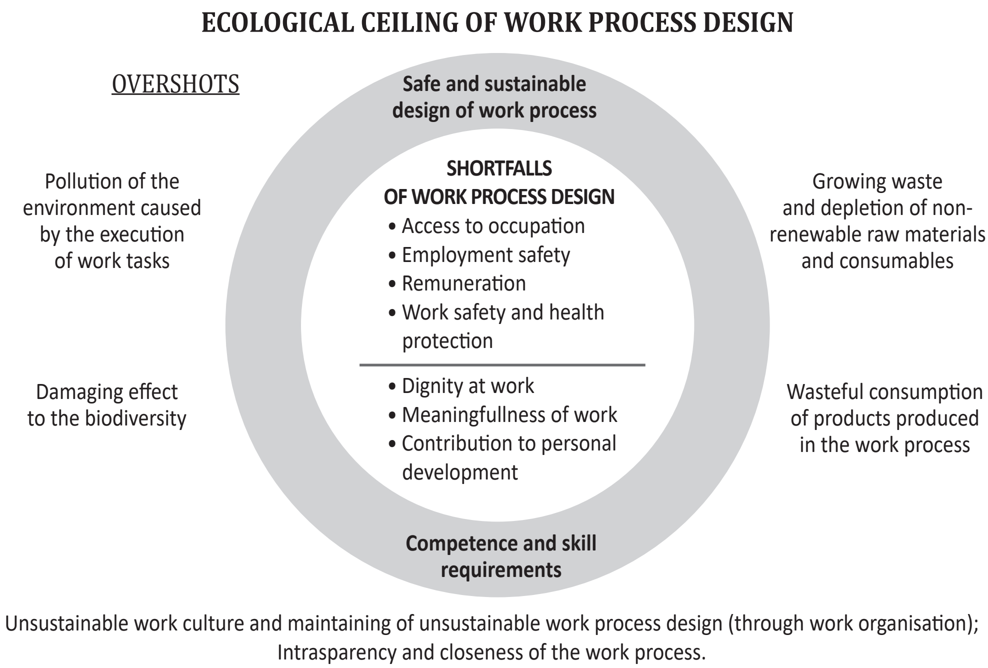

Figure 2. **Environmental and social-economic boundaries of industrial work process design**

Created by the authors.

Here it is important to take into consideration, that both social foundations (shortfalls) and ecological ceilings of the work process can be different and case-specific, depending on the economic, ergonomic, technological, organizational and socio-cultural specificities of a given work process. One of the key challenges in creating and developing such a safe and sustainable design of the work process is to enable strong synergy between respecting/sustaining the ecological ceiling from the one side, and keeping/protecting the social foundations of the work process. For example, there could be established synergy between the application of the technologies and modes of work organization which eliminates or reduce the pollution or waste of raw materials from the one side and contributes to the work effectiveness, safety and satisfaction of customers from the other side. These categories of work processes will be taken into consideration in the analysis of the work process of welding.

To create a roadmap of changes to the VET curricula the authors used the Work and Learning Station Analysis (WLSA). The WLSA represents an instrument to analyze different aspects of work processes in their relationship with work-based learning (WBL). It is a very important tool to train qualified welders as they require practical experience to obtain the next level of competence. This instrument was developed jointly by trainers from Airbus Germany and researchers from the Bremen University approximately 15 years ago and has been widely used for the analysis of industrial work processes in the different ERASMUS+ projects like «Apprentsod», «DualTrain», «Metals», «ICSAS», and others. It helps to evaluate the learning potential of work processes by taking into consideration different specificities or specific aspects of work. It helps to identify and to describe the apparent good practice of work process execution, to disclose related competence requirements, and to indicate the potential of these practices to be used in the WBL and other forms of VET.

The first stage of the WLSA analysis requires the identification of the occupations and job positions to be analyzed. The proposed model structure of the welding work process (Figure 1) has been used as a reference for such identification. Other information sources are lists of existing occupations and qualifications, current occupational standards in the field of welding, training curricula, descriptors of jobs developed by the enterprises.

Once the occupations/job positions for analysis have been identified and selected, the potential informants were selected and their participation in the analysis agreed with the enterprises and informants themselves.

The WLSA has been implemented by organizing a structured workshop (or focus group interview) lasting up to a few hours. Each of these workshops involved experienced employees with different qualifications/competence profiles mainly welding technicians and welding engineers. Besides these experts, experienced VET teachers and trainers working in the training programs also were involved which provide qualifications of welders. By participating in these workshops, VET teachers and trainers provided their insights about the competencies, which are necessary for the accomplishment of sustainable and «circular economy» – oriented work processes of welding.

The workshops were organized in Lithuania, Italy, Germany, Spain and Poland by using online platforms of communication (Zoom, MS teams and others). The workshops were carried out by using the questionnaire developed based on the WLSA analysis but adjusted to the object of the study – implementation of the circular economy principles in the welding processes. These questionnaires were translated into the native languages of respondents and delivered before the workshops (Table 1).

The workshops and interviews in the project partner countries were conduct-

Table 1

Guiding questions for the interviews/focus groups of Work and Learning Station Analysis

Analytical category	Central questions
General features of work process (welding)	- Which products are manufactured? - Where do pre-products come from? - Where in the further process are the products used? - Which industries are the clients/customers of the service/product?
Workplace characteristics	- Where is the analyzed workplace located (inside/outside)? - Prevailing climatic conditions (heat, cold, radiation, ventilation, gas, vapours, fog, dust)? - What are the key emissions/sources of pollution of the executed welding process to the workplace environment (pollution of air, water, soil, etc.)? - What kind of protective measures are used in order to prevent negative implications of emissions and pollution at the workplace for the welder/welding operator, other employees and the external environment? - What kind of waste is produced at the workplace? What is the average quantity of this waste? - Are there any procedures for collecting and recycling the waste produced at the workplace? What are these procedures? - What are the possible good practices in the collecting and processing of waste at the workplace? - Are welders /welding operators incentivized to follow the recommendations or requirements about the processing of the waste at the workplace? How?
Subjects and methods of sustainable work	- What are the key tasks being executed in the work process of welding (preparation of materials, executing of welded joints, quality control, finishing off the welded surfaces)? - What kind of welding regimes are applied? - What kind of emissions are produced during the preparatory stage, executing of welded joints, quality control and finishing of the surface? How these emissions are being further treated? - What kind of practices/methods are applied to reduce the volume of emissions at each stage of the work process? - What kind of practices/methods are applied to reduce the volume of main materials (e.g. metals) and consumables in the welding process? - To what extent and how do the existing quality requirements and procedures of welding permit and enhance to apply such welding regimes, which generate fewer emissions and create less waste of materials and consumables? - To what extent and how the welders/welding operators can adjust the working methods and regimes in ways that reduce emissions and consumption of materials and consumables? Do the welders and welding operators receive any support from the engineering staff in this field?
Tools/equipment of sustainable work	- Which tools and equipment are used to perform the welding task (machines, tools, devices, software)? - To what extent and how are the tools and equipment permitted to apply the working methods, regimes, and procedures that reduce the pollution and waste of materials and consumables? What knowledge and skills are needed to use these functionalities?

End of Table 1

Analytical category	Central questions
Organization of sustainable work	- How the work of welders/welding operators is being organized (e.g. individual work or group work, division of labor)? - What problems or shortages of work organizations contribute to the increasing pollution, usage of materials and consumables, as well as increase of waste in the process of welding? - What kind of cooperation and interfaces between the welders/welding operators and other workplaces/specialists are critical in order to make welding processes more green and sustainable (to reduce pollution, consumption of raw materials and consumables and volume of produced waste)? - What are the possible good practices of work organization, which enable reduction of pollution, optimal use of materials and consumables and recycling of produced waste (co-operation between the different departments, teams of welders with different qualifications and specialization, team-working between welders and representatives of the engineering staff, etc.)?
Environmental requirements of sustainable work	- Which national/European standards, laws and specifications of environment protection need to be considered in the work process of welding? - Are there any operational environmental requirements or standards initiated and suggested by the enterprise? If so, what are they? - Which demands are placed by the customer? To what extent do the demands of customers comply with the operational environmental requirements of welding processes? What are the biggest challenges in this regard and how these challenges are being met?
Implications for the VET curricula (questions to the involved VET teachers and trainers)	- What competencies related to the sustainability of the work process have been discovered in the workshop? - Are these competencies included in the current VET curricula? If not, how the existing curricula can be updated? - What key sources of information and learning are needed for the provision of these competencies? - What are the most suitable training methods and approaches for the development of these competencies?

Created by the authors.

ed by involving 3 groups of informants from Lithuania, Germany, Italy, Spain and Poland (Table 2).

The transcripts of focus groups and workshops were analyzed by using a prepared template of analysis (Table 3).

Research findings. Participants of the focus groups represented a wide range of enterprises involved in the production of the different products and application of the various welding processes. These work processes in-

Table 2

Informants of the research by the countries

Country	Categories of informants		
	Welders and welding operators, technicians	**Engineering and man managerial staff of enterprises**	**VET teachers and trainers**
Lithuania	–	12	5
Germany	2	10	5
Italy	–	12	3
Spain	–	5	1
Poland	2	10	5

Created by the authors.

Table 3

Template of data analysis

Description	Work process/occupation
Location/site	Corresponding VET qualification/program
General features of work process (welding)	Type of product/service Internal supplier of pre-products Further/direct user of product/service Client of product/service
Workplace	Location of workplace Prevailing climatic conditions (heat, cold, radiation, ventilation, gas, vapours, fog, dust) The key emissions/sources of pollution of the executed welding process to the workplace environment (pollution of air, water, soil, etc.) Protective measures are used in order to prevent negative implications of emissions and pollution at the workplace for the welder/welding operator, other employees and the external environment Waste produced at the workplace – types and quantities Availability of procedures for collecting and recycling the waste produced at the workplace: yes/ no. If yes, the types of procedures. Possible good practices in the collecting and processing of waste at the workplace Applied incentives for welders/welding operators to follow the recommendations or requirements about the processing of the waste at the workplace
Subjects and methods of sustainable work	Key tasks in the work process of welding (preparation of materials, executing of welded joints, quality control, finishing off the welded surfaces) Applied welding regimes Emissions produced during the preparatory stage, executing of welded joints, quality control and finishing of the surface. Treatment of emissions Practices/methods applied to reduce the volume of emissions at each stage of the work process Practices/ methods applied to reduce the volume of main materials (e.g. metals) and consumables in the welding process The most important synergies and/or trade-offs between the quality requirements and more «green» (environmentally friendly) approaches and methods in the process of welding Autonomy of the welders/welding operators to adjust the working methods and regimes in ways that reduce emissions and consumption of materials and consumables. Availability of support for welders and welding operators from the engineering staff
Tools/equipment of sustainable work	Tools and equipment used to perform the welding tasks (machines, tools, devices, software) Functionalities of the tools and equipment enable the application of the working methods, regimes and procedures that reduce the pollution and waste of materials and consumables
Organization of sustainable work	Modes of work organization (e.g. individual work or group work, work in shifts, hierarchy) Problems or shortages of work organizations contribute to the increasing pollution, usage of materials and consumables, as well as increase of waste in the process of welding The ways of cooperation and interfaces between the welders/welding operators and other workplaces/specialists, which are critical to making welding processes more green and sustainable Possible good practices of work organization, which enable reduction of pollution, optimal use of materials and consumables and recycling of produced waste

End of Table 3

Description	Work process/occupation
Environmental requirements of sustainable work	National/European standards, laws and specifications of environment protection need to be considered in the work process of welding Operational environmental requirements or standards initiated and suggested by the enterprise Demands by the customer and their compliance with the national/operational environmental requirements to welding processes
Implications for vocational training curricula	Newly identified competencies related to the sustainability of the work process Key sources of information and learning are needed for the provision of these competencies Suggested training methods and approaches for the development of these competencies

Created by the authors.

volve qualifications of welder, welding operator, welding supervisor, welding engineer, product designer (EQF levels 2-6/7).

The welding processes are used for the production of different products or delivery of technological services starting from truck trailers and bodies, trough and roll-off trailers for waste disposal companies, superstructures, sheet metal assemblies, housings, subracks, products for exhaust systems, made of stainless steel and titanium ending with heat exchangers, stainless steel tanks and equipment for food, beverage and chemical industries, components for the energy sector, wind energy components, different constructions and elements for the nuclear power plants.

Applied welding processes produce a wide range of different emissions/sources of pollution to the workplace environment: industrial gases, aerosols and dust generated during welding processes (argon gases when welding with TIG, NO_x, CO, PM2.5 and PM10 suspended dust, total dust with separated compounds MnO_2, CuO_2, NiO_2, chromium particles from welding of austenitic steel, nitric acid vapours from the chemical pickling of welds), as well as UV radiation, noise, especially at plasma or gas cutting stations, welding fumes, metal active gas in case of MAG welding, waste after cleaning of chemically treated wastewater from the pickling process (neutralized sludge with coagulated heavy metal particles).

These emissions are dealt with by using different protective measures in order to prevent negative implications of emissions and pollution at the workplace for the welder/welding operator, other employees and the external environment. The gases and dust at the workplace are extracted by using automatically functioning extraction systems per workplace, using local exhausts with a filter of > 99 % efficiency, purified air being recirculated to the hall, and through general ventilation of the welding room. There is a limitation of light emissions in the welding booths by separating walls. There is applied electronic spark prevention, mobile partitions against electric arcs. Welders use personal protective equipment: helmet with automatic lens, double visors, overpressure to prevent the entry of gases, respirators, leather gaiters, noise-reducing measures, adapted hearing protectors, fireproof protective clothing.

The welding processes also produce different hazardous and non-hazardous waste. Non-hazardous waste includes scrap metal, iron scrap, paper/cardboard of packing, wood, industrial waste type 1, grinding residues, dust, electrode rods and electrode welding rod caps, welding wire, tungsten welding needles, protective clothing, spare parts of the welding machines, grinding discs and other grinding tools. Hazardous waste includes waste oil, packaging that has contained RP, rags or material soaked in RP, WEEE, used batteries, spare parts of the welding machines.

Enterprises apply different procedures for collecting and recycling the waste produced at the workplace. They tend to implement waste management systems and delegate the responsibilities for the collecting and sorting of waste in production to the employees. Companies also use registers for waste, especially national environmental registers for packing waste and chemical materials. Waste collecting and recycling also make a part of employee training and competence development programs. There are also used services of specialized waste collecting companies assisting in the disposal of hazardous waste.

Some companies follow their general waste management procedures and controlled internal notes with information on waste management. Prevention of waste occurring at the workplace is executed by establishing, reinforcing and revising the procedures on the sequence of work operations. The collecting of waste is also regulated by the defined procedures for collecting the different types of materials: steel CR17, magnetic steel, stainless steel. There are also economic regimes used in programming the CNC machines of sheet cutting and preparation. Some companies tend to outsource calculating the amount of dust and metals emissions as well as matters related to environmental fees and the collection and disposal of waste, including scrap.

While executing the welding work processes, welders and welding operators apply different practices and methods to reduce the volume of emissions at each stage. For example, at the stage of the design of welded products and constructions, there is minimized volume of joints taking into consideration the volume of waste and its management options resulting from the design. The workpieces for cutting from the sheets are positioned in the most «economic» way, while the remaining materials are registered to ensure their traceability for usage in the production of other parts and products. There are different measures applied for the optimization of the weld joint design.

At the stage of the selection of technological process of welding, the most economic and environmentally friendly welding processes are selected for each case by taking into consideration technological and product requirements not compromising quality but avoiding excessive welding regimes. For example, very often the usage of submerged arc welding for thick sheets helps to economize on the preparatory edge cutting of sheets and to reduce emissions from this process. Excessive requirements to welding at the design stage often become the core source of increased pollution and waste, very often these overshoots in the design and technological preparation of the welding process occur because of the speedy execution of the design, lack of «patience» and time for high-quality calculations of the needed volume of materials. Welding can also be partially replaced with screwing and riveting.

The possibilities provided by suitable and optimal selecting of the welding regimes are also exploited according to the technological requirements of the concrete case, according to the required types of joints. The selection of welding regimes is controlled in seeking to avoid applying excessive regimes in terms of thermal impact. The welders must keep within the limits of thermal impact defined in the welding procedure.

Quality control of materials and intermediate products also contributes to the circularity of welding processes by executing proper quality control of the metal sheets, avoiding the practices of saving on the quality of the metals by using cheap and low-quality materials, which requires additional preparations and involves additional emissions. Less «contaminating» welding consumables are chosen and used. For example, welding with solid welding wires produces much fewer emissions compared to using «powder» based welding wire. Strictly following quality management procedure, approval of the WPS and preparation of the welding instructions are also critical for the sustainability of welding processes and involve executing test pieces of welding, certification of applied welding processes and welders in the company with the approved international/national audit and certification bodies.

Applying savvy procedures of the preparation of raw materials for welding and optimal welding regimes also permits to save on the surface treatment operations after welding (metal and sandblasting). The usage of abrasive materials for surface treatment of welds is reduced by using more cutters, grinding plates. The volume of welding work is minimized by maintaining a high quality of welding (avoiding repairs of welds). Emission reduction is sought by improving the quality of welds, by selecting and fine-tuning the composition of shielding gases and welding wires. The volume and intensiveness of the welding process are optimized by the edge preparation before the welding process, usage of the X welds, minimization of the zones of the weld area.

Robotization of welding processes also significantly enhances their sustainability. The shift to work with the use of welding robots and laser cutters (especially fiber type) allows for greater use of the starting material and reduces waste through optimized nesting. The robots perform welds in a repeatable manner, which, with the right choice of means and parameters of the technological process leads to the reduction of defects. Usage of CNC machines (plasma cutters, lasers) significantly limits the harmful impact of welding processes on the operation of other stations (machining in a closed machine space).

The quality and environmental impact of pickling of welds highly depend on the quality of cleaning of the surface after welding (remaining slags before pickling requires additional pickling operations with negative environmental implications). Surface treatment by painting requires an optimal calculation of the needed volume of paint and choosing an optimal painting system according to the corrosiveness of the environment of product usage, avoiding excessive painting. Using metal blasting is more environmentally friendly compared to sandblasting because of the repetitive use of abrasive materials.

Interviewees also discerned different practices and methods which are applied to reduce the volume of main materials (e.g. metals) and consumables in the welding process. These practices concern: 1) practices of purchasing, like concentration of purchases of raw materials, integration of materials from engineering to make the most of raw materials; 2) practices of the product design, like applying lightweight design and modular construction of products (vehicle units); 3) practices of work organization at the workplace, like registration of work parameters of the performed process in the welding device and assigning to a specific welder, or reducing the amount of waste of materials by filling the free spaces in the metal sheet during the cutting of parts with elements for future orders, or arrangement of items on the sheet by taking into account the placement of smaller elements inside the holes punched in larger details, as well as using what can no longer be used in the production for «by-product» production, labelling unused sheets and profiles (steel grade, order) and sending to the warehouse in order to use them with the next order; 4) practices of the on-the-job training of welders by using simulator before executing the real operations; 5) practices of circular usage of the contaminating consumables, like usage of the filtered wastewater of the pickling units and baths.

Some synergies and/or trade-offs between the quality requirements and more «green» (environmentally friendly) approaches and methods in the process of welding were also distinguished. Informants noticed rather strong compliance and complementarity between the goals of quality assurance and the environment-friendly approaches of the organization and execution of work processes in welding because the quality of weld preparation is of critical importance for the reduction of emissions and economies of materials through avoiding repairs. In case of subcontracting in executing welding processes, some customers (mostly from the countries of Central and Eastern Europe) favour quality and durability of the welded products but still ignore the factor of sustainability of manufacturing, whereas other customers (from the Nordic countries) prioritize the environmental aspects of welding processes in making decisions about orders and apply audit and certification practices. The trend of the growing importance of following environmental requirements and having «green» welding processes as a part of the strategy in seeking to promote exports and enter new demanding markets is noticed.

Focus group discussions with welding experts disclosed, that the autonomy of the welders and welding operators to adjust the working methods and regimes in ways that reduce emissions and consumption of materials and consumables is very limited because these methods and approaches are prescribed by the welding procedures, standards and other documents. Due to a detailed prescription of the working tasks, welders must comply with the technical documents and specifications. Welding is a highly complex work process, especially attaining the quality requirements involves a lot of effort, thus, the responsibility of the welder has to be clearly delimited and cannot be broad.

Welders receive detailed guidelines on the welding procedure specification (WPS). Corrections made by an employee are possible but within the permissible range (e.g. 10 %) of a parameter change. If employees perform their tasks in certain ranges, they do not have to inform technologists about changes. In the case of piecework, welders cannot change any process parameters on their own, and each such fact is registered in the welding equipment control system in order to prevent the tendency of welders to «accelerate» their work by excessively increasing parameters (e.g. welding current) and, consequently, increasing the volume of non-conformities. Therefore, it is suggested to ensure clear and transparent order in the field of collecting, sorting and processing of wastes and prevention of emissions. Besides, it is recommended to provide the training and awareness-raising of welders on why the concrete practices are applied and how these practices contribute to wellbeing at work, health and environment.

Transparency and clarity of the technical documents of welding (drawings and technical specifications) leave minimal room for interpretation of data by the welder and reduce the risks of non-conformities leading to increasing consumption and waste of materials and growing emissions. However, welders and welding operators must have ergonomically convenient conditions of work in order to comply with the requirements of waste management and minimization of emissions at the workplace. For example, the available and functional necessary infrastructure is needed for sorting waste and protecting the environment from emissions. Some experts also indicated that waste and emissions can be reduced by applying more intensive surveillance of the execution of welding processes, including video monitoring for control of the work of welders. These suggestions lead to the idea, that competence of welders cannot compensate for the lack of quality of the engineering and design stage. However, some experts suggested that welders and welding operators still have to possess competence enabling autonomous preparation of the welds. Besides, welders can be encouraged to come up with initiatives regarding efficiency, quality and reduction of waste and scrap, they just cannot interfere with the technology process themselves. There was also noticed, that consultations with welders are important and useful for welding engineers when preparing technical documents and procedures, collecting their feedback and practical recommendations on the optimization of welding processes.

Companies can also exploit more different functionalities of the tools and equipment which enable to reduce the pollution and waste of materials and consumables. These functionalities include, for example, using the competition of the providers of welding equipment in seeking to offer more energy-saving solutions, taking into consideration the energy demands of welding machines when purchasing new welding equipment.

With regards to work practices of welders and welding operators, they can entail different possibilities of the optimization and saving of resources. For example, applying a pulse regime in welding helps to control the thermal input and to regulate the volume of energy, while using synergetic regimes of welding helps to control and optimize the energy consumption. Usage of submerged-arc welding or combination of welding regimes with submerged arc welding for the welding of high thickness metal sheets permits to reduce of the number of welding passes. For example, in welding 100 mm sheets the root of the weld is welded by semi-automatic welding, the remaining weld being done with the tractor of submerged arc welding by using the wire of 4 mm diameter.

Robots replace welding sources in seeking to reduce or eliminate ineffective and energy-intensive operations. Automation permits the reduction of the volume of rejects and increases the efficiency and repeatability in welding and cutting: CNC cutters use software that optimizes the distribution of elements on the sheet and facilitates the management of material and cut orders.

The skills and competences of welders play a crucial role in making welding processes sustainable. For example, companies tend to favour «faster» welding by experienced and skilled welders in seeking to use fewer materials and save emissions. It entails the risks of mistakes and non-conformities that can increase the usage of materials, consumables and waste of the welding process. Personalized methods and approaches in reducing the volume of emissions are also applied, depending on the individual experience of the welder or apprentice.

Focus groups helped to distinguish a range of different competencies of welding operators, technicians and engineers which are important to the sustainability of the work process. For example, holistic practical know-how of the welding processes in order to apply the proper sequence of operations is important. Dexterity of welders and their psycho-manual skills in manipulating the welding equipment to ensure the optimal accuracy of welds is also very important for avoiding non-conformities and for reducing the usage of materials and consumables. The welding engineers and design specialists should possess the know-how of the welding quality requirements for the different constructions and products, especially when deciding about sufficient (not excessive) quality requirements for the welding process, or when suggesting alternative procedures of welding. The customer-oriented and environmentally friendly manufacturing in the welding sector, such as the production of lighter weight vehicles, leading to CO_2 savings and increasing possible load capacity also raise the demand for specific know-how and competencies, including the know-how on how to increase repairability of products (USP special vehicle construction, vertical range of manufacturing), how to optimize yield strengths of the steels in the welding process, or how to alternate welding and screwing by referring to the resilience and reliability of the joining. Such know-how should be supplemented and supported by the practical skills and practical (tacit) know-how of welding processes, especially when making decisions about optimal technological processes, procedures, regimes and design. With regards to welding supervisors and masters, they should possess a holistic understanding of the welding product characteristics, to understand the process of waste management at the workplace and work process levels.

The participants of workshops and focus groups noticed, that the current vocational training programs and pathways in the field of welding do not give enough attention and space to the training of «sustainability» competencies, there is a lack of the modules of practical training of such competencies. It especially concerns initial vocational education and training. Current framework curricula are not up-to-date with the requirements of the «green skills» and are oriented only to the covering of basic requirements. Occupational standards and curricula related to welding do not sufficiently cover digitalization and sustainability-related skills and competencies.

Discussion and conclusions. Our research disclosed, that implementation of the circular economy principles in the work processes of welding entails new competence needs in these work processes. These new competencies are referenced to the different qualifications.

Six competence areas and competence development steps of application of circular economy principles in the work process of welding can be distinguished:

1. Following the design and maintaining sustainable work processes and products.
2. Sustainable and circular preparation, maintenance and design of the workplaces in welding.
3. Sustainable and circular execution of technological operations in the field of welding.
4. Sustainable and circular organization of work in welding.
5. Sustainable and circular digitalization of the work processes in the field of welding.
6. Sustainable and circular design of welding processes and products.

Following the design and maintaining sustainable work processes and products is typical for the work processes of welders and welding operators (EQF levels 3 and 4). It entails three main competence development steps. In order to reduce the consumption of materials and production of waste in the welding processes, welders must be able: 1) to read the drawings and understand the symbols and technological information to avoid mistakes and non-conformities; 2) to clarify the technological requirements and possible practices of sustainable technological work regimes (using of materials, applying welding regimes, preparation of materials) with designers and engineers; 3) to discuss possible, from the welder's and his shop's point of view, sustainable resource use practices by arguing one's proposals properly and to apply the instructions and suggestions of sustainable usage of materials and consumables in the welding practice.

Sustainable and circular preparation, maintenance and design of the workplaces in welding requires from the welders and welding operators (EQF levels 2-4): 1) to keep the workplace tidy (e.g. putting scrap metal in the designated place); 2) to verify the parameters of the dust extraction system (the condition of the welding station) and the performance of the welding source (and its changes) by following internal regulations and rules of the enterprise, using control sheets of filtering systems; 3) to sort and dispose the waste at the workplace according to defined waste management procedures and systems (ISO etc.), internal rules of waste management, environmental guides; 4) to evaluate each waste produced at the workplace and its suitability for further use; 5) to execute and ensure the traceability of the used materials in ensuring economic usage of the main materials (metal sheets) by moving the remaining materials to the warehouse and using them in further production (when it is a part of work delegated to welder/welding operator); 6) to evaluate the welding position and to apply the possible countermeasures, evaluating the risk of failures or poor welding regimes.

Sustainable and circular execution of the technological operations in the field of welding contains seven competence development steps of welders and welding operators (EQF level 3-4) typical for different stages of welding process, including abilities: 1) to develop practical skills of welding by using simulator before executing the real operations, practicing; to use test equipment of the alternative methods, e.g. safety-relevant bolting, tightening torques and bolted connections by hand; 2) to perform quality control of the materials and executed welds: reading and checking the markings of the material to be welded and welding consumables, visual control of the metal sheets and workpieces before the welding in order to spot and remove dirt, slags, rust and other deficiencies potentially having harmful effect on quality and volume of used materials; to perform the self-inspection of weld by using inspection gauges, as a way to prevent the non-conformities; 3) to apply savvy procedures of the preparation of raw materials for welding permitting to save on the surface treatment operations after welding (metal and sand blasting); to follow the technological requirements and guidelines for selecting and fine-tuning of the composition of welding consumables: shielding gases, welding wire, electrodes etc.; to prepare the surface and edges of the workpieces and sheets before welding by using cutters, grinding plates instead of abrasive materials (where possible); to perform the edge preparation in the ways which help to optimize the volume and intensiveness of the welding/joining and to minimize the zones of weld area; 4) to strictly follow quality management procedures, requirements of the WPS and welding instructions; to visually assess the quality of weld; to evaluate the effect of changing welding parameters on the quality of weld; 5) to ensure proper quality of cleaning the surface after welding (remaining slags before pickling requires additional pickling operations with negative environmental implications); to strictly follow the requirements of the need of the volume of paint and other surface treatment materials by referring to the corrosiveness of the environment of product usage; 6) to apply higher pace in performing welding operation in seeking to use fewer materials and save emissions (only for highly experienced welders, not compromising the quality); 7) to apply possible changes in the welding process parameters to optimize the welding process; to apply technological solutions of welding regimes that allow for the reduction of subsequent work expenditure on cleaning the connection; while performing welds to keep within the limits of thermal impact defined in the welding procedure; to perform welds in applying savvy regimes, such as pulse regime to control the thermal input and to regulate the volume of energy, using synergetic regimes of welding to control and optimise the energy consumption; to apply submerged-arc welding or combination of welding regimes with submerged arc welding for the welding of high thickness metal sheets, permitting to reduce the number of welding passes; to apply contact welding (point welding) instead of full joint welding, where possible; to use the CNC machines (plasma cutters, lasers) in seeking to limit the harmful impact of welding processes on the operation of other stations (machining in a closed machine space).

Sustainable and circular organization of work in welding is typical for welding supervisors and technicians and contains five competence development steps: 1) to control issuing the materials and welding consumables for welders by disciplining the welders and signaling / discussing the cases of excessive consumption of materials and consumables of welding; to organize proper quality control of the metal sheets, to select and use less «contaminating» welding consumables, like, for example, solid welding wires which produce much less emissions that when using «powder» based welding wire; 2) to ensure the proper division of tasks amongst the welders by considering their qualifications and their fit to the quality requirements related to the complexity of welding processes at individual workplaces; to ensure the right following of the sequence of welding operations defined by the technological specifications; to plan all the working operations in the holistic way by taking into consideration their interdependencies; 3) to define clear goals and clear work plan of welding process; to support transparent and constant cooperation between welding engineers, technologists, experienced welders and welding operators regarding requirements and environmental preferences; to plan the work and control of work by methods and times to avoid unnecessary tasks; 4) to organise the teamwork of welders with different levels of qualifications, including the organisation of work of experienced welders and beginner operators; to mentor the welders by providing suggestions and recommendations on how to apply more sustainable and economic ways of performing different welding operations; to exchange practical and theoretical know-how on the sustainable and circular approaches and ways of welding between welders, welding operators and engineering staff; to collect and evaluate the suggestions from the welders on the improvement of sustainability of the welding processes; 5) to establish and maintain close collaboration between production preparation and programming units in the field of sustainable optimisation of the welding processes.

Sustainable and circular digitalization of the work processes in the field of welding contains the competence to apply the automated welding processes (welding robots, CNC laser cutters used in repeatable processes leading to the reduction of defects) typical for welders and welding operators (EQF level). It also involves the competence to monitor and mitigate the consumption of the materials and energy in operating welding robots at the initial stages of their implementation by seeking to deal with possible increases in this consumption by following and analyzing information about the status and progress of the welding process typical for welding supervisors and technicians (EQF level 5). Finally, it includes the competence to optimize accessibility and communication of the production data between the welding robot, operator and design specialist in seeking to reduce the volume of welding seams and to reduce the volume of emissions typical for welding engineers and designers (EQF levels 6 and 7).

Sustainable and circular design of welding processes and products is typical for welding engineers and designers (EQF 6-7) and involves six main steps of competence development: 1) to apply know-how of the welding quality requirements for the different constructions and products when deciding about sufficiency (not excessive) of these requirements for welding process; to evaluate possibilities to optimise yield strengths of the steels in the welding process; to minimise the volume of welded joints in the design of products, taking into consideration the volume of waste and it's management options resulting from the design; to optimise the weld joint design; 2) to select the most economic and environmentally friendly welding processes, regimes and procedures for each case by taking into consideration technological and product requirements (not compromising quality but avoiding excessive welding regimes, e.g. often the use of submerged arc welding for thick sheets helps to economise on the preparatory edge cutting of sheets and to reduce emissions from this process); to control the selection of welding regimes in order to avoid applying excessive regimes regarding thermal impact; 3) to combine the theoretical know-how and engineering expertise with the practical (tacit) know-how of welding processes possessed by welders and welding operators, especially when making decisions about optimal technological processes, procedures, regimes and design; to engage in consultations with welders when preparing technical documents and procedures, collecting their feedback and practical recommendations on the optimisation of welding processes; 4) to design clear and transparent order in the field of collecting, sorting and processing of wastes and prevention of emissions of the welding processes; to develop the transparent and clear technical documentation for welding (drawings and technical specifications) leaving a minimal room for interpretation of data by the welder; 5) to evaluate the possibilities for applying alternative procedures of welding; to consider and foresee partial replacement of the welding with other technological processes having lower impact on environment (e.g. screwing and riveting), where possible; 6) to design the customer-oriented and environmentally friendly welded products, leading to CO_2 savings; to consider the increasing of repairability of products in the design process (USP special vehicle construction, vertical range of manufacturing, applying lightweight design and modular construction of products (vehicle units)).

There are several possibilities to improve and adapt the existing and approved VET curricula to the requirements imposed by the principles of the circular economy. Here we can suggest several possible scenarios which require further exploration and verification.

The indicated competencies (or some of them) are explicitly indicated in the prescribed VET curricula (descriptors for VET standards, modules, modular curricula), but not (sufficiently) provided and developed in the training practice because of optional status or other reasons like a lack of awareness of their importance from the side of the VET teachers and trainers). Such a situation is highly unfavorable for the introduction of the «circular economy» competencies in the VET curricula and requires strategic interventions from the side of governing bodies and VET providers.

The indicated competencies (or some of them) are not explicitly indicated in the prescribed VET curricula but are included and implemented in the training processes under the initiative of the VET teachers and trainers (as a part of the provision of the other related competencies). This situation, compared to the previous one, is more favorable for the provision of «circular economy» competencies in the VET curricula related to welding, but it entails some risks related to a strong dependence of the provision of competencies on the initiative of the separate VET teachers and trainers (lack of systemic approach).

The indicated competencies make an integral part of both prescribed and realized VET curricula. This is the optimal situation/scenario which ensures both systemic and sustainable provision of these competencies.

References

1. Dujarier, M.-A. (2021). Troubles dans le travail. Sociologie d'une catégorie de pensée. Paris: PUF.

2. Suzman, J. (2020). The 300,000-year case for the 15-hour week. *Financial Times.* Retrieved from https://www.ft.com/content/8dd71dc3-4566-48e0-a1d9-3e8bd2b3f60f.

3. Clot, Y., Bonnefond, J.-Y., Bonnemain, A., & Zittoun, M. (2021). Le prix du travail bien fait. La cooperation conflictuelle dans les organisations. Paris: La Découverte.

4. Mehta, K. P. (2019). Sustainability in Welding and Processing. In K. Gupta (Ed.). *Innovations in Manufacturing for Sustainability*, 125-145. Cham: Springer.

5. Kapil, A., & Sharma, A. (2015). Magnetic pulse welding: an efficient and environmentally friendly multi-material joining technique. *Journal of Cleaner Production, 100,* 35-58. DOI: https://doi.org/10.1016/j.jclepro.2015.03.042.

6. Chiou, R. Y., Mauk, M. G., Husanu, C., Tseng, T., & Sowmithran, S. (2019). Virtual Reality Laboratory: Green Robotic Ultrasonic Welding. In *Proceedings of the ASME 2019 International Mechanical Engineering Congress and Exposition*, *5.* DOI: https://doi.org/10.1115/IMECE2019-11912.

7. Nguyen, T. D. (2016). Study and Fabrication of Virtual TIG Welding Equipment. *Applied Mechanics and Materials, 842,* 288–292.

8. Vimal, K. E. K., Vinodh, S., & Raja, A. (2015). Modelling, assessment and deployment of strategies for ensuring sustainable shielded metal arc welding process – a case study. *Journal of Cleaner Production, 93,* 364-377. DOI: https://doi.org/10.1016/j.jclepro.2015.01.049.

9. Saad, M. H., Darras, B. M., & Nazzal, M. A. (2021). Evaluation of Welding Processes Based on Multi-dimensional Sustainability Assessment Model. *International Journal of Precision Engineering and Manufacturing-Green Technology, 8,* 57–75. DOI: https://doi.org/10.1007/s40684-019-00184-4.

10. Rivas, D., Quiza, R., Rivas, M. & Haber, R. E. (2020). Towards Sustainability of Manufacturing Processes by Multiobjective Optimization: A Case Study on a Submerged Arc Welding Processs. *IEEE Access, 8,* 212904-212916. DOI: 10.1109/ACCESS.2020.3040196.

11. Raworth, K. (2017). *Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist.* VT: Chelsea Green Publishing.

Відмантас Т.
Ph.D., професор, директор Центру професійної освіти та досліджень Університету ім. Вітаутаса Великого, Каунас, Литва, vidmantas.tutlys@vdu.lt
ORCID ID: https://orcid.org/0000-0003-2000-8862

Гедвілієне Г.
Ph.D., професор, науковий співробітник Університету ім. Вітаутаса Великого, Каунас, Литва, genute.gedviliene@vdu.lt
ORCID ID: https://orcid.org/0000-0002-1797-8924

Букантайте Д.
Ph.D., доцент, заступник декана музичної академії Університету ім. Вітаутаса Великого, Каунас, Литва, daiva.bukantaite@vdu.lt
ORCID ID: https://orcid.org/0000-0003-4590-9173

Шчіглінсьєне А.
Ph.D., директор Алітуського бізнес-консультаційного центру, Алітус, Литва, direktore@avkc.lt
ORCID ID: https://orcid.org/0000-0002-3042-1231

Баранаускайте А.
Констультант Алітуського бізнес-консультаційного центру, Алітус, Литва, buhalterija@avkc.lt
ORCID ID: https://orcid.org/0000-0002-9416-0333

Урбанавічус Р.
Проєктний менеджер Алітуського бізнес-консультаційного центру, Алітус, Литва, konsultantas@avkc.lt
ORCID ID: https://orcid.org/0000-0002-3781-1582

Шмідт К.
Проєктний менеджер Дослідницького інституту бізнес-освіти в Берліні, Берлін, Німеччина, christine.schmidt@ibbf.berlin
ORCID ID: https://orcid.org/0000-0002-4635-4563

Торібіо Х. Р. Н.
Менеджер з інновацій «Метаіндустрія 4», Хіхон, Іспанія, jrnatal@metaindustry4.com
ORCID ID: https://orcid.org/0000-0002-0557-5650

Гарсія С. Х.
Менеджер з інновацій «Метаіндустрія 4», Хіхон, Іспанія, cluster@metaindustry4.com
ORCID ID: https://orcid.org/0000-0003-3504-4380

ПРИВЕДЕННЯ ПРОГРАМ НАВЧАННЯ ФАХІВЦІВ ЗІ ЗВАРЮВАННЯ У ВІДПОВІДНІСТЬ ДО ПРИНЦИПІВ ЕКОНОМІКИ ЗАМКНЕНОГО ЦИКЛУ[1]

Анотація. *Провідну роль у підготовці компетентних фахівців, зокрема зі зварювання, відіграє професійна освіта. З огляду на останні зміни у виробничих процесах, пов'язані з розвитком економіки замкненого циклу, програми навчання таких фахівців потребують перегляду. Метою статті є визначення основних напрямів змін у програмі професійно-технічної підготовки фахівців зі зварювання із урахуванням принципів економіки замкненого циклу. У статті розглядаються підходи, що переважно засто-*

[1] Співавтори дослідження: Зінов'єва О. (проєктний менеджер Дослідницького інституту бізнес-освіти в Берліні, Берлін, Німеччина), Поулаковський Я. (операційний директор Центру розвитку та просування інновацій, Білосток, Польща), Пшедлацька М. (менеджер з маркетингу Центру розвитку та просування інновацій, Білосток, Польща), Массарі І. (головний менеджер «Реіндустрія інновацій», Кремона, Італія), Лонгарі Р. (проєктний менеджер «Реіндустрія інновацій», Кремона, Італія).

совуються для визначення складових робочого процесу зварювання й переліку фахівців, потрібних для його ефективного та якісного виконання. Для досягнення поставленої мети використано два основних наукових підходи: модель соціальних і планетарних меж та аналіз навчання на робочому місці. Було проведено структурований семінар для цільових груп, у ході якого опитано досвідчених робітників, а також викладачів і тренерів. Опитування охоплювало вісім напрямів – від організації робочого процесу до оцінки програми підготовки зварювальників та необхідності внесення змін до неї. Детальний аналіз робочого процесу зварювання, а також обов'язкових процедур для його виконання дав можливість визначити основні навички й уміння, якими повинні володіти зварювальники, та на підставі цього – шість ключових компетентностей, що їх повинні набути фахівці під час професійного навчання.

Ключові слова: *програма професійно-технічної підготовки, компетентність, економіка замкненого циклу, фахівці зі зварювання, економія матеріалів, скорочення викидів, оптимізація робочих процесів.*