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WIP: Building an Education Ecosystem for Next Generation Microelectronics Experts in Green and Circular Economy with digitally-supported Teaching Methods for sustainable Chips and Applications (EU Project GreenChips-EDU)

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***Abstract*— This work in progress innovative practice paper intends to report on the outline and the ongoing progress of the EU-project GreenChips-EDU, which has been started in October 2023, and intends to fundamentally redesign educational microelectronics programs especially but not limited to students and professionals. One of the major goals is the design of a new microelectronics master program to which six European universities are contributing. The contents of this program will be substantially enhanced with green electronics contents innovative teaching methods. Other work will be done in the field of a new MBA program, self-standing modules for professionals, and a new microelectronics bachelor designed by one university of applied sciences.**

Keywords—Joint European Microelectronic Master Program, skill gap, green engineering, microcredentials, e-learning, lifelong learning, Industry Involvement.

I. Introduction

The digital and green transitions of nations around the world increasingly rely on semiconductors, which enable innovative solutions for key sectors such as e-mobility, health-care appliances, industrial and renewables [1]. This is why nations worldwide are currently offering large-scale investment programs, such as the U.S. and the European Chips Acts [2], to advance a homegrown microelectronics R&D, design and manufacturing base.

With the EU Chips Act, Europe aims to increase its global production share in semiconductors to 20% in value by 2030. EU semiconductor workforce forecast was expected to grow by 6.5%/year for the period from 2022 to 2023, boosted by numerous investment plans [3], [4], [5], [6]. The forecast for 2030 is about 500k meaning 200k more employees needed, which translates into a massive increase in open jobs in the European semiconductor ecosystem. Jobs that need to be filled by a skilled and diverse workforce that is constantly learning and innovating.

Against this backdrop, Europe is facing an already chronic shortage of microelectronics workers with skills gaps being one of the biggest challenges that undermine the growth potential of not only the semiconductor industry, but the European economy as a whole. In the most recent report of European Labour Authority, STEM profiles were identified as profiles of high magnitude shortages [7]. Likewise, nearly 1.1 million job advertisements for electrical- and electronic engineers were placed in the EU between mid-2018 and the end of 2019 (CEDEFOB, 2020). A university of technology in Austria reports a 60% drop in student inflow in electrical engineering over the last 10 years (see Fig. 1) Similar patterns exist in other universities across Europe.



Fig. 1: Number of first semester students in Electrical Engineering over the last ten years.

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According to the European Chips Survey Report, overall demand for both wafers (volume) and integrated circuits (projects) will increase significantly in the coming years [7]. Similarly, demand for advanced technology nodes will increase in the short and medium term. The report also shows that the most important factor in choosing a new location for a production plant is the availability of skilled labor.

Another survey involving 316 stakeholders from 171 organizations (representative of ~145,000 microelectronics jobs in Europe, ~55% of the European microelectronics workforce) provides another detailed overview of the current and future skills shortage [8], [9]. In the evaluation of the survey, particular attention was also paid to so-called "critical skills". This refers to qualifications that have been in greatest demand by European industry since January 2022 and are also the most difficult to fill. The result indicated 9 key fields of skills confirmed as the most critical across job profiles, which are:

- System architectures (SoC, SiP, ASICs…)
- Data analysis
- Artificial Intelligence Machine learning
- Analog design
- Knowledge of applications (environment, linking components, materials, design constraints to apps)
- Quality/reliability related skills
- Security related skills
- Hardware/software co-integration

In addressing these challenges GreenChips-EDU is building an education ecosystem in microelectronics with a focus on green chips for green applications. Green chips refer to microelectronics or integrated circuits that are designed and manufactured in a way that minimizes their environmental impact. This can include using eco-friendly materials and manufacturing processes, as well as designing chips to be energy efficient and have a longer lifespan. In addition, in a systemic approach to eco-design, minimizing the environmental impacts of all phases of the product life cycle, including manufacturing, distribution, use and repairability or recyclability, is a key factor. The goal of green chips is to reduce the carbon footprint and environmental impact of the microelectronics industry and its products while still meeting the demand for high-performing, reliable devices. This goal can only be reached with a next generation of students who have the right theoretical and practical interdisciplinary and expert knowledge, and also the right mindset for the criticality.

Fifteen partners from seven European countries integrating the knowledge triangle of excellent education, research and innovative businesses will get into action to translate the findings of previous strategic projects into specific cooperative training measures and contribute to the overall aim of worldclass leadership in the training of digital specialists.

II. UNITE! PARTNER UNIVERSITIES AND THE GREENCHIPS-EDU JOINT ATTEMPT

A. Unite!-University Network

Unite! is a network of universities in nine countries that will set a new model for a European virtual and physical inter-university campus. Unite! will connect engineering, science and technology with the challenges of society in co-creation by students, faculty and staff – providing skills for a new generation of European and global citizens. Unite! already builds on three decades of close and dedicated cooperation on different aspects of higher education, research, innovation and social responsibility with eight of the nine partners. Unite! thus creates a reinforcing framework of already existing collaborations. Currently, the Unite!-network consists of the following member universities: Grenoble INP-UGA (France), TU Graz (Austria), TU Darmstadt (Germany), Universidade de Lisboa (Portugal), UPC Universitat Politècnica de Catalunya (Spain), Politecnico di Torino (Italy), KTH Royal Institute of Technology (Sweden), Aalto University (Finland), Wroclaw University of Science and Technology (Poland). Except the last three universities (KTH, Aalto and Wroclaw), all other universities are project partners in the GreenChips-EDU project. All Unite!-partners have already established procedures and contracts for simplified cooperation, student and staff mobility.

B. Addressing the microelectronics skill gap in a joint effort

Integrated electronics education has undergone a significant change since the 1980ies – in those times, the study of a single course or book was essentially sufficient to get an overall idea of the underlying technology, circuit design and verification [11]. Today, only few large universities are, due to the explosion of knowledge and involved disciplines, but also due to the lack of qualified staff including numerous professors, able to offer fundamental courses for analog, mixed-signal and digital integrated circuit design, which include solid basis of technology understanding, as well as elective courses, which lead master level students towards specialized topics required for starting a research-oriented master thesis in this field.

III. GREENCHIPS-EDU PROJECT STRUCTURE

The EU is funding the GreenChips-EDU project with 7.15 million euros. Project start has been in October 2023, and it end by September 2027. While first students are expected to enroll in the green microelectronics curriculum by October 2024, it will be continuously extended in content and number of modules, it is expected that by the end of the project an appreciable number of students have completed their master´s degree in green microelectronics, and also used the physical (double degree) and virtual mobility (remote learning at a Unite!-university). It is also expected that during the project a substantial number of professionals have been trained (microcredentials), or participated in the MBA or LLL programs. Overall, it is expected that GreenChips-EDU project attracts more students to enroll in a microelectronics curriculum, also due to increased early insight into the impact on sustainability and environmental protection that was previously not obvious for microelectronics.

Fig. 2 shows the overall project ecosystem. The upper green bar shows the expected new or redesigned programs and curriculum outcomes. In the following sections we will shortly outline the planned programs. The middle orange horizontal line describes the degrees or certificates that are envisioned within GreenChips-EDU, whereas the blue bottom field mentions exemplary methods for achieving the goals and increasing efficiency by cooperation.

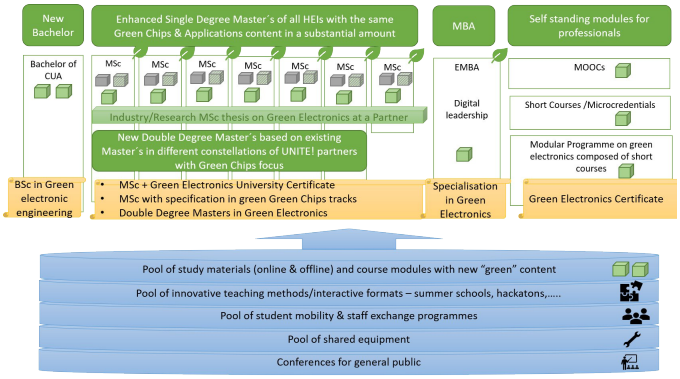


Fig. 2: GreenChips-EDU project structure

A. New Bachelor program

The new bachelor program in the field of microelectronics will be driven by CUAS (Carinthia University of Applied Sciences, Austria). As a modern and broad-based course of study in electronics engineering, the Bachelor's degree program "Green Electronic Engineering" enriches the already well-designed curriculum with topics related to the sustainable development goals such as low-power and energy-efficient systems, design for recyclability and repairability and new, eco-friendly materials. Special topics range from efficient conversion of electric energy, e.g. for photovoltaic applications and battery charging, application of organic semiconductors for low power and efficient displays to environmental sensors to monitor the biosphere and industrial processes.

B. Enhanced single degree masters´ of all higher education institutions with Green Chips and application content

Students will apply to one of the local master programs of the seven awarding universities and in parallel to the "Green electronics focus" program within the GreenChips-EDU project.

As part of the typically four-semester master program, students are introduced to compulsory fundamentals at the beginning. An increasing number of lectures will also be made available as online courses. In the further course of the degree program, students can choose from a range of courses on the subject of green chips and green applications. To complete the degree, students will be required to write a thesis on a green electronics topic. Students are also encouraged to participate in summer schools, hackatons or makerspaces as part of this specific degree program.

Students graduate with a master´s degree and, depending on the university program, either an additional certificate or a specialization in green electronics. Since six universities are members of the Unite! program, the students will also have the opportunity to enroll in and complete a double degree program during the course of the project.

The advantage of this approach of building on existing master programs is, that the first student pilot cohort can start as early as the beginning of the second year of the project. Otherwise, as prior consultation between the Unite! partners has revealed, the accreditation process takes too long to be able to award a degree within the project duration.

Nevertheless, the aim of the project is to harmonize fundamental courses, jointly digitize content and to develop joint new green electronics modules. As a first step, in the preparation of the proposal, all university partners listed all their courses of the relevant master´s regarding the title, the type, the ECTS, the category and compulsory subject. It was then screened where courses should be digitized together, where new green content can be added and where completely new green courses should be developed. Therefore, GreenChips-EDU will as well use existing courses in microelectronics but also new material prepared within the project. The master programs will be rolled out and piloted during the project. Students will be empowered with the following skills:

- General: Applied and research skills in all aspects of integrated microelectronic circuit and system design, from deep understanding of system and specification level needs (project management, agile methods, specification), design and verification (on various levels for analog, mixed-signal, digital, smart-power), fabrication (PDK/foundry usage, DfT, production test) and test chip setup and measurement.
- Specific to the focus on green chips and green applications: deep understanding of the circularity needs for chip design, usage and eco-friendly microelectronic hardware during usage and at the end of its life-cycle will be taught in theoretical and practical aspects. Furthermore, the aspects of power efficiency, energy harvesting and power supply (ranging from power semiconductors, regulated chip power supply to novel energy efficient computing paradigms (e.g. neuromorphic computing vs. digital)) for integrated microelectronics will be significantly strengthened. On PCB level, the aspect of eco- and repair-friendly design with modern design tools will be introduced on theoretical and practical level.
- A focus will also be on environmentally sustainable chip manufacturing as well as design of energy-efficient chips used in green applications. Novel courses related to AI and quantum technologies will demonstrate power electronics' increasing relevance and contribution to these areas.

Environmental awareness according to METIS [3], [9] findings:

- Circular economy: Circular economy in the design process to include at design level green economy and green growth aspects, as an industrial product's environmental performance is fixed up to 80% at the design stage.
- Sustainability, recyclability and reusability of production: How to produce "green microelectronics" for instance dealing with issues that relate to the processing of raw materials and disposal of industrial waste.
- Ability to assess the environmental impact of a design.
- Environmental aspects associated to traditional and new materials
- Energy efficiency of the manufacturing processes: How to minimize energy consumption and protect the environment through manufacturing processes.
- Artificial intelligence & sustainability: Specific courses given to students aiming to work on cloud / edge computing and/or artificial intelligence. The goal is to sensitize students to the energy consumption of AI and present good practices and alternative solutions.

- Soft skills: Soft skills, as a major ingredient for a successful career, are integrated and treated in a transversal manner across all lectures, subjects, and degrees. Particular attention will be placed on developing entrepreneurial skills, also partly through collaboration with several technology transfer institutions within the university or LLL departments. This approach allows students to develop a well-rounded skill set, including technical and business acumen, critical thinking, problem-solving, and effective communication.

Ethical principles of a trustworthy technology:

- A majority of modules (lectures, seminars, labs) will be enhanced towards inclusion of power and resource aspects. To illustrate this, we have to be aware that in the 1980ies most electronic designs have only been designed in terms of functionality and manufacturability. In the following decade timing was growing in importance, and with SoCs verification became a major issue. It is currently foreseeable that any electronic IP (integrated or discrete) has to be designed over its lifecycle towards reusability, possible repair/upgrade-friendliness, supply-chain/2nd source and low-power-aspects. The need for this is obvious if we face the envisioned AI and IoT applications, that will intrude every aspect of industrial and private life in numbers beyond billion devices.

C. Project metrics and Evaluation of project success

One workpackage has been dedicated to roll-out, implementation and improvement of the novel GreenChips courses, self-standing modules and MBA. As for regular modules, a quality assurance system based on enhanced feedback forms will be established. The enrollment of approx. 600 students working towards a green microelectronics degree during the project duration is targeted.

IV. MBA AND SELF-STANDING MODULES

Most of the university partners have “Life Long Learning” departments installed that can easily take over roles in upskilling and reskilling.

A. MBA

The Life Long Learning department of e.g. TU Graz is offering a wide range of digital transformation courses, Tech MBAs or Executive MBAs (EMBAs). These courses and MBAs will be enriched with the possibility of a specialization in green microelectronics. The learning material is based on the already developed content within GreenChips-EDU.

B. Self Standing Modules

Aside from the highly modularized typically 5 ECTS modules offered by the university partners in their master programs, it is planned to offer significantly shorter digitally enhanced learning materials. This learning material is planned to be based partially on available material in the 5 ECTS modules, but the focus is quite different:

- These short courses (or microcredentials) can be used to enhance the knowledge of a student going to attend a partner university with different curriculum. Potentially missing skills, methods or learning outcomes are efficiently acquired.
- Such courses can also be used for experienced professionals, who are lacking certain methods, or simply want to acquire technical knowledge in a certain field. These fields can be new/modern fields (e.g. AI, or novel technologies), or simply brushing up knowledge.

By combining individual microcredentials, a broad, flexible, topic-related offer can be developed in a structured and systematic way, consisting of both shorter units, such as a module with a scope of 5 ECTS, and longer continuing education measures such as certificate courses (10/15/20/25 ECTS), up to multi-semester continuing education master's programs between 60 and 90/120 ECTS in the fields of Green Electronics and Digital Transformation.

V. INNOVATIVE TEACHING METHODS

All those programs will be accompanied by a pool of innovative teaching methods (gamification, supplementary online material (interactive formats), integrated labs, modern/motivational applications, flipped classroom [12], [13]) that students participate in and where business partners will strongly be involved. Through student projects, sustainability hackathons and specific courses, it is shown how electronics and concepts of appliances with modern eco-design can help to avoid waste, extend product life cycles, effectively manage the repairability of appliances, and enable second life concepts and recyclability. Learning repair cafés are also a highly interactive format. Broken devices or negative design examples are used to emphasize the importance of a holistic, green design. Beyond this, the involved large companies, such as Infineon Austria, are offering summer schools with experts and guest professors from participating universities. The broad range of teaching methods aims also aims to emphasize the immense green impact of designing electronics for applications, motivate a continuous participation during the semester, but also to minimize dropouts at any stage of the curriculum.

VI. ATTRACTING QUALIFIED TEACHING STAFF AND STUDENTS

Staff exchange programs are part of the GreenChips-EDU project: the complementary expertise of the staff involved of all partners will ensure that students benefit from a universal know-how. On the other hand, the exchange of staff and mutual visits with the possibility to get to know the infrastructure and resources of the partners will drive cooperation not only in education projects but also in R&D.

SUMMARY

This work-in-progress paper intends to inform on the project goals and first outcomes resp. strategically decisions for implementation. The project partners are convinced that the success of such educational projects is the key for addressing important problems, such as lack of skilled students and engineers, but also increasing the attractiveness of studying electrical engineering. GreenChips-EDU is building an education ecosystem in microelectronics with a focus on green chips for green applications. Green chips refer to microelectronics or integrated circuits that are designed and manufactured in a way that minimizes their environmental impact, while still contributing significantly to continuous business success.

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