

Teaching Sustainable Food Systems Engineering in the times of a Pandemic

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Abstract: Sustainable food systems embrace a range of aspects such as security of the supply of food, health, safety, affordability, quality, a strong food industry in terms of jobs and growth, and environmental sustainability in terms of issues such as climate change, biodiversity, water and soil quality. In recent years, quantitative modelling and engineering tools are being developed to better cope with these challenges at the level of all stakeholders involved, including industry, government and regulatory agencies. For example, Life Cycle Assessment (LCA) and related concepts (such as carbon or water footprints) are being exploited within a multi-objective food chain optimization framework.

A well-balanced pan-European MSc programme “Sustainable Food Systems Engineering, Technology and Business” (FOOD4S ‘*food force*’) 2020-2026 (2029), with a specific integrated and international outlook, fills an increasing need in the transfer of knowledge, experience and standards to developing countries in particular, while contributing to the necessary transformation towards social, environmental, and economic sustainability in food systems.

The purpose of this paper is to address the nature of the challenges facing agriculture and food systems, to provide knowledge about the threats and to indicate possibilities of knowledge transfer by education and research.

Keywords: sustainable food systems, food engineering, food processing, modelling and control in agriculture and biosystems, life cycle assessment, risk assessment, teaching curricula development, risk assessment, higher education

1. INTRODUCTION

1.1 The main challenges for the current food systems

While very real and significant progress has been made in reducing world hunger over the past 30 years, increasing food production and economic growth are degrading the environment. By 2050, the world population is expected to increase to nearly 10 billion people. In a scenario of moderate economic growth, this will increase demand for agricultural products, increasing the pressure on already strained natural resources.

The food chain is causing significant environmental impacts due to CO₂ emissions and enormous food waste (Adekomaya et al, 2016; Wittman et al., 2017; Acevedo et al., 2018). Globally, a third of the food produced for human consumption is lost or wasted, representing 1.6 billion tons of food and generating 8% of global greenhouse gas emissions. Producing food that is not consumed generates more than 20% of global pressure on biodiversity and is responsible for the use of almost 30% of agricultural land worldwide (FAO, 2011).

Food systems use many natural resources, including land, soil, water, phosphorus, and energy for nitrogen fertilization, processing, packaging, transportation, and cooling causing environmental impacts at a global level, including biodiversity loss, deforestation, soil degradation, water and air pollution, and greenhouse gas emissions. The continued loss of biodiversity remains a matter of great concern (Eastwood et al., 2021). Food systems are one of the causes of climate change and at the same time are inevitably affected by it. The changing climate is the cause of the variability of precipitation, an increase in the frequency of droughts and floods and is having an impact on food production. Climate change will affect the availability of basic natural resources (water, soil), leading to significant changes in food and industrial production conditions in some areas. Extreme climatic conditions, as well as the further spread of climate-related plant and animal diseases, are already affecting food production today and the impact will increase in the future.

For all participants in the food chain, the knowledge and elimination of biological, chemical and physical hazards is crucial. A threat to food safety may occur at any stage of the food chain, therefore appropriate control is required

throughout the entire process of food production - starting from raw materials, through the technological process, and ending with the storage of finished products and distribution to the consumer. Ensuring safe food, compliance with safety systems and risk control are important at every stage of food production. Due to the continuous technological progress, there is a need to improve the control system and analytical methods that are able to identify these threats not only in a scientific laboratory, but above all on the production line.

Food safety and quality worldwide faces increased pressures and challenges arising from the globalization of food trade, intensive production systems and changing consumer preferences (King et al., 2017). There is an urgent need to move to more sustainable food systems covering all stages: from production to consumption - more food has to be produced while reducing environmental impact, and consumers should be encouraged to switch to diets based on healthy and nutritious products with less food carbon footprint.

No food production system alone can safely feed an entire planet, but a combination of various conventional, innovative and agroecological practices could contribute to better dealing with the environmental and climatic effects of current food production systems. In particular, a combination of precision farming, including the further development of ICT and satellite systems and agroecology, could complement conventional agriculture by providing a set of principles and practices to make farming systems more sustainable, such as better biomass use, storage and use, providing favorable soil conditions, promoting crop diversification and minimizing the use of pesticides.

1.2 Key areas for action for the transition to more sustainable food systems

1.2.1 Promote more resource-efficient and climate-resilient food production

Reducing the environmental impact of agriculture, aquaculture and fisheries, including reducing greenhouse gas emissions, requires a change in the way food is produced. More sustainable practices are required to halt the depletion of natural resources and to adapt and mitigate the effects of climate change. A number of actions could improve efficiency while increasing environmental sustainability and climate resilience. These include increasing the diversity of plant varieties and animal breeds, improving the quality of livestock through breeding, plant breeding, improving the functionality of agricultural ecosystems and water management, promoting research and innovation and applying their results, optimizing soil functions, facilitating knowledge transfer and training, and promoting technological change by supporting investment. The further development of big data processing centers should be promoted to facilitate the early detection and prevention or preparedness of extreme weather conditions and various diseases. Precision farming should also be promoted.

1.2.2 Strengthen the link between food systems and climate change strategies

The impact of climate change is felt in all aspects of food security - not only in terms of crops, but also in terms of spread

of pests and diseases, biodiversity loss, income instability, water quality etc. loss of arable land due to soil degradation and urbanization of agricultural land. Institutions and the private sector play a very important role in ensuring the resilience of food systems, for example by improving crop diversification and developing genetic resources; investing in resilient agricultural development both on and off farm; and the implementation of systems conducive to better management of the risks associated with climate change.

In response to the environmental challenges, Life Cycle Assessment (LCA) and related tools (such as carbon or water footprints) have proved to be an essential element on the evaluation of the environmental performance of food value chains (Biswas et al., 2010; Abecassis et al., 2018). Predictive modelling tools can be applied to evaluate the effects of climate change on food safety in regard to managing this new treat for all stakeholders, including industry, government and regulatory agencies. Risk analysis is a valuable tool in food safety management. This tool allows and prompts regulatory authorities and the food industry to systematically control the risks posed by pathogens and substances present in food. This analysis covers risk assessment, risk management and risk communication. Predictive modelling and quantitative (microbial/chemical) risk assessment play a crucial role in food quality and safety, providing tools which are used by the food industry, policy makers and managers to formulate and implement risk management policies and controls with the view to protecting human health and environment (Acevedo et al., 2018; Tamplin, 2017).

1.2.3 Developing the knowledge base and supporting research and innovation

Many of the challenges of global food and nutrition security require the involvement of the research community to generate knowledge, promote innovation, collaborate with society and help shape a more sustainable food system. A solid understanding of the complexity of the global food chain system and study of the principles of management, economics, marketing and finance, as they apply to the management of sustainable food businesses and the global food sector is a subsequent benefit applying to agri-food industry. Capacity building and awareness-raising are crucial, as is the transfer of knowledge from scientists to farmers and other actors. The needs analysis revealed there is a requirement for such oriented programme in education and professional field that is also in line with the strategic objectives of the WHO European action plan for food and nutrition policy in protecting the food chain, prevention and control of foodborne contamination and food safety management.

In conclusion, there was a large need for an educational programme where all the elements required for a sustainable food chain, including process dynamics aspects, quantitative risk assessment, statistics, predictive modelling and LCA are brought together in one coherent structure at an advanced, research based academic level. With the increased need for such tools comes the need for skilled individuals to develop and implement quantitative tools for safe, sustainable food and energy in the food chain.

2. METHODOLOGY OF THE EDUCATIONAL PROGRAMME

Within the context of sustainable food systems and identified

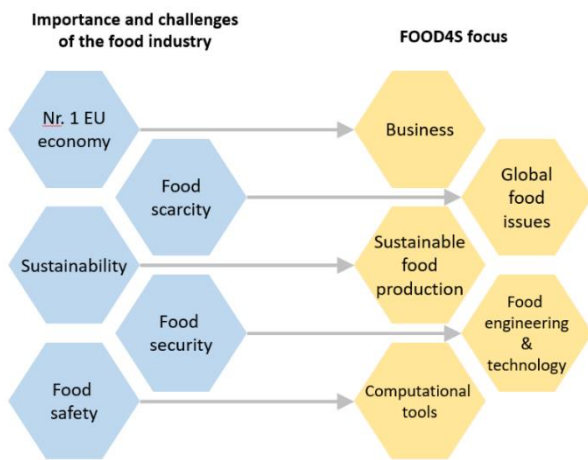


Figure 1. Programme focus towards identified challenges.

threats to food production and environment, a concept of an interdisciplinary programme has been developed (Fig. 1).

The long lasting cooperation and the existing fully complementary expertise of four European partners (KU Leuven, University College Dublin, Anhalt University of Applied Sciences, and Universidade Católica Portuguesa) evolved into the development of a novel and unique project, European Master of Science in Sustainable Food Systems Engineering, Technology and Business (FOOD4S 'food force').

It is a conjoint degree within the Erasmus Mundus framework. The European Union's Erasmus Mundus programme aims to enhance quality in higher education through scholarships and academic co-operation between the EU and the rest of the world. The supported Master programmes are expected to offer high quality education, promote the European dimension in higher education through joint curricular development, inter-institutional co-operation in teaching and supervising students, inter-institutional transfer of knowledge, joint recognition of qualifications, support mobility streams within Europe and between the EU and third countries, and finally contribute to the worldwide attractiveness and competitiveness of the European Higher Education Area (EHEA).

The interdisciplinary FOOD4S programme in innovative fields assembles a broad coverage of areas and subjects that could hardly be provided at any single institution alone. It offers an education which is at the same time broad and in-depth aiming to foster and develop knowledge and awareness of scientific trends in food science, safety and quality, food product and process design, sustainable production, ecological footprint and quantitative methods and risk analysis in food systems in a global context as 4S stands for Science, Sustainability, Safety and Simulation.

This collaborative and multidisciplinary programme brings together food scientists, food technologists, microbiologists, international experts, statisticians and process systems engineers with complementary expertise. This ensures wide appeal across the disciplines and the engagement of multidisciplinary students and encourages collaborations with industry and international scientists for the benefit of the public good.

The FOOD4S programme is quite unique in Europe, in terms of its curriculum structure and content. On the one hand, the MSc programme is covering a *broad range* of sustainable food production and processing related topics including quantitative methods such as predictive modelling and risk assessment within a horizontal, methodological and multidisciplinary approach. On the other hand, FOOD4S fully allows for a vertical *in-depth specialization*, with units of coherent course modules focusing on state-of-the-art topics in Risk and Safety, Innovative Technology, Energy and Food Chains, and Sustainable Food Production (Fig. 2).



Figure 2. Programme design and its components

Within the scope of this conference paper it is not possible to highlight all aspects of this MSc programme. We therefore limit ourselves here to those themes possibly of interest to process systems engineers.

With the globalization of international trade and the emergence of new and novel food hazards, (quantitative) risk assessment has gained international support as a tool to evaluate and manage these food safety risks. Since predictive modelling and quantitative (microbial, chemical) risk assessment play a crucial part in food quality and safety around the globe, the FOOD4S programme highly relies on this approach and aspects in its curriculum.

The risk assessment training within the FOOD4S programme is designed to explore new advances in food safety management and the implementation of risk assessment tools to provide mathematical knowledge on how to assess food safety risks. To develop a dynamic learning environment the pedagogical approach relies on a combination of some traditional lectures but with an emphasis on Problem Based Learning (PBL). At all levels of education critical thinking is a key student outcome. PBL is based upon critical thinking as

a core learning process. The problem solving process ensures students play an active role in their own learning and they use their own problem solving skills and rational to solve complex food safety problems. As a teacher the focus is not only on the final risk assessment outcome, but also on the route students take to solve a particular problem. By using multifaceted food safety problem based learning case studies, students use a combination of theory and practice to learn and develop their risk assessment skills and to communicate a rational solution to a real life food safety problem. PBL techniques are used where students work both alone and in teams (representing real life working conditions) to solve multifaceted food safety problems using risk assessment techniques. These innovative practices contribute to the development of a new generation of engineering students with a focus on applying mathematical solutions to solve complex food safety problems. These methods were also acknowledged and recognized in a session devoted to *Food engineering education: from undergraduate learning to doctoral research training* at the most recent International Congress on Engineering and Food - ICEF as evidenced by Bourke et al. (2019), Cummins et al. (2019), Polańska et al. (2019), Suciú et al. (2019), and Valdramidis et al. (2019). The FOOD4S programme integrates and provides predictive tools which are used by the food industry, policy makers and managers to formulate and implement risk management policies and controls with the view to protecting human health and environment.

For a clearer understanding of the quantitative tools to assess product quality, safety, resources intensity and environmental impacts in the food industry a number of initiatives has been developed and incorporated into the taught curriculum. In order to accomplish the goals of a good learning experience, a combination of resources is needed. These include textbooks and journals, web-based information, practical experiments, or real world problems. An integral part of the teaching assignments and methodology implemented within FOOD4S is a recent package (textbook, videos, computer exercises) on Quantitative Tools for Sustainable Food and Energy in the food chain (Q-Safe) (Valdramidis et al., 2017) (Fig. 3, Fig.4) with its primary aim to train early stage researchers, i.e., MSc and PhD candidates, in the area of predictive modelling, risk assessment and Life Cycle Assessment through inter-institutional cooperation.

The textbook's first edition was a result of Erasmus+ Q-Safe Intensive Programme (Q-Safe) with objectives to (i) bring together teaching and industrial staff who are currently working on different aspects of modelling for simulation and optimization of the quality, safety of food products and energy usage; (ii) achieve a more rounded student experience with an impact in employability of youths; (iii) address student needs by covering topics regarding Predictive Modelling, Quantitative Risk Assessment and LCA; (iv) to help young scientists to build scientific networks and collaborations, and stimulate advanced research and new directions in European academia and industry.

The provided tools included the Q-Safe textbook with theoretical background and tutorials, USB drive with computer exercises and solutions, and recorded introductory videos of

the programme's topics. One of the major outcomes of the project was the development of an e-learning course environment available to enrolled participants, which cover all the aforementioned areas (Q-Safe/e-learning) (Fig. 4). The e-learning material are also supported by the textbook with several exercises in the form of spreadsheets, programming codes or calculation exercises. In COVID-19 times especially, the e-learning platform has been proven to be a valuable tool and it has been integrated in a learning experience of our FOOD4S students, where online or hybrid mode of teaching was imposed.

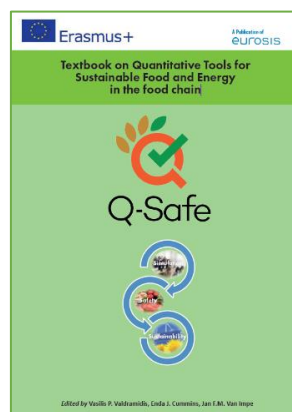


Figure 3. Q-Safe textbook

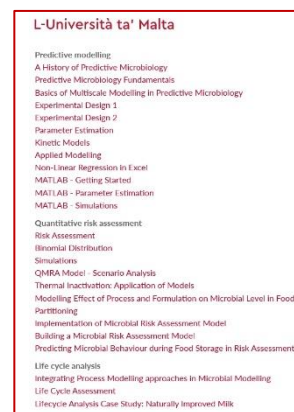


Figure 4. Q-Safe e-Learning

The Q-Safe bundle consists of 3 parts. Part I deals with Quantitative Microbiology by providing an introduction to this scientific area followed by the theory, applications and exercises in multiscale modelling and simulation. This is showcased through macroscopic, mesoscopic and microscopic modelling. The section is concluded by presenting the principles of the design of experiments and optimal experimental design for model calibration.

Part II deals with Risk Assessment. Following a detailed description of its principles two subsections are presented focusing on food safety and quantitative microbial risk assessment during food processing and predicting the microbial behavior during distribution and storage of foods in exposure assessment. Both sections are described in detail with a number of examples and exercises for the better comprehension by the readers.

The book ends with Part III, which focuses on Life Cycle Assessment. Firstly the topic of food processing and energy demand assessment are presented followed by the steps required to conduct Life Cycle Assessment studies and providing examples of its implications for sustainability.

The theoretical sections of the book cover all the fundamentals and basic principles of Predictive Microbiology, Risk Assessment and Life Cycle Assessment while examples and exercises are developed to solve realistic multifaceted problems with the use of computer programming software. These problems include the construction of experimental designs, risk model development, regression analysis, sensitivity analysis, safety risk scenarios and energy analysis.

Computer-based software packages (Excel, R, @RISK, SimaPro, open-LCA, Matlab demos) are extensively used to perform case study analysis within the principles of problem based learning.

For students the Q-Safe material can serve as a useful reference, providing a fundamental grasp of both theory and practical applications of quantitative tools, leading to a better comprehension of product quality, safety, resources intensity and environmental impacts in the food industry. The book will lead students to an appreciable understanding of the substantial body of applied modelling, statistics and its recent developments in the field of Food Science, Quantitative Risk Assessment and Life Cycle Analysis. Students will get a grasp of the principle concepts in the theory and practice of empirical and theoretical modelling and learn about existing available software packages and modelling practices. The practical examples and exercises will contribute to developing students' skills on defining problem objectives in realistic and dynamic food environments and to critically assess the application of mathematical knowledge in particular contexts.

For teachers the Q-Safe package can aid class plans and provide pre-solved examples and exercises with practical applications helping to add the assimilated new techniques in their own educational programmes. It will also help to develop new ideas in planning case studies and the development of theoretical and practical learning programmes.

For industry and regulatory readers the Q-Safe bundle will give some insight on developing and applying Risk Assessment and Life Cycle Assessment schemes which can be used for decision making and for better safety and operation management.

3. CONCLUDING REMARKS

By teaching the FOOD4S master course the consortium wants to provide *technologists* with a better understanding of the general scientific background and social aspects linked to the technology its deployment and application in food production and processing. On the other hand, we want to provide *scientists* with a better view on the needs and implications of the indispensable technologies used in food production and processing (innovation) and highlight the needs for taking into consideration an environmental impact of the food industry.

Simulation tools have a myriad of applications in food and bio-industries: food technologies, food sciences, food management (traceability, food safety). Food can be formulated optimally, but food substrates (both fluid and solid) are subject to important biochemical/functional/organoleptic issues during processing. The dependence of these issues upon operations is strategically important for food safety and quality; and the holistic evaluation, that only Life Cycle Assessment (LCA) can provide, is required in order to guarantee that environmental impact is also taken into account and that burdens are not transferred among to different stages of the value chain.

The learning material on Quantitative Tools for Sustainable Food and Energy in the food chain (Q-Safe) can play an important role in food safety, risk assessment and process engineering. The text provides a comprehensive guide for students and teachers, providing insight into developing quantitative tools in food microbiology, processing and exposure assessment. The book will appeal to those with an interest in mathematical modelling approaches in the Food and Bioscience field. It enhanced innovative problem based learning initiatives by the use of simulation, optimization modelling tools and relevant software (@RISK, MATLAB, etc.).

It is envisaged that graduates of the FOOD4S programme will have a clearer understanding of the quantitative tools to assess product quality, safety, resources intensity and environmental impacts in the food industry. The simulation tools can be applied to various aspects in the food and bio industries, from food technologies to food management, food engineering and quantitative microbial risk assessment. This will enable research activities on more efficient and effective monitoring techniques and promote the employability of researchers with high competencies.

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