



## Cross-European initial survey on the use of mathematical models in food industry



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### ABSTRACT

Mathematical modelling plays an important role in food engineering having various mathematical models tailored for different food topics. However, mathematical models are followed by limited information on their application in food companies. This paper aims to discuss the extent and the conditions surrounding the usage of mathematical models in the context of European food and drinks industry. It investigates the knowledge, nature and current use of modelling approaches in relation to the industry main characteristics. A total of 203 food companies from 12 European countries were included in this research.

Results reveal that the country where the company operates, and size of the company, are more important predictors on the usage of mathematical models followed by the type of food sector. The more developed countries are positioned at the higher level of knowledge and use of available models. Similar pattern was observed at the micro level showing that small or medium sized companies exhibit lack of knowledge, resources and limiting usage of models.

### 1. Introduction

Mathematical modelling is a useful tool to ascertain the effects of different system and process characteristics on the outcome of a process

(Sandeep and Irudayaraj, 2001). Modelling various food products and/or processes is challenging mainly due to the lack of understanding the phenomena, difficulties in modelling experiments and uncertainties related to reliable data and food properties (Trystram, 2012). Food

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quality and food safety properties become a major concern of both consumers and food industry whereas mathematical models on food behavior through the food chain provide information related to food characteristics and different phenomena that occur during all activities/processes (Fito et al., 2007).

Food process modelling and/or multiscale simulations from food ingredients up to entire food supply chain, improve the exploration of competing alternatives (Vitrac and Touffet, 2018). It is worthy to note that food tissues are multiscale assemblies with different characteristics at each spatial scale where multiscale modelling becomes a must (Abera et al., 2016). Therefore, the main objectives in engineering food processes is to understand a certain phenomenon based on existing theoretical understanding and available measurements, to design processes and control them (Trystram, 2012). Datta and Rattray (2009) specify two major uses of food process modelling: (i) to better understand a process and (ii) to check various “what-if” scenarios when the model is applied. Furthermore, advanced model-based techniques could be applied for food product and process modelling. Those techniques may include mathematically-based product/process optimization or model-based control in production. Knowledge transfer methods aim at finding “good” data points or feature representations to increase the prediction accuracy and the credibility of the target model (Bang et al., 2019).

Application of models in the food industry relies on simplified, stationary models that usually don't produce a realistic evaluation of observed processes, quality or safety conditions and environmental impact (Trystram, 2012). Also, these models simplify food system descriptions, mechanisms and rate equations of changes (Fito et al., 2007). One way of categorizing models is by distinguishing three groups: (a) analytic models, (b) numerical models, and (c) observational models. Other way of categorizing models is by the point of view into three groups: product, (b) process and (c) product-process relations (Fito et al., 2007). In order to overcome the complexity of modelling at different spatial scales, a new paradigm has appeared known as multiscale modelling (Ho et al., 2013). Complexity of modelling relies on the fact that various competencies are needed from food science to applied mathematics and statistics, engineering, computer science, etc. (Trystram, 2012). However, it is important to consider that each modelling method has certain limitations. According to Trystram (2012), although numerous models have been published, their application under real conditions is very low. In order to overcome the role of food operators in small companies, Allais et al. (2007) suggest certain methodological guideline for modelling knowledge extraction and formalization.

Therefore, the objective of the current research was to assess the use of mathematical models in food industry in terms of mathematical techniques knowledge, level of using these tools in companies and barriers when using mathematical modelling. Furthermore, modelling of environmental impacts and environmental targets/indicators were also analyzed. As a result, this research identified needs for food modelling in various application areas. The results were deployed according to the country where the companies operate, companies' roles in the food chain and size of the companies.

### 1.1. Literature review

A critical literature review was performed by analyzing published articles using the scholarly databases Web of Science, EBSCO and ScienceDirect. These databases identified the most relevant academic papers published on mathematical modelling of food products/processes (i.e. modelling food processes, quality/food safety of food products and environmental models). There were no geographical restrictions applied, while searching was limited to studies that were published in the last decade. The majority of publications related to modelling in the food sector were focused on: (i) food technology process-based modelling; (ii) modelling food products (quality) and risks from a food safety/environmental point of view; (iii) a

combination of the two.

Complexity of analyzing this topic is related to the level of understanding a certain phenomenon. For instance, heat transfer is a transport phenomenon present in many unit operations during food processing, where a large number of heat transfer processes occur such as cooling, pasteurization, sterilization, freezing, cooking, baking, etc. (Erdogdu, 2010). Apart of heat transfer, mass transfer is another common topic covered in numerous publications. Modelling of mass transport is needed to analyze food processing operations such as drying, crystallization, humidification, distillation, evaporation, leaching, absorption, membrane separation, rehydration, mixing, extraction, and storage (Mittal, 2010). Simultaneous heat and mass transfer in food processing can be observed in food drying models (Dincer, 2010), baking processes (Zhou, 2010) or roasting processes (Rabeler and Feyissa, 2018). From a technological point of view, all food processes may occur with conventional or non-thermal technologies where modelling assumptions differ since these emerging technologies have different types of action, depending of the source of energy transfer (Rezek Jambrak et al., 2018). Reasons for developing non-thermal processing is to assure food safety (Jambrak et al., 2018) while retaining quality of food. One of the latest updates on modelling heat transfer in conventional and innovative technologies was presented by Erdogdu et al. (2018).

Quality modelling of various food quality properties such as taste, texture, appearance and nutritional content evolved by Molnár (1995), while some of the latest attempts to model quality index were covered by (Djekic et al., 2018d; Rezek Jambrak et al., 2018). Food safety models range from modelling to optimize shelf-life (Chandra Mohan et al., 2016; Sofra et al., 2018) and transportation (Djekic et al., 2018c) to risk assessment (Sieke, 2018; Zanabria et al., 2018) and food security (Bakker et al., 2018). Having in mind the importance of sustainable development goals developed by the United Nations, modelling of environmental impacts and environmental targets/indicators in the food sector is coming into focus (UNESCO, 2017). Scale of environmental models in the food chain has three perspectives: food products, food processes and food companies (Djekic et al., 2018b).

This literature search revealed that analysis of application of mathematical models in food companies has not been a focus of such research, and this was identified as a research gap by the authors of this paper. Working hypothesis of this research was that mathematical models are not commonly used in food companies.

## 2. Materials and methods

### 2.1. Characteristics of the survey

The study was conducted during the first half of 2018. A questionnaire was developed in English language and was translated from English language to local languages of the participating countries. A total of 203 food companies from 12 European countries were included which have been divided in two categories: Inclusiveness Target Countries (ITC) and Other European Countries (OEC). ITC as less research-intensive countries are defined in the Framework Partnership Agreement signed between the European Cooperation in Science and Technology (COST) Association and the European Commission (COST, 2015). Companies were chosen from all parts of the sampled countries. The authors recognize that this method does not provide a truly random sample of food companies, but instead, represents a ‘convenience sample’. In spite of its limited size of companies per country, the sample is comparable to various published surveys on implementation of certain tools in different countries with less than 60 food companies per country such as quality management (Djekic et al., 2014c), hygiene practices (Djekic et al., 2014b), pest control (Djekic et al., 2019) or food fraud (Djekic et al., 2018a). Our results under a certain dose of caution may be projected to the general food sector in Europe.

The only criterion was that they operate in at least one of the parts

**Table 1**  
Number of participating food companies by businesses type and number of employees.

Region	Food businesses type	Number of businesses	Number of employees			Certification status		
			< 50	50–250	> 250	FSMS	QMS	EMS
ITC		n <sup>a</sup> (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
	Animal origin food <sup>b</sup>	26 (24.3%)	9 (34.6%)	11 (42.3%)	6 (23.1%)	22 (84.6%)	12 (46.2%)	10 (38.5%)
	Plant origin food <sup>c</sup>	43 (40.2%)	11 (25.6%)	19 (44.2%)	13 (30.2%)	41 (95.3%)	31 (72.1%)	19 (44.2%)
OEC	Food service <sup>d</sup>	38 (35.5%)	11 (28.9%)	13 (34.2%)	14 (36.8%)	30 (78.9%)	27 (71.1%)	13 (34.2%)
	Animal origin food <sup>b</sup>	17 (17.7%)	5 (29.4%)	2 (11.8%)	10 (58.8%)	11 (64.7%)	7 (41.2%)	3 (17.6%)
	Plant origin food <sup>c</sup>	37 (38.5%)	10 (27%)	8 (21.6%)	19 (51.4%)	24 (64.9%)	18 (48.6%)	14 (37.8%)
	Food service <sup>d</sup>	42 (43.8%)	21 (50%)	13 (31%)	8 (19%)	28 (66.7%)	33 (78.6%)	25 (59.5%)
	<b>Total</b>	203 (100%)	67 (33%)	66 (32.5%)	70 (34.5%)	156 (76.8%)	128 (63.1%)	84 (41.4%)

ITC - Inclusiveness Target Countries (Bosnia and Herzegovina, Croatia, Cyprus, Portugal, Romania, Slovenia, Serbia).

OEC – Other European countries (Denmark, France, Germany, Greece, United Kingdom).

FSMS - Food safety management system (e.g. ISO 22000, BRC, IFS, GlobalGAP).

QMS - Quality management system (e.g. ISO 9001).

EMS - Environmental management system (e.g. ISO 14001).

<sup>a</sup> n represents the number of establishments; (%) represents their share in the sample.

<sup>b</sup> Animal origin food covers primary production and food processing of meat and poultry, fish, dairy and eggs.

<sup>c</sup> Plant origin food covers primary production and food processing of fruit, vegetables and beverages.

<sup>d</sup> Food service covers storage, distribution, wholesale, retail and food service establishments.

of the food chain - primary production, food processing, storage/distribution, retail/wholesale or food service establishments from both animal origin and plant origin food sectors. When authors contacted the companies in advance, they explained that the survey is anonymous and that they wish to distribute the questionnaire related to the use of mathematical models in food industry. The breakdown of type of companies that participated in this research is shown in Table 1.

## 2.2. Questionnaire

A questionnaire has been developed to analyze the status of the European food sector in adopting modelling and optimization methods from mathematics and computer science. The set of answers gave the possibility to review the current use of tools for various applications such as product and process development, process control, food safety, decision support and environmental impacts.

The first section included general information about the companies (country of origin, size, activity sector and implemented management systems). The second section explored the knowledge on various mathematical techniques, level of use of the tools in companies and barriers when using mathematical modelling. The respondents had the option to rate their degree of agreement according to a five-point Likert scale from 1 'strongly disagree', 2 'disagree', 3 'no opinion', 4 'agree' to 5 'strongly agree'. The third section consisted of analyzing needs for modelling in various application areas. The respondents had the opportunity to rate their needs from 0 'not applicable in our company'; 1 'there is no need for mathematical models in my company'; 2 'we would like to use some mathematical models'; 3 'there is some (limited) use, we would like to expand our knowledge in this area' to 4 'we have an extensive use of models in this area'. The fourth section was dedicated to environmental impacts where respondents had the opportunity to rate their awareness from 0 'there is no analysis of this environmental impact'; 1 'company analyses basic environmental data'; 2 'company calculates specific environmental indicators for this impact'; 3 'company converts basic data to calculate environmental impacts per process/functional unit'; to 4 'company calculates environmental footprints related to this environmental impact'. In the last section, companies were asked to answer whether they have documented environmental targets/indicators using the same five-point Likert scale from 1 'strongly disagree' to 5 'strongly agree'.

## 2.3. Statistical processing

Likert scale data were considered as ordinal values and non-parametric statistical tests have been used since data were not normally distributed. A cluster analysis was conducted in order to classify the observed statements. A two-step cluster analysis using country type, company size and food sector as categorical variables was performed. The Mann-Whitney *U* test was used to uncover statistically significant differences among the clusters.

A principal component analysis (PCA) was run on 16 statements that measured desired needs for modelling in various application areas as well as on 10 statements measuring awareness of environmental impacts to gain a better understanding of the overall correlations in the two data sets. The suitability of PCA was assessed prior to analysis. The overall Kaiser-Meyer-Olkin (KMO) measure related to the needs for modelling was 0.913 with individual KMO measures all greater than 0.8, classifications of 'meritorius' to 'marvelous' (Kaiser, 1974). Bartlett's test of sphericity was statistically significant ( $p < .0005$ ), indicating that data were likely factorizable. The overall KMO measure of awareness of environmental impacts was 0.838 with individual KMO measures all greater than 0.75, classifications of 'meritorius'. Bartlett's test of sphericity was statistically significant ( $p < .0005$ ). Having the criteria of eigenvalues above one (Cattell, 1966), the PCA extracted two components explaining 64.7% of the total variance for analyzing needs for modelling and two components explaining 78.6% of the total variance for awareness of environmental impacts. Statistical processing was performed using MS Excel and SPSS. The level of statistical significance was set at 0.05.

## 3. Results and discussion

### 3.1. Knowledge, use and barriers of food modelling

A two-cluster analysis, using country type, company size and food sector as categorical variables was employed (Table 2). Overall results show that the highest level of agreement among companies was related to the knowledge of transport phenomena and mechanics (3.9), production planning (3.8) and real time process control (3.7) and that they routinely use production planning models (3.6). They disagree about routinely use of response surface modelling (2.2) and they don't believe their product is too simple to gain from any modelling (2.5). Food modelling implies good skills in understanding food technology, instrumentation, computer, applied mathematics highlighting the need

**Table 2**  
Description of the two clusters in terms of country, company size and food sector (N = 203) – 29 statements.

		Cluster 1 (n = 100)	Cluster 2 (n = 103)	Total (100%)
Country (*)	ITC	65 (60.7%)	42 (39.3%)	107 (100%)
	OEC	35 (36.5%)	61 (63.5%)	96 (100%)
Size (*)	Small size company	35 (52.2%)	32 (47.8%)	67 (100%)
	Medium size company	36 (54.5%)	30 (45.5%)	66 (100%)
	Big company	29 (41.4%)	41 (58.6%)	70 (100%)
Food sector (*)	Animal origin food	22 (51.2%)	21 (48.8%)	43 (100%)
	Plant origin food	47 (58.8%)	33 (41.3%)	80 (100%)
	Food service	31 (38.8%)	49 (61.3%)	80 (100%)
<b>I have knowledge of</b>				Mean ± StD <sup>a</sup>   Mode <sup>a</sup>
	Transport phenomena and mechanics	2.4 ± 1.2 <sup>a</sup>	3.6 ± 1.1 <sup>b</sup>	3.9 ± 1.3   3.0
	Molecular modelling/Multi scale modelling	2.0 ± 1.0 <sup>a</sup>	3.4 ± 1.1 <sup>b</sup>	2.7 ± 1.3   3.0
	Flowsheeting	2.3 ± 1.2 <sup>a</sup>	3.7 ± 1.2 <sup>b</sup>	3.0 ± 1.4   3.0
	Response surface modelling	1.9 ± 1.0 <sup>a</sup>	3.1 ± 1.9 <sup>b</sup>	2.5 ± 1.2   3.0
	Multivariate data analysis	2.1 ± 1.2 <sup>a</sup>	3.7 ± 1.9 <sup>b</sup>	2.9 ± 1.3   4.0
	Data mining and machine learning	1.9 ± 1.1 <sup>a</sup>	3.5 ± 1.2 <sup>b</sup>	2.8 ± 1.4   1.0
	Production planning	3.5 ± 1.3 <sup>a</sup>	4.1 ± 1.9 <sup>b</sup>	3.8 ± 1.2   4.0
	Real time process control	3.3 ± 1.3 <sup>a</sup>	4.1 ± 1.1 <sup>b</sup>	3.7 ± 1.2   4.0
	Supply chain models	2.9 ± 1.3 <sup>a</sup>	3.7 ± 1.1 <sup>b</sup>	3.3 ± 1.3   4.0
	Decision support	2.6 ± 1.3 <sup>a</sup>	3.9 ± 1.9 <sup>b</sup>	3.3 ± 1.3   4.0
	Productivity analysis	3.0 ± 1.4 <sup>a</sup>	3.9 ± 1.9 <sup>b</sup>	3.5 ± 1.3   4.0
<b>This technique is routinely used in our company</b>				
	Transport phenomena and mechanics	1.9 ± 1.2 <sup>a</sup>	3.4 ± 1.1 <sup>b</sup>	2.7 ± 1.4   1.0
	Molecular modelling/Multi scale modelling	1.4 ± 0.6 <sup>a</sup>	3.0 ± 1.2 <sup>b</sup>	2.2 ± 1.3   1.0
	Flowsheeting	2.0 ± 1.3 <sup>a</sup>	3.6 ± 1.2 <sup>b</sup>	2.8 ± 1.5   1.0
	Response surface modelling	1.5 ± 0.6 <sup>a</sup>	2.9 ± 1.0 <sup>b</sup>	2.2 ± 1.1   1.0
	Multivariate data analysis	1.6 ± 0.8 <sup>a</sup>	3.5 ± 1.0 <sup>b</sup>	2.6 ± 1.3   1.0
	Data mining and machine learning	1.6 ± 0.8 <sup>a</sup>	3.5 ± 1.1 <sup>b</sup>	2.5 ± 1.4   1.0
	Production planning	2.9 ± 1.4 <sup>a</sup>	4.2 ± 0.9 <sup>b</sup>	3.6 ± 1.4   4.0
	Real time process control	2.9 ± 1.6 <sup>a</sup>	4.2 ± 0.9 <sup>b</sup>	3.5 ± 1.4   5.0
	Supply chain models	2.2 ± 1.2 <sup>a</sup>	3.8 ± 0.8 <sup>b</sup>	3.0 ± 1.3   4.0
	Decision support	2.1 ± 1.2 <sup>a</sup>	3.8 ± 1.0 <sup>b</sup>	3.0 ± 1.4   4.0
	Productivity analysis	2.8 ± 1.4 <sup>a</sup>	4.0 ± 0.8 <sup>b</sup>	3.4 ± 1.3   4.0
<b>Barriers for using mathematical modelling in our company</b>				
	We lack competence on mathematical modelling	3.7 ± 1.2 <sup>a</sup>	2.9 ± 1.3 <sup>b</sup>	3.3 ± 1.3   3.0
	We lack sensors/instrumentation to collect data	3.6 ± 1.2 <sup>a</sup>	3.0 ± 1.1 <sup>b</sup>	3.3 ± 1.2   4.0
	We lack infrastructure for data/model management	3.5 ± 1.1 <sup>a</sup>	3.0 ± 1.3 <sup>b</sup>	3.3 ± 1.2   4.0
	Our product/process is too complex for modelling	2.7 ± 1.2	2.9 ± 1.1	2.8 ± 1.2   3.0
	Our product/process is too simple to gain from modelling	2.8 ± 1.1 <sup>a</sup>	2.3 ± 1.0 <sup>b</sup>	2.5 ± 1.1   3.0
	We have problems with upscaling our models	3.1 ± 1.1	3.2 ± 1.2	3.1 ± 1.1   3.0
<b>We have documented numerical targets/indicators for ...</b>				
	Energy savings on a company basis	3.1 ± 1.1 <sup>a</sup>	3.9 ± 0.9 <sup>b</sup>	3.5 ± 1.1   4.0
	Energy savings for all processes	2.5 ± 1.0 <sup>a</sup>	3.8 ± 0.9 <sup>b</sup>	3.2 ± 1.1   3.0
	Water savings on a company basis	3.1 ± 1.1 <sup>a</sup>	3.9 ± 0.9 <sup>b</sup>	3.5 ± 1.1   4.0
	Water savings for all processes	2.6 ± 1.1 <sup>a</sup>	3.7 ± 0.8 <sup>b</sup>	3.2 ± 1.1   3.0
	Decreasing air pollution	2.3 ± 1.0 <sup>a</sup>	3.3 ± 1.0 <sup>b</sup>	2.8 ± 1.1   3.0
	Decreasing water pollution	2.3 ± 1.0 <sup>a</sup>	3.5 ± 1.0 <sup>b</sup>	2.9 ± 1.2   3.0

**Table 2 (continued)**

		Cluster 1 (n = 100)	Cluster 2 (n = 103)	Total (100%)
Country (*)	ITC	65 (60.7%)	42 (39.3%)	107 (100%)
	OEC	35 (36.5%)	61 (63.5%)	96 (100%)
	Decreasing impact on the ecosystem	2.2 ± 1.0 <sup>a</sup>	3.1 ± 1.2 <sup>b</sup>	2.7 ± 1.2   3.0
	Decreasing greenhouse gas emission	2.2 ± 1.0 <sup>a</sup>	3.1 ± 1.1 <sup>b</sup>	2.7 ± 1.2   3.0
	Decreasing amount of hazardous waste	2.2 ± 1.0 <sup>a</sup>	3.4 ± 0.9 <sup>b</sup>	2.8 ± 1.1   3.0
	Decreasing amount of all types of waste	2.5 ± 1.2 <sup>a</sup>	4.0 ± 0.9 <sup>b</sup>	3.2 ± 1.3   4.0
	Improving my product	3.0 ± 1.2 <sup>a</sup>	3.9 ± 0.9 <sup>b</sup>	3.4 ± 1.1   4.0

Note: Items denoted with different letters are significantly different at the level of 5%.

(1) “Strongly disagree”, (2) “Disagree”, (3) “No opinion”, (4) “Agree”, (5) “Strongly agree”.

Animal origin food sector covers primary production and food processing of meat and poultry, fish, dairy and eggs.

Plant origin food sector covers primary production and food processing of fruit, vegetables and beverages.

Food service sector covers storage, distribution, wholesale, retail and food service establishments.

ITC - Inclusiveness Target Countries (Bosnia and Herzegovina, Croatia, Cyprus, Portugal, Romania, Slovenia, Serbia).

OEC – Other European countries (Denmark, France, Germany, Greece, United Kingdom).

<sup>a</sup> The Mean values ± Standard deviations and modes were obtained from the raw data.

for multidisciplinary approach (Trystram, 2012). In view of the above overall results, we may note the most routinely used models in food companies are those supporting management and logistics, rather than models dedicated to the knowledge of the food matrix.

Modes highlight that for half of the statements, respondent have no opinion. This pattern occurs in the subset of answers related to having knowledge on transport phenomena, molecular modelling, flow-sheeting and multivariate data analysis, lack of competence on modelling, complexity/simplicity of products for modelling and upscaling problems. It is worthy to note that they also showed no opinion for environmental targeting of energy savings, water savings, and prevention of pollution of air, water, ecosystem and greenhouse gas emission. This is a result of the fact that most models are not “user-friendly” since models were historically developed to serve research purposes and then adapted to address user needs. Therefore, it remains difficult for many users to access model outputs or to otherwise make use of models (Jones et al., 2017).

Cluster analysis defined two modelling clusters, named ‘developing’ and ‘developed’. Cluster 1 (100 companies - ‘developing’), consists of ITC countries, small and medium-sized companies and companies mostly operating in the food production sector. For most of the models within this cluster, respondents confirmed lack of knowledge (scores from 1.9 to 3.3) and lack of using models (scores from 1.4 to 2.9). They also confirmed lack of resources (knowledge and infrastructure) and problems to implement any models. Within this cluster, respondents agree that they don't use modelling for any environmental targets. Knowledge transfer plays an important role in success of companies, while both scientists and experts seek to discover optimal methods of knowledge transfer in companies (Rodgers et al., 2017). Hamdoun et al. (2018) assume that knowledge management, in conjunction with quality and environmental management lead to innovation. Latest study on environmental models within food chain confirmed that simplified models for the assessment of environmental performance should be developed to enable wide and easy application in food

companies with limited resources (Djekic et al., 2018b). In a larger perspective, a wide range of models developed at the research level require advanced knowledge transfer to fit various company profiles (Aceves et al., 2017).

Cluster 2 (103 respondents - 'developed'), consisted of OEC countries, big companies and companies operating in the food service sector. Within this cluster, respondents confirmed knowledge on modelling (scores from 3.4 to 4.1) and use of these models (2.9–4.2) but didn't agree on having lack of resources for modelling. Regarding environmental issues, answers prevailing in this cluster showed that companies work on the improvement of environmental performance and prevention of pollution (scores from 3.1 to 4.0). This confirms a positive relationship between environmental and overall business performance (Heras-Saizarbitoria et al., 2011). Study on environmental management effects of certified companies recognized prevention of pollution as the main trigger for implementing any environmentally related management system (Djekic et al., 2014a). It is worthy to note that numerous companies included in this cluster have a certified environmental management system. Results obtained in this cluster were higher than in Cluster 1 with statistically significant differences between clusters observed for 26 out of 28 statements ( $p < .05$ ). This first family of results tends to show that, unsurprisingly, bigger companies are better provided with advanced modelling skills on the one hand, and on environmental impact issues, on the other hand.

### 3.2. Level of needs for modelling

Reliability of 16 items was determined by calculating Cronbach's  $\alpha$  coefficient (Table 3) as a measure of internal consistency to determine if the scale is reliable (StatSoft, 2013). Cronbach's  $\alpha$  was 0.941 which indicates a high level of internal consistency for our scale (Hair et al., 1998). Our results showed that there is limited modelling of food quality and food safety, including microbial growth modelling. For these statements, the most frequent answer was that companies have an extensive use of models. This is not surprising since product quality management is a particular manufacturing application where

**Table 3**  
Reliability tests and factor loadings measuring desired needs for modelling.

Factors	Items	Loadings <sup>a</sup>	Results	
			Me $\pm$ StD <sup>b</sup>	Mode <sup>b</sup>
Application areas for modelling				
$(\alpha = 0.941)$	Product development	0.668	2.3 $\pm$ 1.2	3.0
	Process development	0.739	2.4 $\pm$ 1.2	3.0
	Real-time process optimization and control	0.731	2.3 $\pm$ 1.2	3.0
	Food storage optimization and control	0.754	2.4 $\pm$ 1.3	2.0
	Food quality control	0.711	2.6 $\pm$ 1.3	4.0
	Microbial growth modelling	0.658	2.6 $\pm$ 1.2	4.0
	Food safety	0.716	2.6 $\pm$ 1.3	4.0
	Characterizing food quality	0.726	2.6 $\pm$ 1.2	3.0
	Value chain management	0.788	2.3 $\pm$ 1.3	3.0
	Decision control	0.818	2.3 $\pm$ 1.2	2.0
	Productivity analysis	0.791	2.4 $\pm$ 1.2	2.0
	Life cycle assessment	0.719	2.1 $\pm$ 1.2	2.0
	Carbon footprint	0.678	1.9 $\pm$ 1.1	2.0
	Water footprint	0.714	2.0 $\pm$ 1.1	2.0
	Energy footprint	0.688	2.1 $\pm$ 1.1	2.0
	Waste management	0.746	2.3 $\pm$ 1.2	2.0

Scoring rules: "0" – Not applicable in our company; "1" – There is no need for mathematical models in our company; "2" – We would like to use some mathematical models; "3" – There is some (limited) use, we would like to expand our knowledge in this area; "4" – We have an extensive use of models in this area.

<sup>a</sup> Item loadings for the first extracted component.

<sup>b</sup> The Mean values  $\pm$  Standard deviations and modes were obtained from the raw data.

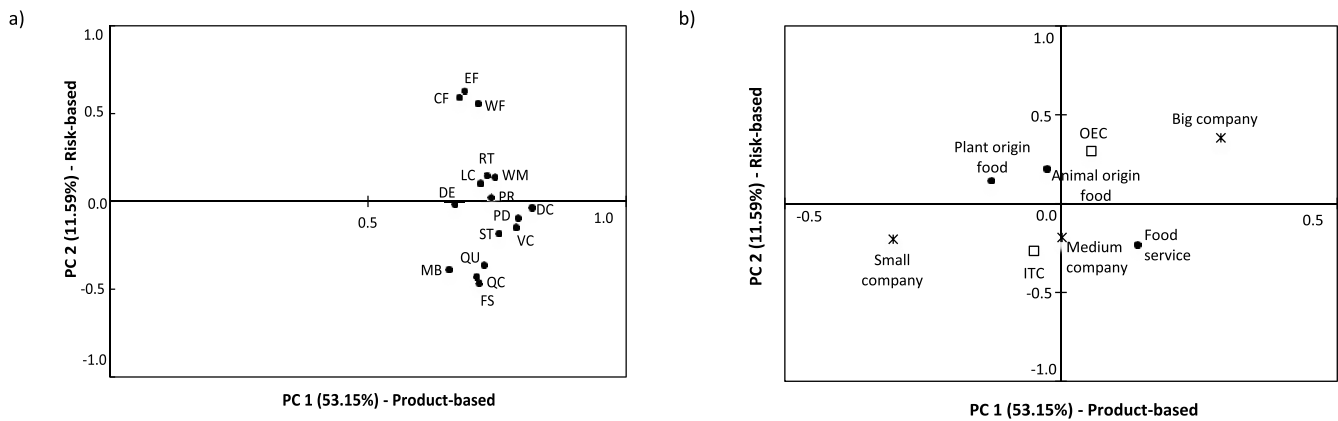
knowledge transfer method is used (Bang et al., 2019). Previous studies have explored the use of quality tools in food companies from basic tools (Djekic et al., 2013; Sousa et al., 2005) to more complex tools that require advanced knowledge of use (Fotopoulos et al., 2010; Psomas and Fotopoulos, 2010). Regarding food safety, some regulations require that food companies should include predictive mathematical modelling by using critical growth or survival factors for the microorganisms of concern (Regulation, 2005). In contrast, lowest scores imply lack of any mathematical modelling in the environmental field (average between 1.9 and 2.3) with the most frequent answer that companies would like to use some mathematical models. Application of environmental models in the food industry depend on whether the model is generic or specific for food industry, is it user friendly, free or payable and does it require specific environmental knowledge (Djekic et al., 2018b).

PCA output for the data matrix is shown in Fig. 1. Dimension reduction by PCA separated the observed factors into two distinct directions that have been recognized as two dimensions: a 'product-based dimension' (PC1) directed towards modelling various product-based models and a 'risk-based dimension' (PC2) as a dimension directed towards environmental or food safety risks. As a response to threats, regulators and policymakers are continuously putting forward standards with the goal of identifying and mitigating risks (Linkov et al., 2014). Typical risk based standards are food safety management standards (BRC, 2018; IFS, 2014; ISO, 2018) and environmental management standards (ISO, 2015b). In our study 76.8% of surveyed companies have a food safety system in place and 41.4% have an environmental system in place (Table 1). By building on the extant literature that supports modelling in the food industry, affirmation of these two dimensions, the product based and the risk based may further contribute to the analysis of food modelling.

A loading plot (Fig. 1a) provides a summary of the results. From Fig. 1a, it is obvious that all results show positive loadings, meaning that they have a strong positive influence on the 'product-based' components. The 'product-based dimension' (PC1) was loaded heavily ( $> 0.65$ ) with all statements. When it comes to the 'risk-based' dimension (PC2) highest positive loading are for environmental modelling (carbon footprint, water footprint and energy footprint) and highest negative loading for modelling food safety, microbial growth and quality control.

The loadings of nine of the statements (product and process development, real-time process control, decision support, food storage, value-chain, productivity, life-cycle assessment and waste management) was low on PC2, meaning that companies did not recognize these items as food safety or environmentally risk-based. However, these models do have other types of risks. Product and process development, value chain and productivity may be considered as quality oriented models where the risks are mainly focused on (not) fulfilling customer requirements. Quality is a degree to which a set of characteristics of a product fulfils customer needs and requirements leading to customer satisfaction (ISO, 2015a; Juran, 1998). Life cycle assessment from a risk perspective may help in identifying important sources, contaminants, receptors and exposure pathways along the life cycle of a product (Shih and Ma, 2011). Also, waste management poses a risk to human health as well as risk to groundwater (Mehta et al., 2018).

The scores plot (Fig. 1b) gives a summary of the relationships among countries and companies. Big and small companies were opposed to each other, representing companies with opposed modelling practices. Companies based on their activity and by country type were located close to center indicating that they shared similar average modelling practice scores. This second family of results thus tends to show that modelling efforts are put on a highly sensitive part of food industry, with regard to consumer expectations: the control of safety-related risks.



**Fig. 1.** Principal component analysis loadings (a) and scores (b) plots for the 16 factors influencing needs for modelling in various application areas deployed by country type, size of the companies and their activities in the food sector. The two extracted components explain 67.7% of total variance. Factors: DE - Product development PR - Process development; RT - Real-time process control; ST - Food storage optimization and control; QC - Food quality control; MB - Microbial growth modelling; FS - Food safety; QU - Characterizing food quality; VC - Value chain management; DC - Decision control; PD - Productivity analysis; LC - Life cycle assessment; CF - Carbon footprint; WF - Water footprint; EF - Energy footprint; WM - Waste management. Country type: ITC - Inclusiveness Target Countries (Bosnia and Herzegovina, Croatia, Cyprus, Portugal, Romania, Slovenia, Serbia); OEC – Other European countries (Denmark, France, Germany, Greece, United Kingdom); Company size – small, medium and large; Food sector: Animal origin food covers primary production and food processing of meat and poultry, fish, dairy and eggs; Plant origin food covers primary production and food processing of fruit, vegetables and beverages; Food service covers storage, distribution, wholesale, retail and food service establishments.

3.3. Awareness of environmental impacts

Cronbach's  $\alpha$  coefficient related to the reliability of 10 items was 0.934 indicating a high level of internal consistency for our scale (Hair et al., 1998). Overview of the results (Table 4) showed poor awareness on any environmental modelling where companies are aware of only basic environmental data for electric energy consumption, water consumption and waste. This is due to the economic and legal issues that lie behind pointing that prices of energy and water are increasing. Thus, companies are mainly interested in cost-cutting as well as monitoring quantities of waste due to legal requirements. Economic dimension of environmental performance is also confirmed by Muhammad et al. (2015). In the meat sector, water and energy management, contributes

**Table 4**  
Reliability tests and factor loadings measuring awareness of environmental impacts.

Factors	Items	Loadings <sup>a</sup>	Results	
			Me $\pm$ StD <sup>b</sup>	Mode <sup>b</sup>
Our company is aware of its ...				
( $\alpha = 0.934$ )	Electric energy consumption	0.784	1.8 $\pm$ 1.5	1.0
	Thermal energy consumption	0.779	1.8 $\pm$ 1.6	0.0
	Sources of energy consumption	0.843	1.8 $\pm$ 1.5	0.0
	Water consumption	0.842	1.9 $\pm$ 1.4	1.0
	Impact on air pollution (atmosphere)	0.845	1.0 $\pm$ 1.4	0.0
	Impact on water pollution (hydrosphere)	0.793	1.1 $\pm$ 1.4	0.0
	Impact on soil contamination (lithosphere)	0.799	0.9 $\pm$ 1.3	0.0
	Impact on the ecosystem (biosphere)	0.770	0.8 $\pm$ 1.3	0.0
	Impact on climate change	0.774	0.8 $\pm$ 1.4	0.0
	Impact from waste generated in our company	0.696	1.6 $\pm$ 1.4	1.0

Scoring rules: “0” - There is no analysis of this environmental impact; “1” - Company analyses basic environmental data; “2” - Company calculates specific environmental indicators for this impact; “3” - Company converts basic data to calculate environmental impacts per process/functional unit; “4” - Company calculates environmental footprints related to this environmental impact.

<sup>a</sup> Item loadings for the first extracted component.

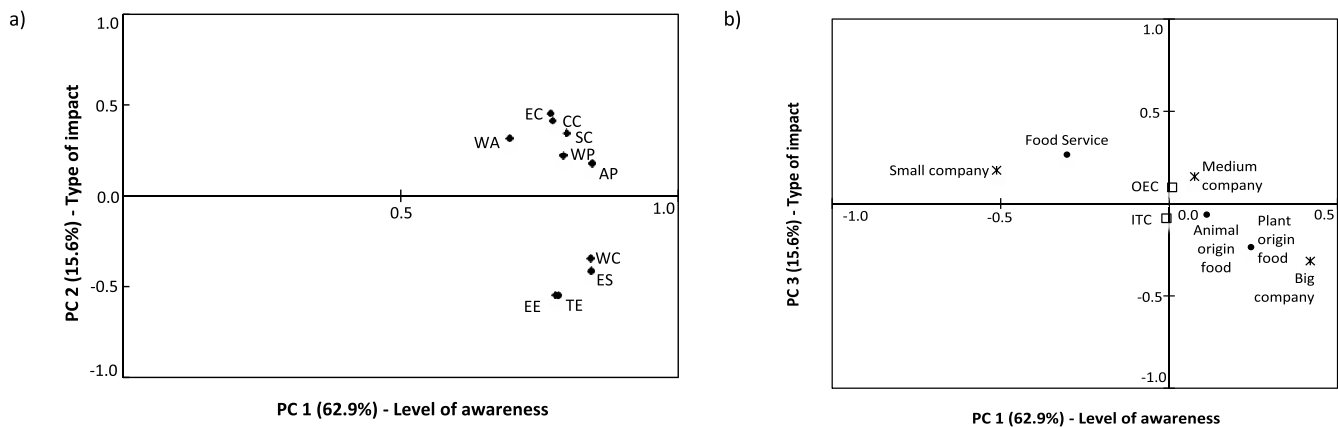
<sup>b</sup> The Mean values  $\pm$  Standard deviations were obtained from the raw data.

to the meat chain's sustainability through the enhancement of financial benefits (Djekic et al., 2016). Regarding waste, it is expected that companies have some data related to the waste they generate in line with the polluter-pays principle outlined in EU legislation (EC, 2008).

PCA output for the data matrix is shown in Fig. 2. Dimension reduction by PCA separated the observed factors into two distinct directions recognized as two dimensions: a 'level of awareness dimension' (PC1) and a 'type of impact dimension' (PC2). A loading plot (Fig. 2a) summarizes the results. All results show positive loadings, meaning that they have a strong positive influence on the 'level of awareness' component. Results contributing to similar information are grouped together, showing that they are correlated.

The 'level of awareness dimension' (PC1) was loaded heavily (> 0.69) with all statements. Depending on their environmental level of awareness, Gomez and Rodriguez (2011) identified two types of companies, the ones that grow competences to fulfill only environmental legislation and the others that include environmental performances in business decision making. When it comes to the 'type of impact' dimension (PC2), positive loading is related to pollution impacts (air pollution, water pollution, soil contamination, ecosystem. Climate change and waste disposal) while negative loading is reflecting resource depletion impacts such as energy and water consumption. Environmental impacts of the food chain influence the consumption of natural resources (mainly water and energy) and pollute the environment with various types of waste and waste water discharge (Djekic et al., 2018b; Djekic and Tomasevic, 2018).

The scores plot (Fig. 1b) provides a summary of the relationships among countries and companies. Small companies and companies operating in food service sector were opposed to big companies, while companies operating in the plant origin sector represented opposed awareness levels. Both country types were located close to center indicating that they shared similar average awareness levels. This is in line with conclusion of Jones et al. (2017) pointing out that there is a large unrealized potential for data and models to be more effectively utilized through various kinds of “knowledge products”. This third family of results thus tends to show that, beside the size of the company (already highlighted above), the sector animal/plant of the company impacts its environmental awareness.



**Fig. 2.** Principal component analysis loadings (a) and scores (b) plots for the 10 factors influencing awareness of environmental impacts deployed by country type, size of the companies and their activities in the food sector. The two extracted components explain 76.8% of total variance. Factors: EE - Electric energy; TE - Thermal energy; ES - Sources of energy consumption; WC - Water consumption; AP - Air pollution, WP - Water pollution, SC - Soil contamination; EC - Ecosystem; CC - Climate change; WA - Waste generated. Country type: ITC - Inclusiveness Target Countries (Bosnia and Herzegovina, Croatia, Cyprus, Portugal, Romania, Slovenia, Serbia); OEC - Other European countries (Denmark, France, Germany, Greece, United Kingdom); Company size - small, medium and large; Food sector: Animal origin food covers primary production and food processing of meat and poultry, fish, dairy and eggs; Plant origin food covers primary production and food processing of fruit, vegetables and beverages; Food service covers storage, distribution, wholesale, retail and food service establishments.

### 3.4. Practical implication for stakeholders in the food chain

This approach in analyzing application of mathematical models on-site provides added value regarding analysis of the current practices in the food chain and level of understanding of food models in the food sector. These findings invite stakeholders in the food chain, mainly food companies and academia, to increase efforts regarding transfer of knowledge. Results confirm differences when the size of companies, their core activity, and their country of origin are taken into account.

By considering the benefits of modelling in the food industry, managers can identify the potential for improving their products and processes. These results may also be of interest for food consultants in expanding their portfolio of services offered to food companies. Finally, our findings can serve as a guide in developing various user-friendly models tailored for specific food sectors and for small and medium-sized companies to increasing competitive advantage.

## 4. Conclusion

At a macro level, countries have different approaches of using models. The more developed countries are positioned at the higher level of knowledge and use the available modelling. A similar pattern is observed at micro level showing that small and medium sized companies express lack of knowledge and resources and consequently show a limited use of models.

Differences among countries, in most of the models examined here, were not that wide and use of mathematical models in the food industry can be considered as low to moderate. This is also important since small and medium sized companies operate at national level while big companies may operate in more than one country.

Results reveal low to moderate level of knowledge related to various models present in food companies where higher level of knowledge was associated with specific food processes (and associated food safety/environmental risks) than food products bearing in mind complexity of food matrices. Regarding their usage, most commonly used models are related to understanding and improving various aspects of food safety and food quality with limited use of environmental models in food production.

The authors believe that, education efforts towards modelling and simulation tools should be increased in both the industry (especially in SMEs) and academia, to reach a higher level of competency and awareness of its industrial potential. Limitations of this study are that

this research was focused on companies' perceptions and beliefs related to the use of mathematical and no on-site assessments were performed to evaluate the correctness of results provided by the companies. Additional limitation is related to the sample size, company profiles and number of European countries that participated in the survey. Under a certain dose of caution, this survey and the results may be projected to the entire food sector in Europe.

### Conflicts of interest

The authors have no other conflict of interest to declare.

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