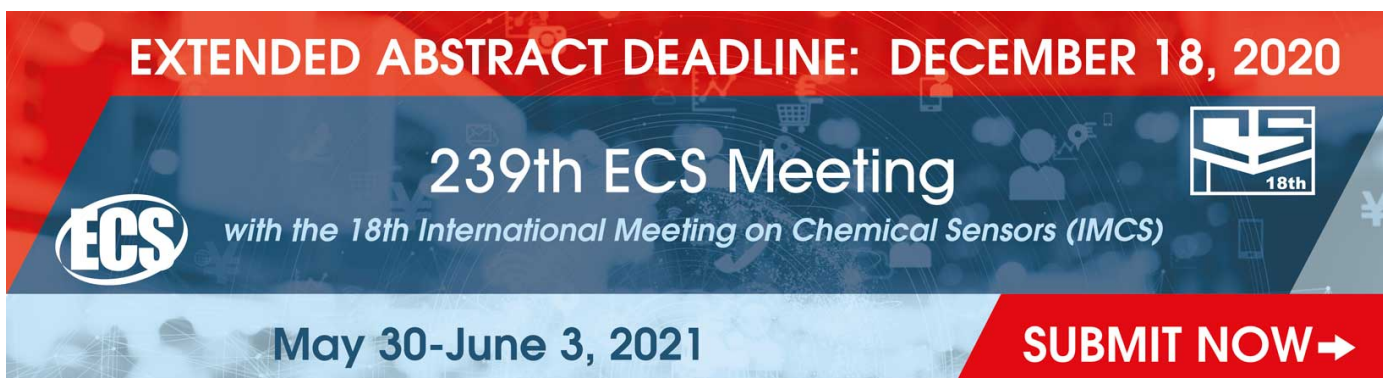


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To cite this article: I Djekic *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **333** 012011

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# Food safety and environmental risks based on meat and dairy consumption surveys

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**Abstract.** This paper gives an overview of the possibilities of using meat and dairy consumption studies in food safety and environmental risk scenarios. For both types of risk-based scenarios, common denominators are consumption patterns such as frequency and quantity of consumed food, demographic profile of consumers and food safety hazard or environmental impact of a specific type of food. This type of data enables development of simulation models where the Monte Carlo method is considered as a useful mathematical tool. Synergy of three dimensions – field research used in consumption studies, advanced chemometric tools necessary for quantifying chemical food safety hazards or environmental impacts and simulation models – has the potential to adapt datasets from various sources into useful food safety and/or environmental information.

## 1. Introduction

Knowledge of food patterns of a certain population is important for understanding various dietary profiles [1] and can aid in deploying the data into various risk-based scenarios. In order to perform a food consumption survey, it is mandatory to develop a structured questionnaire taking into account general principles and guidelines on data collection of national food consumption outlined by the European Food Safety Authority [2]. It covers basic demographic data such as gender, age and weight, and depends on the type of research specific information such as frequency and quantity of food consumption [3].

The Food and Agriculture Organization/World Health Organization (FAO/WHO) define exposure assessment as a “qualitative and/or quantitative evaluation of the likely intake of a chemical agent via food” [4]. To perform such an analysis, contamination and food consumption data are combined to obtain an estimation of the exposure level.

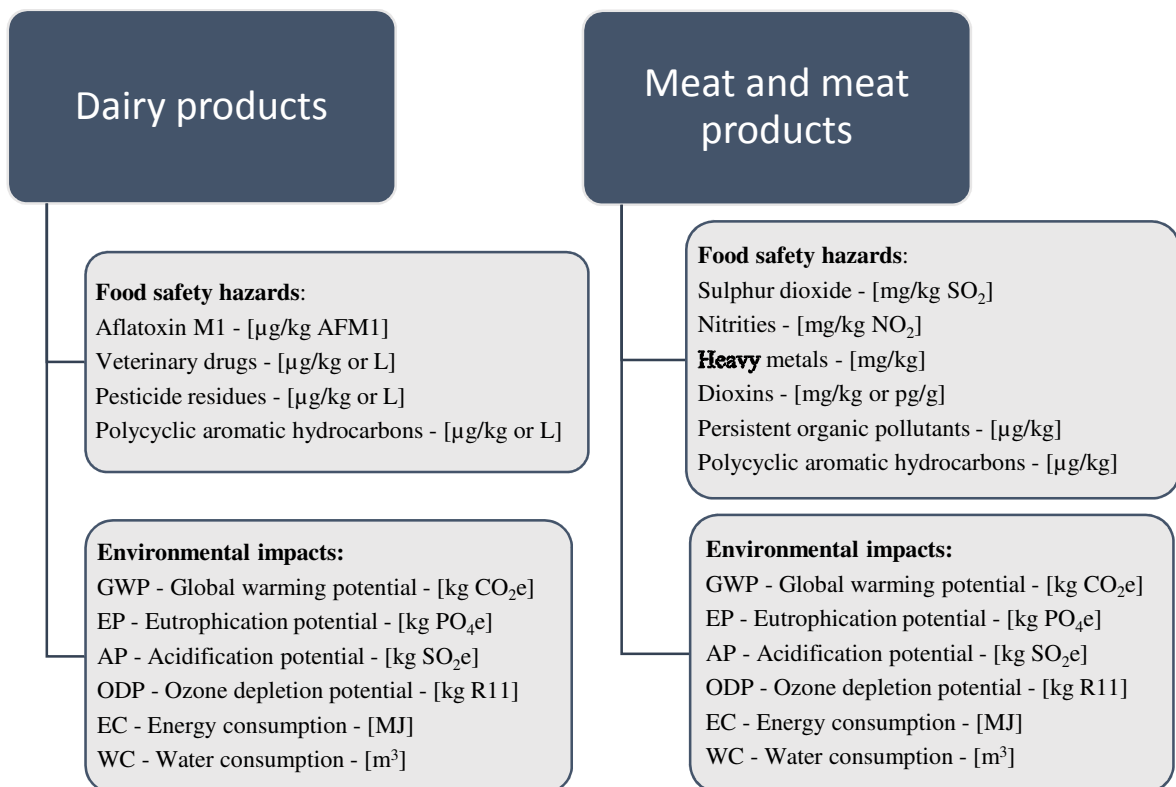
Azzura *et al.* [5] recognise food as one of three consumption domains with the largest environmental impact share. Food consumption is associated with water pollution, climate impact and loss of biodiversity [6]. This brings us to the transition of food chains towards developing sustainable food systems [7]. In order to analyse environmental impacts associated with food consumption, it is important to have dietary patterns and consumed quantities.

The aim of this paper is to present a generic food safety and environmental risk-based model based on consumption surveys dealing with animal origin food.



## 2. Materials and methods

For the purpose of this paper, a literature review was performed through examining scientific papers covering food safety and/or environmental risks of animal origin food spanning the research for the period 2000 - 2018. The emphasis was on international journals to assure appropriate scientific content, and selection of manuscripts was based on the journals' impact factors and preferring those indexed by international repositories such as Scopus index and Web of Science. This research identified that the majority of publications covered quantification/modelling of two types of risks – food safety and/or environment deployed on specific types of food (dairy products, meat and meat products, poultry, etc.). Figure 1 depicts a brief overview of the analysed chemical food safety hazards/environmental impacts that were in focus [8-28].

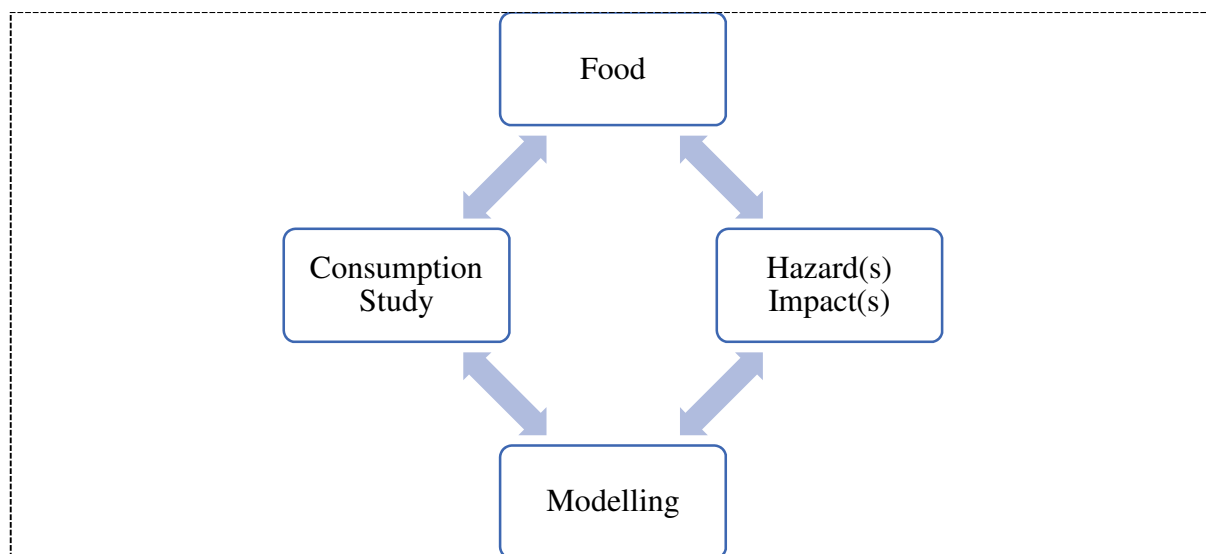


**Figure 1.** Overview of analysed chemical food safety hazards and environmental impacts

## 3. Modelling consumption studies

A generic food safety and environmental risk-based model based on consumption surveys dealing with animal origin food is presented in Figure 2. It consists of the following four elements: (i) Food; (ii) Consumption study; (iii) Food safety hazard and/or environmental impact; (iv) Modelling.

Within the first part, it is important to identify product(s) in focus, meaning the study can be performed for one specific animal origin food (yoghurt) or for a group of products (fermented meat products). The second element is related to designing the consumption study in terms of sample size, sampling methods and type of questionnaire to be used. The third element is associated with defining food safety hazard(s) and/or environmental impact(s). Within this element, it is important to define how the data will be obtained, i.e. from experiments, from expertise, or from literature review. Finally, the fourth element is modelling the data, identifying equations to be used and mathematical simulation to be employed, bearing in mind uncertainties linked with the quality of data.



**Figure 2.** Generic food safety and environmental risk-based model

### 3.1. Sample and sampling method

The tested population should be a convenient sample having, as a “rule of the thumb”, at least 500 respondents for a country the size of Serbia with around seven million citizens [29]. With a confidence level of 95% and confidence interval of 5%, estimated sample size should be at least 385 [30, 31]. However, to make the survey comparable to related published surveys, 1,000 respondents should be the right number if we analyse various exposure assessments in the EU ranging from 303 in Cyprus up to 10,419 in Germany [32]. When it comes to age, taking into account that substantial life-changing transitions and changes in eating behaviour usually occur when young adults complete high school [33], it is typical to interview a population over 20 years of age. Respondents are recruited either by randomly choosing citizens near food retailers or by employing existing professional and family networks, and further dissemination of the questionnaire through their networks [34].

Finally, the recall periods differ, but two of them prevail – the 24-h dietary recall as the most common recall method used or a 7-day dietary recall [2]. EFSA suggests that in some surveys, it is more efficient to include more recording days per person in order to estimate habitual exposure to compounds from foods.

### 3.2. Questionnaire – research instrument

Since these studies are about consumption quantities, the questionnaire should have understandable questions related to the frequencies and amounts of eaten food. To avoid any bias in self-reporting, it is not unusual to place food on plates/dishes (as they are usually served) and determine exact values of product portions (in grams or mL) and take photos of the investigated food [34]. Then, the interviewees are provided with photographs as a visual aid including the weight/volume of the portions so they can exactly report their consumption patterns.

### 3.3. Modelling food safety risks

Human exposure to a certain contaminant through consumption of food can be calculated using consumption data for animal origin products, concentration of a certain contaminant in animal origin food and body weight, as follows [35]:

$$EDI = \frac{\sum_{i=1}^n Q_i}{d} * \frac{1}{bw} * C_t \quad \{1\}$$

EDI is the estimated daily intake of a certain contaminant [ $\mu\text{g}/\text{kg}$  bw/day].  $Q_i$  is the quantity of animal origin food consumed [kg]. Average daily intake of animal origin food is divided by the number of recall-days,  $d$ . Body weight ( $bw$ ) is expressed in [kg].  $C_t$  is the concentration of contaminants [ $\mu\text{g}/\text{kg}$ ].

Regarding concentration of contaminants, the use of raw data is recommended in order to assume the statistical distribution of the data. If not, then results from other studies can be used, as was presented in exposure assessments of aflatoxin intake through consumption of maize [34] or dairy products [3], where recent publications were used to determine concentration limits. However, if it is not possible to assume data distributions, and if the number of analysed samples is low with many data below limit of detection, triangular distribution can be assumed [3, 36].

If necessary, equation {1} could be expanded by adding a coefficient reflecting the content of animal origin food (i.e. content of meat in a meat product, content of milk in a dairy product, etc.). However, it is important to note that content should be calculated based on food in the “ready to eat” or “ready to serve” form.

Mathematical simulation has become an essential tool in exposure assessments using software to recreate scenarios, like consumption patterns [37]. Our literature review revealed that Monte Carlo simulation is one of the techniques often used in analysing chronic exposure assessment scenarios, such as the works of Wang *et al.* [38] related to health risk assessment of Chinese consumers to nickel or Cardoso *et al.* [39], covering methyl-mercury intake through cephalopods in Portugal. Monte Carlo simulation assumes a particular distribution based on the data and involves the use of random numbers to perform a stochastic simulation and, therefore, is recognised as a powerful tool to analyse complex problems that can occur in various food safety scenarios [37]. In order to estimate the intake of a certain contaminant by the entire population, it is common to perform 10,000-100,000 iterations in Monte Carlo simulations [3]. Therefore, to complete such simulations, it is mandatory to determine the probability distributions for both body weight and daily/weekly consumption patterns [34]. If no probability distribution is supplied or calculated, when comparing data with different distributions (usually provided in statistical software), visual analysis of the distributions should be considered as a technique to assess the fitting of the probability distributions [40].

Data can be further deployed in risk characterisation using exposure levels of diets and contamination levels in foods to predict death and mortality [41]. FAO/WHO and EFSA propose various models for performing risk characterisation [42-45]. An example of risk characterisation of aflatoxin M1 (AFM1) intake through consumption of milk and yoghurt was presented by Udovicki *et al.* [3]. The following assumptions were applied: (i) aflatoxin B1 (AFB1) carcinogenic potency is based on the synergistic hepato-carcinogenic effects of AFB1 and hepatitis B virus infection; (ii) as AFM1 is a metabolite of AFB1, than AFM1 induces liver cancer by a similar mechanism; (iii) the potency of AFM1 is one-tenth of AFB1 [46]. Thus, the carcinogenic potency of AFM1 was estimated to be 0.001 cancer cases/year/ $10^5$  individuals per  $1 \text{ ng kg}^{-1} \text{ bw day}^{-1}$  in Hepatitis B virus surface antigen negative (HBsAg<sup>-</sup>) individuals and 0.03 cancer cases/year/ $10^5$  individuals per  $1 \text{ ng kg}^{-1} \text{ bw day}^{-1}$  in HBsAg<sup>+</sup> individuals [47]. In line with the assumptions, the following equation was applied [3]:

$$P_{cancer} = 0.001 \times \%HBsAg^{-} + 0.03 \times \%HBsAg^{+} \quad \{2\}$$

As a result, the risk of hepatocellular carcinoma (HCC) incidence per year, resulting from dietary AFM1 intake through milk consumption, can be calculated using EDI data multiplied by the AFM1 cancer potency:

$$HCC \text{ risk} = EDI \times P_{cancer} \quad \{3\}$$

Additional risk characterisation can be deployed in terms of calculating the margin of exposure (MOE). In order to assume MOE, the use of benchmark dose (BMD), i.e., the dose that causes a low but measurable response or BMDL10 (benchmark dose lower confidence limit 10%), which is an estimate of the lowest dose that is 95% certain to cause no more than 10% cancer incidence, is recommended [42]. The MOE is the ratio between the reference dose and the EDI, and considering overall uncertainties in the interpretation, MOEs equal to or higher than 10,000 would be of little concern from a public health point of view [3].

### 3.4. Modelling environmental risks

Calculation of the environmental impact related to consumption of animal origin food requires a partial life-cycle assessment (LCA) be conducted. As a minimum, system boundaries should cover three subsystems: Farm, Plant and Consumer. Subsystem 1 – Farm should cover all livestock activities; subsystem 2 – Plant includes all food processing activities, while; subsystem 3 – Consumer contains of all consumption activities from purchasing food to discarding food waste [19, 48]. Finally, it is necessary to choose a functional unit (FU) in which the impacts are expressed and which is used as a basis for comparisons [49]. In the meat chain, the most common FUs are one kg of livestock [50, 51]; one kg of carcass [52, 53], and; one kg of meat/meat products [54]. In the dairy sector FU is either 1 L of raw milk or 1 kg of dairy product [19].

The environmental impact caused by consumption of animal origin food can be calculated using data on food consumption, environmental impact of the products calculated from food production (subsystems 1 and 2) and body weight (bw), as follows:

$$EDEI = \frac{\sum_{i=1}^n Q_i}{d} * \frac{1}{bw} * I_e \quad \{4\}$$

EDEI is the estimated daily environmental impact. The latest research confirms that global warming potential (GWP) is often used in presenting the environmental impact of the meat and dairy chains [19, 55]. So, to calculate GWP, EDEI is expressed as CO<sub>2</sub> emissions [kg CO<sub>2</sub>/kg bw/day]. Q<sub>i</sub> is the quantity of animal origin food consumed [kg]. Average daily intake of animal origin food is divided by the number of recall-days, d. Body weight (bw) is expressed in [kg]. The last coefficient, I<sub>e</sub>, is the environmental impact per functional unit (in the case of GWP, this is kg CO<sub>2</sub>/kg). The GWP of the meat chain can be calculated as follows [56]:

$$GWP = \sum_i^n GWP_i \times m_i \quad \{5\}$$

Where: m<sub>i</sub> is the mass of emitted gas (kg) and GWP<sub>i</sub> is the global warming potential of the emitted gas. The GWP is calculated for every subsystem within the meat chain. The same approach can be applied to the dairy chain.

The importance of analysing the entire food chain is presented in the work of Skunca *et al.* [16], where chicken meat was the focus. The LCA model included five poultry chain subsystems: farms, slaughterhouses, meat processors, retailers and households, and the results revealed that GWP of the farms is equal to the GWP of the other four subsystems combined, highlighting the impact of households/consumers. From a consumer point of view, this study covered purchasing of chicken meat, its storage and preparation, ending with food waste and packaging disposal. Schanes *et al.* [57] points out several activities that directly affect food waste such as planning, shopping, storing, cooking, eating and managing leftovers. How data from households/consumers can be further modelled is presented in an environmental study on household waste in Serbia [58], where GWP was at the focus of a Monte Carlo simulation. Quantities of food waste were calculated using data from a household survey, as follows:

$$QFW_i = \sum_{j=1}^n F_j * Q_j \quad \{6\}$$

QFW is the quantity of food waste [kg].  $F_i$  is the reported weekly disposal frequency of a specific food category,  $i$ .  $Q_i$  is the quantity of a specific food category reported by each of the respondents,  $j$ . The GWP of food waste in terms of CO<sub>2</sub> emitted was then calculated using the data from the survey, as follows:

$$GWP_{FW} = \sum_{i=1}^n FW_i * GWP \text{ [kg CO}_2\text{e]} \quad \{7\}$$

$FW_i$  is the amount of food waste of a specific food category discarded weekly [kg]. GWP is the assumed CO<sub>2</sub> emitted from the food waste. This Monte Carlo simulation quantified the GWP of food waste as being around 3.46 kg CO<sub>2</sub>e/household per week, enabling us to estimate the annual CO<sub>2</sub> emissions due to food waste from Serbian households amounts to 687,346 tons [58].

#### 4. Conclusion

To keep pace with the increased need for simulation models to predict various risks, consumption studies are now an essential part of the process. Synergetic effects of field research needed for consumption studies, joined with advanced chemometric tools and simulation models can help us adapt detailed datasets obtained from different sources and complex samples into useful food safety and/or environmental information. The advantages of this approach enable using one consumption study for different purposes in terms of calculating various food safety and environmental risks. Proposed model, although generic, may be employed in combining food safety and environmental issues.

Future research should explore possibilities of data modelling when dealing with imperfect data, especially when data are from heterogeneous data sources. This is pronounced when modelling activities cover integrating data with various levels of precision and certainty, quantitative or qualitative, different structuration and terminologies. Also, future research should validate models, regardless of type of food (meat/dairy) and physical properties (solid/liquid).

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