The Innovation of the characterisation factor estimation for LCA in the USETOX model

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Different Life Cycle Impact Assessment (LCIA) methods in the impact assessment may lead to disparate results. Those disagreements in LCIA results are mainly linked to differences in the characterization model on a spatial scale. Most models only provide information about large geographical areas, ignoring ecological aspects of regions that can vary in accordance with geological conditions and the industrial influence level. The current investigation proposes an approach to reduce the spatial limitation of impact modeling. Based on the results of analytical investigations carried out by the research group, and taken from the literature, the characterization factor (CF) is recalculated. Among existing LCIA models, the USEtox is taken as the model recommended by the European Union for human health impacts assessment. In the USEtox model calculation, the general bioaccumulation factor is replaced by the regionalized concentration coefficient to obtain the indirect human exposure factor. The modified characterization factor for 5 USEtox geo zones is calculated.

Keywords:
Spatial LCA
Spatial LCIA
Human exposure
USEtox
Heavy metals
Characterization factor

1. Introduction

Pollution from heavy metals and other chemicals is one of the types of environmentally negative effects on the environment and particularly on living organisms. Complicated environmental tensions dictate the need to develop measures to minimize negative impact on the environment. To make effective decisions, it is necessary to have a clear idea of the current methods, approaches, concepts and models used for assessing the state of the environment worldwide, due to the lack of a uniform gradation and structure of these methods.

The Life-Cycle Assessment method, LCA, is one of the leading instruments of environmental management in the European Union, based on a series of ISO standards, designed to assess social and environmental impacts of production and waste management systems (Fig. 1). This universal method of LCA is used in almost all branches of industry, in particular machine building, construction, electronics, traditional and alternative energy, polymer production, food products, product design and waste disposal ("Environmental management – Life cycle assessment – Principles and framework ISO 14040:2006," n.d., "Environmental management - Life cycle assessment - Life cycle impact assessment International standard ISO 14042 2006," n.d.).

Life Cycle Impact Assessment (LCIA) is a vital phase of any LCA. Life cycle impact assessment aims at understanding and quantifying the magnitude and significance of the potential environmental impacts of a product or a service throughout its entire life cycle (The International Standards Organisation, 2006). LCIA is the

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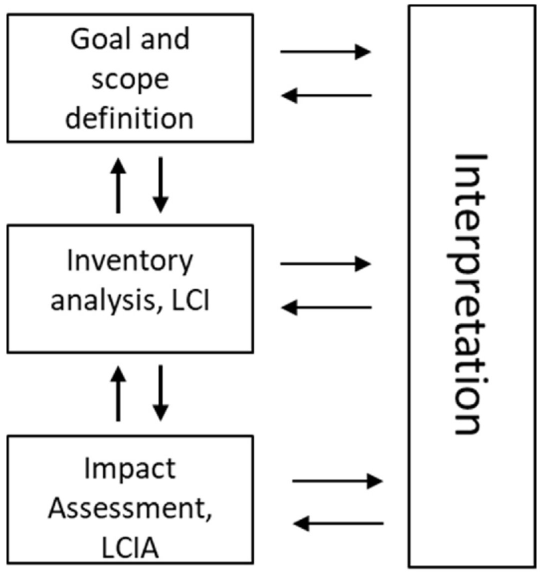

Fig. 1. LCA framework("Environmental management - Life cycle assessment - Life cycle impact assessment International standard ISO 14042 2006," n.d.).

most critical step of the Life Cycle Assessment, because it deals with large amounts of data provided by Inventory analysis, so the choice of appropriate inventory results is important for LCIA (Beloin-saint-pierre et al., 2012). These Inventory results are transformed into understandable impact indicators. Impacts considered in a Life Cycle Impact Assessment include climate change, ozone depletion, eutrophication, acidification, human toxicity (cancer and non-cancer related), respiratory inorganics, ionizing radiation, ecotoxicity, photochemical ozone formation, land use, and resource depletion. The emissions and resources are assigned to each of these impact categories, which are then converted into indicators using impact assessment models (Recipe, USEtox, Traci, Caltox, etc.) (Menoufi, 2011; Nikolic et al., 2017) as the Characterization factors (CFs).

The Characterization factors can be derived from impact assessment models and expressed in Disability Adjusted Life Years per kg of pollutant (DALY/kg) for the calculation of human health impact (the intrinsic values of human health (Verones et al., 2017)). CFs enable us to evaluate and compare the level of impact on populations depending on geographical areas and type of pollutant. Calculations in impact assessment models include several parameters (Fantke et al., 2017; Pu et al., 2016), such as environmental fate of elements, their toxicity, solubility, intake via different mediums, regional differentiations etc. In the current research, we focus only on the spatial aspect.

Disagreements in LCIA results (Monteiro and Freire, 2012; Pizzol et al., 2011) are mainly connected with differences in the characterization model at a spatial scale (Dreyer et al., 2003). The importance of the territorial approach in environmental investigations has already been recognized (Dreyer et al., 2003; Li et al., 2020; Mutel et al., 2019; Nitschelm et al., 2016; Payraudeau and Van Der Werf, 2005), and introducing spatial differentiation (or regionalization) in LCIA models can help improve the accuracy of LCA results (Peña et al., 2018; Verones et al., 2017). There are several types of spatial differentiation among LCIA models, most models can provide information about impact on the environment at the continental level (Table 1) or as standardized world with generic characteristics (Nitschelm et al., 2016; J. J. Potting and Hauschild, 2006), or at the country level (Mutel et al., 2019).

Fewer studies consider regional levels of ecosystem or human health impact assessment (Bratec et al., 2019). Choosing an appropriate spatial domain is critical in impact assessment, considering potentially affected resources (Eccleston, 2017).

There is also a lack of regional data showing the impact in border areas which have different industrial influences. The industrial influence often affects not just the areas where products are produced, but near-border zones also by wind and water transfer, so using site-specific models is more relevant for the impact assessment. Its relevance will be the greatest in studies of product systems where local impacts from the industries are an issue (Potting and Hauschild, 2006). Consequently, development of the spatial aspect leads to improved accuracy of LCA (Hiloidhari et al., 2017).

Among all LCIA methods, the USEtox model is recommended by the European Commission as the only LCIA model that has a geographic separation parameter. The USEtox model includes 8 continental and 17 subcontinental zones, each of which is characterized by various climatic, hydrological, geographic-economic and other parameters. The USEtox model is sufficient for performing non-organic ecosystem impact assessments produced at the global scale (Karim et al., 2019) and on a country scale (Makarova et al., 2018; Tarasova et al., 2018). However, when using the USEtox model in assessing the impact of the life cycle, the regional aspect still needs to be developed. In the USEtox model plenty of literature references are found for metal transfers and accumulations in each territorial unit: the International Atomic Energy Agency (Sheppard, 2011); RTI (Rosenbaum et al., 2007) with a preference for the IAEA-data, and Ng (Ng et al., 1979) for copper (Cu) (Fantke et al., 2017). According to the USEtox documentation, the model's structure provides for full mass balance but lacks a high level of spatial resolution (Fantke et al., 2017). The current research is focused on the evaluation of the spatial aspect of the USEtox.

Considering that emissions enter the body in food products, the current research is focused on the modification of the indirect exposure factor with meat products (pork meat). The importance of the exposure factor is determined, taking into account the influence of a given source's location, and the conditions of its surroundings, as well as the exposure of emissions to possible sensitive receptors of organisms, i.e. the spatial variability of human health impacts related to exposure to toxic substances (Bulle et al., 2019).

In our case study, pork meat sufficiently reflects the state of the environment (insert to be used?) as a bio-indicator. The concentration of chemicals in the environment correlates with their content in bio-indicators (Markert et al., 2009). It affects and transforms the elemental composition of organisms with consequent accumulation of certain metals and pollutants (Lamborg et al., 2014). There are a lot of species used for bioindication. Although vertebrate animals, such as domestic pigs, are much less frequently used as bio-indicators than invertebrate animals or plants. Meanwhile, the sustainable functioning of natural ecosystems is determined by the integrity of the entire trophic system, since it is the highest trophic levels that act as (insert the most?) significant factors in the stabilization and intensification of biogeochemical cycles. In this case the chemical composition of meat products is the sensitive environmental indicator that allows us to recognize their geographical origin and industrial influence as an intake of heavy metals (Huang et al., 2017), or nanoparticles (Adam et al., 2015; Pu et al., 2017, 2016). The elemental content of the animal reflects the emissions into the atmosphere and its pollution i.e. the heavy metal content in snow cover, water, and diet. According to the data of Nikolik et al. (Nikolic et al., 2017), different styles of pig breeding, namely free grazing, impact the elemental composition of their meat. Studies by Haldimann et al. (1999) (Haldimann et al., 1999) confirm the dependence of the Se concentration in the meat of farm animals on the concentrations of

Table 1
Types of spatial differentiation (Bare et al., 2018).

Levels of spatial differentiation	Description	Models
Site-generic	All sources are considered to contribute to the same generic receiving environment	EDIP 97 (J. Potting and Hauschild, 2006), CML2001 (European Commission – Joint Research Centre – Institute for Environment and Sustainability, 2010), EcoIndicator 99 (Pizzol et al., 2011)
Site-dependent	Source categories are typically defined at the level of countries or regions within countries (scale 50–500 km).	TRACI (Bare, 2012), EDIP 2003 (Hauschild and Potting, 2000)
Site-specific	Models allow large accuracy in modelling of the impact very close to the source.	USEtox (Fantke et al., 2017), Recipe (Huijbregts et al., 2016)

this element in the soils in the region of residence. M. Lopez-Alonso et al., 2002 (Lopez-Alonso M et al., 2002) notes a positive correlation between the As content in the soils of the studied region and the livers and kidneys of pigs. Chemicals enter organisms from the soil (Baranovskaya and Rikhvanov, 2011). The geographical and ecological aspects of regions (spatial scale) influence the content of pork meat, and consequently the absorption of this metal into the human body is already proven (Baranovskaya et al., 2016; Franke et al., 2005; Wang et al., 2014; Zhao et al., 2016).

This work distinguishes chromium accumulation in the pork meat depending on the its origin. Chromium and other metals are widely studied because of their pathogenic influence on living organisms. Some investigations focus on the "air/soil pollution-plant" models of exposure (Martin et al., 2018). Others study the direct dermal or inhalation effects on the human body (Andersen et al., 2018; Lin et al., 2016; Walser et al., 2014) or small mammals (Jia et al., 2017). The high level of the scientific interest in the modeling of pollution of the environment-living organism system by heavy metals is due to their toxicity (Pen and Anto, 2017; Shrivastava et al., 2002) and non-biodegradability (Krishnamoorthy et al., 2013). Plant-oriented models are not applicable in case of human impact modeling, and medically oriented investigations are usually more expensive and cause ethical difficulties. In this case, pork meat as a popular food and as a great source of organic and inorganic substances is a perfect media for modeling the human health impact.

The USEtox model spatial limitation can relate to the lack of the local information. All models and databases mentioned in the supporting information of the USEtox model only center on transfer of elements into the organisms of cow and beef. The USEtox model includes other types of meat (pork, poultry, and sheep) that populations consume in higher quantities than beef, and which provide a wide range of different elements to the organisms. We assume the modeling of element transfer should consider all types of meat provided by the model. Sources included in the USEtox provide the transfer of radioactive elements through ecosystems, but they do not include local information about concentration of metals, such as chromium (Fantke et al., 2017). References presented in the model are less representative than data obtained with regional and analytical approaches because they do not consider the spatial aspect. We suppose that the characterization factor of chromium can be completely different even in the case of two areas only 45 km apart. According to this supposition, we proposed a modification to the characterization factor calculation in our previous investigation (Belyanovskaya et al., 2019). The previous investigation, using the chemical analysis results in the USEtox model dataset, was extended with local information. The characterization factors for two districts with different levels of anthropogenic tension were obtained. In the article, the importance of the local information in the impact assessment was highlighted. The characterization factors for geographically close villages (45 km distance), but with different environmental conditions were differentiated. In the previous research only information about one local area was considered, whereas, in the current work, the comparison between the modified characterization factors calculated for different countries and different USEtox model geo areas is observed. The current research proposes an approach to the human health impact which relies on the geoecological conditions of different countries.

The current paper includes:

1. Introduction into the obtained methodology, analytical and modeling parts;
2. The description of materials and methods, analytical (I.) and model (II.) approaches
3. Results of the characterization coefficient calculation modification and the comparison with the default one;
4. Discussion section, where the significance of the results obtained is highlighted;
5. Conclusions of the research.

2. Material and methods

The main objective of the current investigation is to analyze the importance of spatial aspects on results of the characterization factor calculation as part of the life-cycle impact assessment. To estimate the impact of regional aspects two scientific approaches

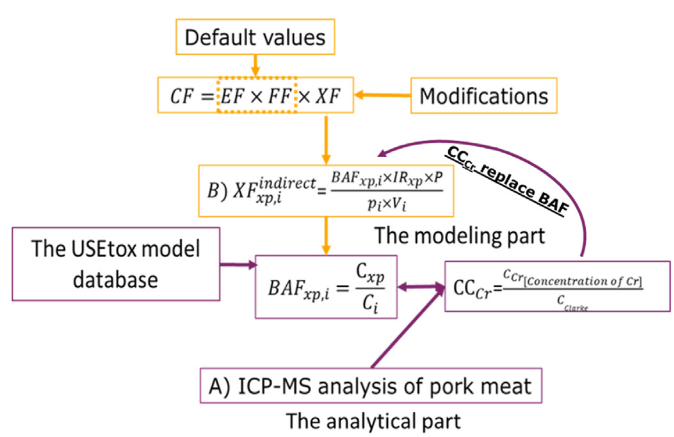

Fig. 2. The main framework of the investigation
Note: I. 1) CF – characterization factor; 2) EF -Effect factor; 3) XF – exposure factor;II. 1) $BAF_{xp,\ i}$ – Bioaccumulation factor, 2) IR – is the individual ingestion rate of a food substrate corresponding to exposure pathway xp; 3) P – is the population head count; 4) p_i – is the bulk density of medium i [kg_i/m_i^3], V_i-is the volume of medium i linked to the exposure pathway xpIII. 1) $BAF_{xp,\ i}$ – Bioaccumulation factor 2) C_{xp} – is the concentration of an element in the food substrate corresponding to the xp exposure pathway;3) C_i - is the concentration in the environment (soil, air);IV. 1) CC_{Cr} – the concentration coefficient; 2) C_{Cr}-the concentration of Cr (C_{Cr}) [mg/kg_{xp}] in pork meat (according to the results of chemical analysis); 3) C_{clarke} – the Clarke number concentration of Cr.

are proposed: analytic and modeling (Fig. 2). Our own practical research and analysis of literature data are included in the analytical section of the investigation. The extrapolation of measured concentrations of Cr into the USEtox model is a model section.

The analytical section provides local information about the elemental composition of the pork meat. It allows the USEtox model dataset to be extended with local information about the concentration of non-organic pollutants (chromium) in meat products.

In the modeling section of the investigation, we start with the modification of the indirect human exposure factor and the results obtained are extrapolated into the characterization factor calculation.

I. **The analytical part** of the investigation is the chemical analysis by inductive coupled plasma spectrometry (ICP-MS) of pork meat as the polluted media, which transports the chemicals into the human body through the food chain. The analytical part includes our own result of sample selection and analysis, and information about Cr content in pork according to the literature references. All results were obtained by ICP-MS analysis.

Data processing the analytical section results includes assessing the numerical characteristics of the chemical element content in the pork meat. The results of the ICP-MS, or other chemical analysis method, can be used in the Life-cycle inventory as information about emissions in different environmental media.

Sampling areas represent "Central Asia" (our own research) and "Europe", "Japan & Korean peninsula", "USA & Southern Canada", "Southeast Asia" (references from literature) geo zones in the USEtox.

Data about Cr content in the pork meat grown in the region "Central Asia" was taken from our own investigation. The sampling was carried out by the researchers from the Division for Geology of Tomsk Polytechnic University. 18 samples of organs and tissues (2 pigs) were taken from private farms in the area of the Tomsk region of Tomsk oblast (Russia) (Fig. 3).

Tomsk Oblast is a region of the Russian Federation with a total area of 316.9 thousand km^2, located in the southeastern part of the Western Plain on both sides of the Ob River. The work carried out by scientists, geologists, ecologists, and geochemists showed that the

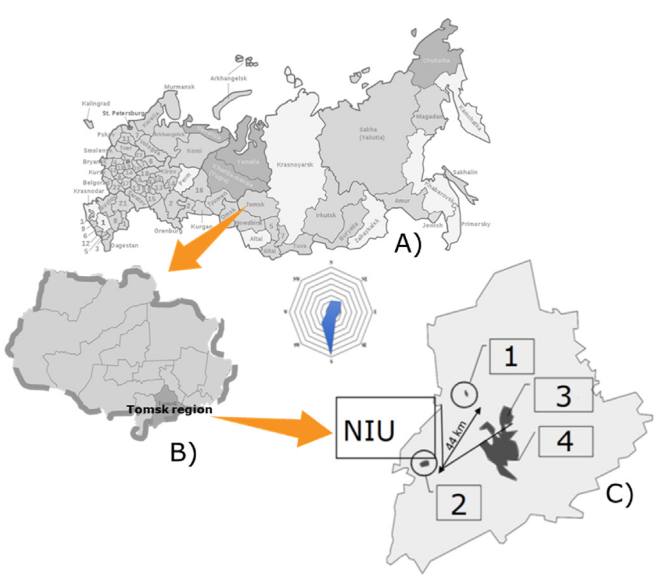

Fig. 3. Tomsk region (C) of Tomsk Oblast (B) on the map of Russia (A)
Note: NIU – Northern industrial unit; 1 – village Kizhirovo sampling point; 2 – village Verkhnee Sechenovo sampling area; 3 – Seversk city; 4 – Tomsk city.

territory of the Tomsk Oblast is characterized by significant geochemical heterogeneity due to both natural and technogenic factors (Rikhvanov, L. et al., 2006). This heterogeneity creates conditions for the accumulation of chemical elements by living organisms living in this territory. Amongst all the districts of the Tomsk oblast, the Tomsk district is of particular interest (Fig. 3B and C), as a specific industrial center of the region, where the bulk of the population lives. The Tomsk region has the highest population density (7,3 persons per km^2), but in comparison with the size of the area, the density is low.

The ecological problems of the Tomsk region were also studied because of the complexity of influence on the health of the population of this district. For example, studying the chemical composition of biomaterials and abiotic media demonstrates multiple intake pathways for chemicals (Perminova et al., 2017; Rikhvanov et al., 2008).

The potential human health problems of the population of the Tomsk region include natural and anthropogenic reasons. Studied areas hold many natural deposits (brown coals, a wide range of minerals, ore mines, etc.). The processes connected with their extraction and treatment, as well as the highly developed industrial structure of the region (more than 200 large and medium-sized industrial enterprises) and traffic congestion in big cities of the region (Tomsk city, Seversk city) have a great influence on the population's health. In addition, the industrial structure of the Tomsk region includes the world's largest nuclear fuel production enterprise - the Siberian Chemical Combine and Russia's largest oil and gas refinery - Sibur (formerly Tomsk Petrochemical Plant).

The samples of organs and tissues of the domestic pig represent the whole organism of the animal and all parts that can be consumed as food. The food samples were taken on private farms, growing animals for sale in the local market for the native population. Samples were analyzed with the modern method of chemical analysis – inductive coupled plasma mass spectrometry - in the accredited laboratory in the analytical center of the Plasma Chemical and Analytical Center LLC (Tomsk, RA.RU.516895 accreditation certificate 03.24.2016).

The representability of biomaterials of domestic pigs as a sufficient geoecological indicator was already presented in a previous investigation by the research group of Tomsk Polytechnic University (Baranovskaya and Rikhvanov, 2011; Belyanovskaya et al., 2019). Results of the chemical analysis are presented in the table (Table 3), under the 'Results' subsection.

Apart from the results of our own investigations we analyzed literature references from international scientific databases (Science direct, Scopus, Springer, ACS, etc.) and compared them with USEtox model default data. In the current article, we provide information about the content of Cr in pork meat samples in the nine countries (4 geo areas in the model) obtained by the ICP-MS analysis method in the years 2013, 2016 and 2017 (Fig. 4, Table 3).

These countries have different environmental conditions, economies, legislation on pollutants and, consequently, there are different anthropogenic impacts on the population.

Countries obtained from literature references represent 4 geo areas in the USEtox model (Table 2).

Using the results of own investigation and literature data (Table 3) we propose to extend the database of the USEtox with more local data: namely the results of the bio indication. The current approach has some uncertainties, including in the standard deviation of the chemical analysis.

II. **The modeling section** is the integration of measured concentrations of chemicals into LCIA models (e.g. USEtox) and then the calculation of the characterization factor from our own results and with default results of the model. Calculation of the potential human health impact (CF calculation) can be performed using the

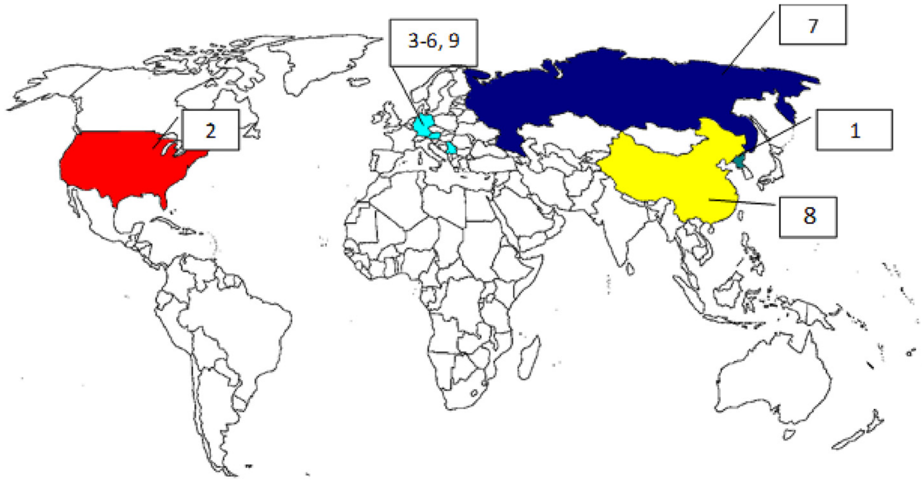

Fig. 4. Sampling map of pork meat according to own investigation and literature references
Note: 1. Korea; 2. USA; 3. Germany; 4. Austria; 5. Netherlands; 6. Belgium; 7. Russia; 8. China; 9. Serbia1-6 (Kim et al., 2017), 7 — own results, 8 - (Demirezen and Uruç, 2006; Zhao et al., 2016), 9 - (Nikolic et al., 2017).

Table 2
The USEtox geo-zones selected for the LCIA (Fantke et al., 2017).

N	Geo zones	ID in the model	Countries included
1	Central Asia	W1	Russian Federation, Afghanistan, Iran (Islamic Republic of), Kazakhstan, Kyrgyzstan, Mongolia, Tajikistan, Turkmenistan, Uzbekistan, Western China
2	Europe	W13	Gibraltar, Greece, Hungary, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, TFYR Macedonia, Malta, Moldova, Monaco, Netherlands, Poland, Portugal, Romania, San Marino, Serbia, Slovakia, Slovenia, Spain, Switzerland, Turkey, Ukraine, United Kingdom; Southern parts of Norway, Sweden, Russian Federation
3	Japan & Korean peninsula	JAP	Japan, North Korea, South Korea
4	USA & Southern Canada	W10	Southern Canada, USA (except Alaska)
5	Southeast Asia	Southeast Asia	Indochina, East Indies & Pacific, China, Japan

Table 3
The Cr content obtained by ICP-MS analysis of pork meat according to the literature references and our own investigation, mg/kg ash residue.

№	Country	Cr mean, [mg/kg]	Number of samples	Data of sampling [year]	Geo zone in USEtox model	Reference
1	Korea	3	227	2016	Japan and Korean peninsula	Kim et al. (2017)
2	USA	0,9	36	2016	USA and southern Canada	
3	Germany	0,6	12	2016	Europe	
4	Austria	0,07	15			
5	Netherlands	0,5	14			
6	Belgium	0,5	19			
7	Serbia	0,08	192	2017		Nikolic et al. (2017)
8	Russia	0,7	18	2013	Central Asia	Own results
9	China	2,01	100	2016	Southeast Asia	(Demirezen and Uruç, 2006; Zhao et al., 2016)

combination of results of chemical analysis with further extrapolation.

The Characterization factors (CF) are calculated according to USEtox documentation. The default values of the fate factor (FF) and effect factor (EF) are used in the calculation of CF.

The current investigation is focused on developing the indirect human exposure factor calculation. The modification of calculations of the exposure factor has already been published in a previous publication (Belyanovskaya et al., 2019). In the current investigation, we use the same methodology. Modified data is presented in the following table (Table 4), and default values from the USEtox can be found in the model support information (Rosenbaum et al., 2008).

The necessity of the modification is determined by the lack of local information. The same data about metal transfers and accumulations (BAF, BTF) for each geo zone is presented in the model. Values only differ depending on types of metals. References included in the model do not reflect the regional aspect as the level of anthropogenic tension. At the same time, the results of bioindication reflect the environmental specifications of the studied area (concentration of Cr changes dependent on the sampling area). We postulate that the spatial resolution provided by the model and its references is insufficient, in comparison with data obtained by bioindication.

For the normalization of the chromium concentration, the Clarke concentration number for Cr in the biosphere is used. The Clarke concentration number was originally developed by F.W. Clarke (Clarke, 1889). The Clarke presents the average

Table 4
The Characterization factor of chromium in pork meat via soils and air, Daly/kg_{Cr}.

N	Geo zones	Country	ID in the model	Soil		Air	
				Modified CF	Default CF	Modified CF	Default CF
1	Japan and Korean peninsula	Korea	JAP	6.00E-08	4.00E-14	5.00E-07	7.00E-12
2	USA and southern Canada	USA	W10	1.00E-11	7.00E-16	9.00E-15	1.00E-17
3	Europe	Germany	W13	7.00E-11	6.00E-15	8.00E-10	2.00E-12
		Austria		8.00E-12		9.00E-11	
		Netherlands		6.00E-11		6.00E-10	
		Belgium		6.00E-11		6.00E-10	
		Serbia		9.00E-12		1.00E-10	
		Europe		6.00E-13		5.00E-10	
4	Central Asia	Russia	W1	3.00E-03	5.00E-08	2.00E-07	4.00E-10
5	Southeast Asia	China	Southeast Asia	1.00E-09	4.00E-14	3.00E-07	3.00E-12

concentration of elements in the Earth's crust (lithosphere), and it is used in the calculations of the maximum permitted concentration of metals for the health ratings of Cr in soils in Russia (Federal Law of the Russian Federation, 1999). The current investigation therefore concentrates on the correlation between abiotic/anthropogenic factors, to normalize the concentration of Cr the biosphere/noosphere Clarke of Cr is chosen. The average chemical element concentration (the Clarke) in the biosphere (as a global ecosystem composed of biota and abiotic factors) is investigated by Glazovskies (Glazovsky, 1982) (Glazovsky N.F., Glazovskaya M.A.) published in 1982. The Clarke concentration number of Cr in the biosphere (noosphere) is 0.005 mg/kg (Glazovsky, 1982).

Using concentration coefficients, modified characterization factors were calculated and then compared with each other and with default results.

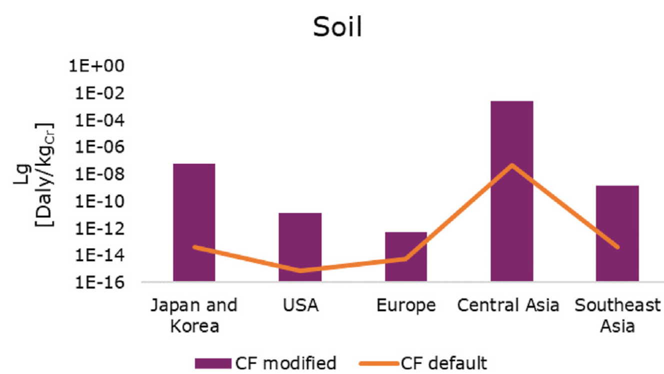

Fig. 5. The Characterization factor of chromium in pork meat via soils, [Lg Daly/kg_{Cr}].

3. Results

According to the results of analytical section, we can observe different levels of Cr content depending on the geographical area (as shown below in Table 3).

Chromium content in countries included in geo zones "USA" and "Europe" are usually similar to each other, the exceptions being Serbia and Austria, where meat contains minimal chromium. The maximum Cr concentration is present in the "Korean peninsula" and "Southeast Asia" zones.

This study is a sample of results of studying the heavy metal content of chromium in 5 of the 17 geographical zones presented in the USEtox model, which allows us to compare the CF presented in the model with data obtained with experimental approach.

Results of the integration of our own data and information from literature resources show a significant difference between CFs calculated using analytical data and the default USEtox model data. Modified chromium CFs significantly exceed the default characteristic factor given in the model. The results of integration our own research data into the USEtox model differ depending whether we are considering "air" or "soil".

Generally, comparing the value of CFs normalized to soils, a significant impact of chromium is observed on territories of Southeast and Central Asia, and Korea: much larger than the USA and Europe (Fig. 5).

Comparing the modified characteristic factors (soils) calculated for each geographical point with the CF default from the model, we observe that the modified CF is higher than the default CF.

We note that the difference between re-calculated CFs and default CFs given by the USEtox model of different geo zones show the same trend (Fig. 5). Values of modified CFs follow the order: Europe < USA < Southeast Asia < Japan and Korea < Central Asia, while the values of default CFs increase in the proportion:

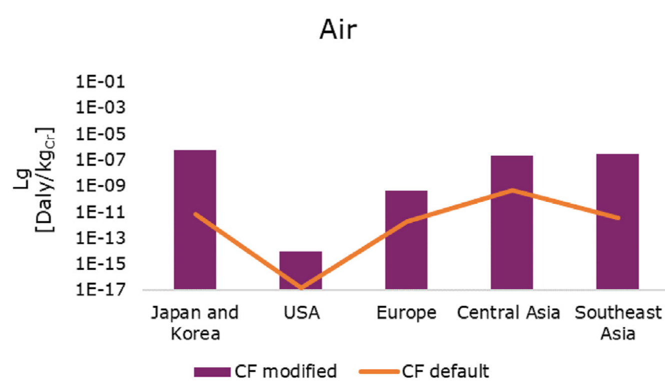

Fig. 6. The Characterization factor of chromium in pork meat via air, [Lg Daly/kg_{Cr}].

USA < Europe < Japan and Korea < Southeast Asia < Central Asia.

The impact of chromium via air (Fig. 6) calculated with the concentration coefficient is also significantly higher than the CF proposed by the USEtox data. The values of modified CF and default CF normalized to air, vary less than in soil. The order of magnitude of impact between different geo areas is also different for the modified CF and default CF. For default CF obtained with CC_{Cr} the order is USA < Europe < Southeast Asia < Japan and Korea < Central Asia, for modified CF it is USA < Europe < Central Asia < Southeast Asia < Japan and Korea. Southeast Asia and Japan and Korea have the biggest CF of Cr via air of all observed areas.

The different proportion of the CFs values can relate to the geological, ecological, geographical conditions of geographic areas studied in the research. The origin of the chromium intake is well reflected in the meat content, which is not considered in the USEtox

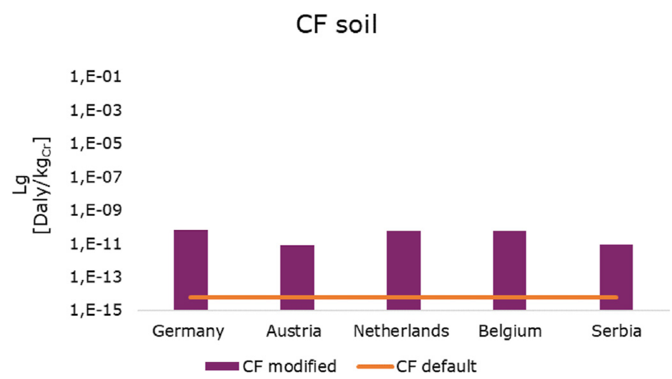

Fig. 7. The Characterization factor modified of chromium in pork meat via soil, Daly/kg_{Cr}.

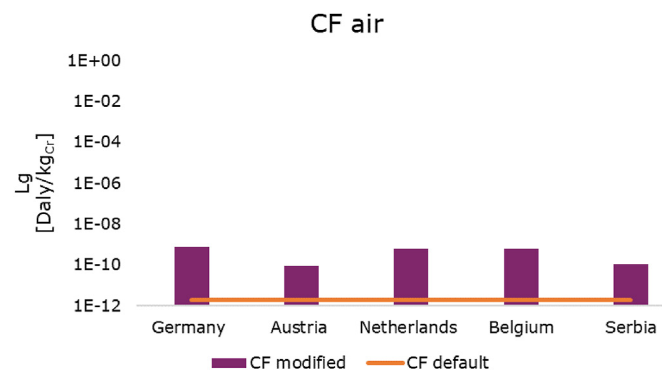

Fig. 8. The Characterization factor modified of chromium in pork meat via air, Daly/kg_{Cr}.

model.

From the detailed study of CF_{Cr} for the countries in the geographical area “Europe”, it can be noted that the countries of Europe show close, but not identical, results, which is impossible to observe using only data given by the USEtox, because the model uses the same CF value for all European countries.

Inside the geo zone “Europe” we can see differences between results of CF calculations for both types of intake (via soils, via air) (Figs. 7 and 8). The difference between CFs is smaller on the scale of “Europe”, which could be linked to more similar environmental conditions in comparison with differences at the global scale.

We observe the slightly higher value of CF for Germany in comparison with other sampling areas, and similar characterization factors between Netherlands, Belgium and Serbia. In contrast, the default value proposed by USEtox is significantly lower than all values calculated manually.

For geo areas USA and Central Asia, we observe that the potential human health impact is higher with the intake of Cr from soils than with the intake of this element via air. This relates to the main pathway of Cr and natural animal behavior. According to the toxicological investigation: the common ingestion intake pathways of Cr are food consumption, drinking water, and ingestion of contaminated soil (Independent Environmental Technical Evaluation Group, 2004). The behavior of pork in the natural environment includes digging, so the ingestion of contaminated soils can be more significant than inhalation.

4. Discussion

Results of the current investigations showcase the importance of regional aspects on the impact assessment of chromium and highlight the significance of using reliable sources of literature.

We can distinguish that, between two obtained spatial recognition (country scale and regional), default parameters are lower than the modified one. This variation relates to the high indicator capability of the bio-indicators, pork meat in the current case. The default calculations of the USEtox model use the generic parameters of the non-organic’s accumulation in meat products. Meanwhile the current research assesses the chromium content in pork meat relying on a very specific analytical dataset, that has a large number of variables. Each studied area has unique environmental conditions, that are basically ignored in the default model parameters. As mentioned before, in the exposure factor calculations the regional aspect is expressed only by the population density. In the USEtox model the transfer of elements or their accumulation do not change depending on the area. On the contrary the analytical data we applied reflects the heterogeneity of the accumulation of chromium by pork meat with different origin. Default characterization factors do vary depending on the geographical area, but with smaller differences between values. It probably demonstrates the lower sensitivity of the model dataset because each geographical area has completely different geographical, ecological, and geological conditions. We can see the reflection of these conditions in the content of chromium in the pork meat.

Also, we see the spatial aspect influence affecting the geo area “Europe”. Different countries of the geographical region identified in the model as “Europe” have different CFs despite their territorial proximity, with lower values than the default factor of the USEtox model. Similar results were obtained in the previous investigation (Belyanovskaya et al., 2019). The variation in the modified characterization factors for two villages of one administrative district was distinguishable. As in the case of the previous investigation, the significant role of environmental conditions is observed.

The other point is the lack of literature sources used in the model dataset. The default CF of all studied regions - intake of Cr with pork through contaminated soils and air - is significantly lower than the factor calculated manually. We assume that this inconsistency can be associated with ignoring the geological features of different countries, and the characteristics of the entry of an element into the body from certain contaminated environments. Information provided by the USEtox model reflects transfer of metals with specific influences such as dust or coal pollution and does not cover a huge spectrum of non-organic elements.

The disagreement between the default and our data for the “Central Asia” zone could relate to population density. Probably, the USEtox model underestimates the value of the characterization factors for large but sparsely inhabited areas. Information about population density, industrial influence on the environment and the volume of available soils is not reflected in the results, even specifying geographic area as “Central Asia”.

As a future perspective of the research, we propose that the results of investigations of elemental composition of different types of meat, and especially pork, could extend the database of the model with more recent information. We assume that the lack of uniformity between the results of our own research and the data proposed by the model may be because the model uses data on the theoretical content of chromium in a polluted environment, and as a result, over- or underestimates the results. We suppose that using the results of an analysis of chromium in meat products, instead of a theoretical calculation of its content, is a more effective way of estimating the biological accumulation of a given heavy metal by living matters. The source of such results, some of which were presented in the article, on the content of chromium or other chemical elements in pork, could be published in research databases.

5. Conclusions

The importance of local information in impact assessment investigations is equally significant at the level of a region and at a level of a country. Implementing the locality-specific data leads to disagreement with the default model dataset. The variations in the content of Cr in the meat products, and consequent human exposure to the element, reflect very specific features of each area. This heterogeneity can relate not only to the geoecological conditions of the region, but also to the biological aspects. However, in the current research, only the importance of the spatial aspect to the metal exposure was considered.

The main conclusion of the investigation is that the spatial orientation given by the USEtox is more generic. Using the USEtox model for impact assessment can be effective at the global level, but for investigation on smaller spatial scales the model needs to be refined.

Looking at the USEtox references and data provided for the CFs calculation, we can see that the model provides the same results for huge areas of Central Asia, China, Europe etc. It does not reflect the real influence on the health of the population.

We would suggest that the reorganization of the geo areas into “urban areas” models around cities or regions, according to the wind or water flow destination, would result in more useful information for decision-making, as was described for the example of the Tomsk region in the previous article (Belyanovskaya et al., 2019). This approach would avoid underestimation of negative influences in cases of geographical locations with mixed environmental conditions.

The public importance of the study results is also relevant. It consists in finding the potential negative impact on population health due to the technological impact. Calculation of human health impact is a new option for determining the indicators of changes in public health. The results of the investigation can become a basis for the development of key policy directions in the field of public health protection at the territorial and, especially, local levels, which underlines the social significance of the research. In the economic sphere, project results can be used as recommendations for enterprises in environmental monitoring, in accordance with the concept of sustainable economic development.

The future perspective of the model dataset extension with experimental data can be performed in several ways, for example, using analytical data for other non-organic emissions. Indirect human exposure and characterization factors can be modified with information about other meat products. Drawing on the current work, soil-plant bioaccumulation factors could equally well be integrated into the model.

CRediT authorship contribution statement

Alexandra I. Belyanovskaya: Conceptualization, Data curation, Writing - original draft, Formal analysis. **Bertrand Laratte:** Conceptualization, Supervision, Methodology. **Vishnu D. Rajput:** Formal analysis. **Nicolas Perry:** Conceptualization, Supervision. **Natalia V. Baranovskaya:** Conceptualization, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Abbreviations

BAF	the bioaccumulation factor
CC	the concentration coefficient
CF	the characterization factor
Default CF	the characterization factor obtained with the default exposure factor
Modified CF	the characterization factor obtained with the modified exposure factor
ICP-MS	the inductive coupled plasma spectrometry
LCA	the life cycle assessment
LCIA	the life cycle impact assessment
XF	the exposure factor

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.122432.

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