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Water footprint of consumption of the Czech households

Bachelor's Thesis

Author: Jana Možíšová

Study program: Economics and Finance

Supervisor: Mgr. Milan Ščasný, Ph.D.

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Declaration

1. I hereby declare that I have compiled this thesis using the listed literature and resources only.
2. I hereby declare that my thesis has not been used to gain any other academic title.
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In Prague on 01.08.2023 Jana Možíšová

References

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Abstract

Since the human society rises the requirements on environment it is important to find ways to mitigate the pressure. One of the possible important aspects could be consumption behaviour of individuals. In thesis we examine the water footprint connected to consumption of Czech households. Using the hybrid input-output analysis we compute the water intensities for domestic production and imported products of 90 product groups and connect them with household expenditures described for 2899 Czech households. In our analysis we use data for 2018 and describe the results separately for blue and green water footprint. The mean annual consumption of blue and green water is 214.3 m^3 and 2544 m^3 respectively per household member. The highest responsible category for total water footprint is category of food with the 74 %. This category has also the largest computed water intensity among the twelve consumption groups. Analysis also showed the water footprint is distributed unevenly through the households divided to deciles by expenditures. The lowest decile uses about 4 % of total water footprint in comparison to tenth decile consuming almost 18 %. By the linear regression of expenditures and water footprints we got the statistically significant elasticities varies between 0.48 to 2.71.

Keywords

Water footprint, Czech households, hybrid input-output method, consumption, blue water footprint, green water footprint

Abstrakt

Vzhledem k tomu, že lidská společnost zvyšuje své požadavky na životní prostředí, je důležité nalézt způsoby, jak tento tlak zmírnit. Jedním z možných důležitých hledisek by mohlo být spotřební chování jedinců. V bakalářské práci zkoumáme vodní stopu související se spotřebou českých domácností. Použitím hybridní input-output analýzy počítáme vodní stopu domácí produkce a importovaných produktů pro 90 produktových skupin a poté je propojujeme s výdaji 2899 českých domácností. V analýze používáme data pro rok 2018 a výsledky prezentujeme zvlášť pro modrou a zelenou vodní stopu. Průměrná roční spotřeba modré a zelené vody na člena domácnosti je 214.3 m^3 a 2544 m^3. Kategorií nejvíce zodpovědnou za vodní stopu je skupina potravin s 74 %. Tato kategorie má také mezi dvanácti spotřebními skupinami nejvyšší spočítanou vodní intenzitu. Studie ukázala, že vodní stopa je mezi domácnostmi rozdělenými do decilů dle výdajů rozdělena nerovnoměrně. Nejnižší decil využívá okolo 4 % celkové vodní stopy, zatímco desátý decil spotřebovává téměř 18 %. Lineární regresí výdajů a vodních stop jsme získali statisticky významné elasticity pohybující se mezi 0.48 až 2.71.

Klíčová slova

Vodní stopa, české domácnosti, hybridní input-output metoda, spotřeba, modrá vodní stopa, zelená vodní stopa

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Acronyms

CES	Consumption Expenditure Survey
COICOP	Classification Of Individual Consumption by Purpose
CPA	Classification of Products by Activity
EE MRIO	Environmentally Extended Multiregional Input-Output model
IO	Input-Output
ISO	International Organization for Standardization
LCA	Life-Cycle Assessment
MRIO	Multiregional Input-Output model
SIOT	Symmetric Input-Output Table
WF	Water Footprint
WFN	Water Footprint Network
WI	Water Intensity

1. Introduction

The water scarcity becomes a problem not only in typical areas such as Africa or south Asia but also in areas of Europe or North America (Kummu *et al.*, 2016). With the growing population the pressure on water resources will be increasing and change in behaviour of society turn out to be necessary (Mekonnen and Gerbens-Leenes, 2020). To track the water used throughout the entire production process of commodity, the water footprint (WF) concept was created by Arjen Hoekstra in 2002. By examination of this indicator, we could indicate critical consumption patterns and change the behaviour in order to reduce the burden on water supplies.

In the thesis we focus on water footprint connected to consumption of Czech households. This indicator is computed using the hybrid environmentally extended multi-regional input-output method (EE MRIO) introduced by (Ewing *et al.*, 2012) which is linked to consumer expenditure survey for almost 3000 Czech households.

To the best of author´s knowledge no research used this method to determine the water footprint of Czech households. Nevertheless, the method was already used for Czech data to examine the greenhouse gas emissions and air pollution connected to the household consumption. The thesis aims to extend the existing research in field of water footprint specified for household consumption. Specifically, to determine the most responsible consumption groups and their average water intensities (WI). Also, thesis shows the allocation of used water with respect to examined households' expenditures.

The calculated average annual consumption of blue and green water per household member is 214.3 m^3 and 2544 m^3 respectively. Consumption group of food is on average responsible for 74 % of overall water footprint but only for 12 % of household member expenditures. The computed water intensities are also highest for the food category. The distribution of expenditures and water footprint is not even through the households. The first decile uses about 4 % of total water footprint whereas tenth decile is responsible for almost 18 %. The linear regression examining the relationship between expenditures and water footprint showed the variously strong link ranging from 0.48 to 2.71 depending on the consumption group. All the results are statistically significant.

The thesis structure is following: literature review describes the concept of water footprint, changes in water cycle and existing literature about input-output modelling. Next, the procedure of using hybrid input-output method is described and results are connected to consumption survey data. Then the results of study are presented, discussed and the limitations of research are included. Finally, the conclusion is provided to the reader.

2. Literature review

Water footprint is a concept introduced by Hoekstra and Hung (2002) following the already existing theory of virtual water developed in the early 1990s by Tony Allan. The name was given by the analogy with the ecological footprint which was first used in 1992 by William Rees. Ecological footprint describes human needs and its sustainability on natural resources. Water footprint together with other footprint indicators (Ecological, Carbon and Land) creates a family of measures enabling access to the effects of our actions on natural resources (Hoekstra, 2003).

WF was first used in the context of virtual water in view of nations and expressed water required by each nation as a sum of water consumed domestically and net virtual water import (Hoekstra and Hung, 2002). Hoekstra (2003) referencing on previous reports determines WF also from the perspective of the individual. Later on, the concept is clearly reshaped into primarily consumption-based indicator approaching the issue closer to the individual (Chapagain and Hoekstra, 2004). Hoekstra *et al.* (2011) afterwards in the Water Footprint Assessment Manual summarise the previous definitions into one: "*The water footprint is an indicator of freshwater use that looks at both direct and indirect water use of a consumer or producer.*" They also specify the measurement of water used in creating a product not only as a volume of water physically connected to the product but also as water evaporated or polluted through the process per unit of time. The concept can be utilised for consumer, producer, or specific product. The water footprint is in this definition also connected to location. In perspective of the water types, three forms are described: the blue, green and grey water footprint. The blue water footprint shows utilization of the surface water and the green water footprint defines the rainwater used up. Water polluted through the process is called the grey water footprint (Hoekstra, 2019).

1.1 Historical background

1.1.1 Virtual water

Virtual water is a concept created in 1993 by Tony Allan preceding the water footprint theory. In the case of virtual water, we consider all the freshwater necessary for the production of goods and services. Virtual water has also its predecessors in the form of "embedded water", "embodied water" or "exogenous water". The first two terms refer to water put into the product through the process of creation. Especially embedded water was used already in 1988 but there was hardly any response to this problem till the introduction of virtual water (Allan, 2011). Exogenous water expresses the real flow of water bonded in the products among the countries. The international trade afterwards results in the consumption of water imported from other regions (Hoekstra, 2003).

Concept of virtual water was established in a period of increasing awareness of the global impact of human actions on the planet and the environment. Virtual water was identified for the purpose to point out growing pressure on local water resources and already existing water-scarce regions, for example, the Middle East. Allan by this theory exceeds the borders of the environmental field. Firstly, showing the water as an economically valuable and limited resource, ideally considered as "*liquid capital*". Secondly, refers to possible political tools for resolving national water shortages and territorial conflicts connected to water resources (Allan, 2011; Stack Whitney and Whitney, 2018). For example, solution to water shortages in certain regions can be found not just in the costly and difficult trade of real water over long distances, but also in the import of water-intensive products from water rich regions. This practice should bring the overall water use efficiency and global savings (Hoekstra, 2003). Renault (2003) demonstrates this view in the first of four visions motivated by the supply side. Other visions emphasise the openness of the water market and more economical distribution of water, support the development of more ecological procedures in water operation and highlight the impact of excessive agricultural production on the water resources located in water scarce countries. Renault furthermore speaks briefly about storing water in the form of food supply. Agriculture dependent on volatile natural conditions may experience fluctuations in productivity Option of storing the food can flatten the variability of yields and reduce the threat of food shortages in worse years by virtually shifting the water supply from abundant years.

The demand driven vision is another view of how to look at the utilization of the concept of virtual water (Renault, 2003). The consumption side describes individual products and measures the volume of water used through the whole process of generation. The information obtained may be summarized into the amount of water necessary to feed an individual, group or nation which can vary depending on numerous variables. For example, the location, wealth or diet. Renault (2003) notes that 1 m^3 of water per day, per capita, is involved in a diet to survive, on the other hand for diet containing primarily animal source foods needs about 10 m^3 per day and capita. This is a good indicator for ordinary individuals to approach the issue and discover the possibilities of influencing water consumption on its own. The water footprint is primarily based on this concept and expands it in more detail.

1.1.2 Water Footprint Network (WFN)

To study water footprint more efficiently and openly to people the Water Footprint Network was created. It is a space connecting individuals, companies and organizations who are aware of increasing water scarcity and other problems connected to the water cycle. WFN was found in 2008 by the creator of the water footprint concept, Arjen Hoekstra with the help of The University of Twente and global leaders and organisations from various fields. This platform was established to create a place to share the knowledge and inventions of how to work with water sustainably. Their main goals are creating the network, raising awareness in public, spreading the knowledge and available data and influencing governments and their decision making ('Aims & History – Water Footprint Network', no date). Under the WFN the Global Water Footprint Assessment was established to convey a comprehensive guide of methods, procedures for calculating the water footprint and accessible tools and structures to get a footprint more sustainable (Hoekstra *et al.*, 2011). The strategy is divided into four parts. The first one is defining goals and setting the framework. The following part is accounting where the most important are data and their gathering. The third part is called sustainability assessment containing the analysis of water use. Specifically tracking if the stability of use is reached according to the need of the people and the environment, the effectiveness of consumption and equitable distribution control. The last part is response formulation connecting all the gathered information into output recommending the changes reducing the water footprint (Hoekstra *et al.*, 2011; 'What is water footprint assessment? – Water Footprint Network', no date).

1.1.3 Life-cycle assessment of water use (LCA)

Life-cycle assessment is to the WFN another community platform sharing analyses of how the generation and life cycle of products and services can affect the natural environment (Sphera's Editorial Team, 2020). Unlike the WFN, LCA does not focus just on water footprint and impacts of products on water management but covers natural resources used and the emissions created usually as an externality of the production or disposal (Sphera's Editorial Team, 2020).

In 2014 the assessment and reporting standard on the field of water footprint results was announced by International Organization for Standardization (ISO) This assessment is based on the LCA standard. Nevertheless, this standard is not consistent with the standard of WFN primarily methodically but also terminologically (Hoekstra, 2019).

The methods of computation of the WF are in these two approaches almost identical, but the difference is in reporting the WF results. This difference is mainly created by the different perspectives. While LCA is focusing on environmental impacts, the WFN aim at the water productivity, fresh water and describes water as a limited resource (Pfister *et al.*, 2017).

1.2 Changes in water supply

Water on Earth can be divided into saltwater and freshwater expressed as a percentage of about 97.5 % and 2.5 % respectively (Allan, 2011; Gleick, 1993). Taking a closer look at the freshwater distribution, more than 69 % of water is stored in the form of glaciers and snow cover and the remaining almost 31 % is preserved in ground water. But only 0.3 % of freshwater is located in lakes and rivers which are the most common sources for human needs. (Gleick, 1993).

Gleick (1993) in his work already underlined the disruption of the water cycle and its consequences on human living. This hypothesis was later on confirmed and described by Durack, Wijffels and Matear (2012), Held and Soden (2006), Huntington (2010), Yu *et al.* (2020) or Unfried, Kis-Katos and Poser, (2022). All the mentioned researchers agree on moderate intensification of the water cycle caused primarily by global warming. The warmer atmosphere can contain and redistribute more water which drive evaporation and precipitation. Change in the water cycle will probably have an effect also on the distribution of water masses. Regions which are already wet will be even wetter and dry locations drier (Huntington, 2010; Durack, Wijffels and Matear, 2012; Unfried, Kis-Katos and Poser, 2022). In general, there is a visible shift of water in the direction from the tropical zone to the colder territory since 1970 (Sohail *et al.*, 2022). Together with the human action of intensive water withdrawal from ground water, vulnerable regions can easily suffer from water scarcity. Therefore, water could become a non-renewable resource in particular locations (Gleick, 1993).

By FAO (2017) the states which pull out more than 25 % of local renewable freshwater resources meet the requirements for being depicted as water-stressed regions. Gleick (1993) also specifies these assumptions by a description of natural runoff. He presents the runoff as a dynamic part of the water cycle, which allows the renewability of water resources and also specifies the sustainable portion of runoff to 25 % of water supplies. Thus, water withdrawal caused by humans, exceeding 25 % of water resources may be regionally unsustainable for nature and water supplies should have decreasing rate. FAO (2017) represents the Water Stress Index showing the freshwater withdrawn as a percentage of total renewable water resources. By that, they depict the degree of danger of water scarcity respectively to each country. The most endangered states are in North Africa, the Middle East and Central and South Asia. In a number of these countries, agriculture is the main cause of water use up to 90 % of the overall water withdrawal (FAO, 2017). Together with the trend of shifting water to cooler locations, severe local water shortages could be the present issue in mentioned regions in the near future.

It is also crucial to distinguish between closed and opened regions in terms of water runoff. Whereas increased water withdrawal from opened regions can cause little to no change in the composition of the oceans, in the case of closed regions, specifically interior seas, it may bring a serious transformation in the salinity and suitability for living (Gleick, 1993).

Probably the most devastating case of water depletion is the Aral Sea. Since 1960 the Aral Sea lost about 88 % of its area and 90 % of its volume. This decline in water renewal was caused primarily by human actions but also by natural factors. The main determinant of Aral Sea reduction was growing agricultural irrigation and the related water withdrawn from rivers flowing into the Sea. This enormous change in the flow resulted in almost irreversible environmental issues such as extinction of fish species, intensification of draught or creation of conditions for dust and salt storms (Micklin, 2007; Wang *et al.*, 2020; Yang *et al.*, 2020).

Another example of the non-renewable withdrawal of water is in the Dead Sea. The receding water level also started in the 1960s as a result of water diversion for irrigation into arid regions of Israel and Jordan. Later mining of valuable minerals also contributed to the aggravation of the situation. Since that, the area of the Dead Sea diminished by about one third. Group Ecopeace Middle East evaluated the change of the water flow into the Dead Sea from 1200 million m^3 in the past to 100 million m^3 nowadays. Lowering of the water level led to the formation of sinkholes on the west coast of the Dead Sea (Tlozek, 2021). There are many more similar examples such as Lake Chad dwindling by more than 90 % in the last 50 years (Notaras and Aginam, 2009; Gao *et al.*, 2011), Lake Poopó shrinking in the last 20 years (Torres-Batlló, Martí-Cardona and Pillco-Zolá, 2020) or Poyang Lake experiencing decreasing of the water level since 1990s (Xu *et al.*, 2020). These stories have something in common. All the above-mentioned researchers agree that a trend of shrinking water resources is at least partially caused by human actions, most often associated with agricultural irrigation. Wine and Laronne (2020) state that irrigation is responsible for 80 - 90 % volume decline of lakes. In general, agriculture is behind 70 % of all the water withdrawals, and 20 % of the water used for crops watering is non-renewable groundwater (Wada, van Beek and Bierkens, 2012; FAO, 2017). From the perspective of non-renewable water extraction, Wada, van Beek and Bierkens (2012) evaluate that 85 % is connected with irrigation. With the increasing population, it is crucial to solve non-sustainable actions as soon as possible. One of the feasible options may be to deal with the problem through consumer behaviour patterns and eating habits.

1.3 Importance of the consumer side

United Nations (2022) expect the world population to attain 9.7 billion in 2050 and project further growth up to 12.4 billion in 2100. Among others, the rise will cause pressure on the agricultural sector which is already using the greatest amount of water for production (Mekonnen and Gerbens-Leenes, 2020). Also, other sectors will be burdened by growing demand. This will presumably result in the unsustainability of a consumptive lifestyle in developed countries and a necessary change of behaviour of the individual. The responsibility transferred on the individual actions brings us to deeper research of the water footprint created in terms of the consumer side. The water required for a human living can be divided into two parts: direct water footprint and indirect water footprint. The direct water footprint refers to water used for example by appliances in a household, water spent on showering, cleaning, cooking, or drinking. In a simplified way, it is the water we see ourselves consuming, which helps to perceive this section more commonly. On the other hand, the indirect water footprint covers all the water used up for the creation of products or services consumed by individual (Hoekstra, 2019; Hoekstra *et al.*, 2011). In other words, the concept sums up the direct water footprint in every previous step of the supply chain.

There is an evident shift in thinking about water consumption in recent years. Governments, companies and non-profit organizations emphasize water conservation in households through advertisements and recommendations. These initiatives are focused mainly on the direct water footprint. They stress the importance of economical patterns from buying more energy efficient appliances, through shorter showers up to more effective use of water in the garden. Nevertheless, the direct part of the water footprint is just a fraction of water used by an individual (Hoekstra, 2019; Allan, 2011). According to Hoekstra (2019), the water footprint of an individual´s food consumption in developed countries is about 4480 litres of water per day for a diet with animal products, 2830 litres per day for a vegetarian diet and 2380 litres per day for a vegan diet. Allan (2011) specifies the water footprint of consumption as 5000 litres per day and 2700 litres per day for non-vegetarian and vegetarian diet respectively. Taking the diet with animal products, which is still the most broaden diet in the world, the water footprint of food represents about 65 % of the overall water footprint of individual, compared to less than 6 % share of direct water use. The remaining part includes the indirect water footprint of the non-food sector and services such as transportation, housing, entertainment and others. In conclusion, there is still great space for stressing out the topic of water footprint and improving the behaviour patterns of consumption.

1.4 The Input-output method (IO method)

The input-output analysis was introduced in the 1930s by Professor Wassily Leontief indicating the macroeconomic method. The analysis primarily describes the relationship and dependency across the sectors in the economy (Miller and Blair, 2009). In simple form, the IO table consists of rows, where each row shows how the output of a specific sector is allocated between the others, and columns expressing which inputs each sector needs from the other sectors (Leontief, 1986). The basic IO tables can be extended by additional data to provide more detailed structures (Miller and Blair, 2009). The multiregional input-output model (MRIO) is an extension of the basic IO method including more economic regions (Leontief, 1986).

1.4.1 Environmentally Extended Multiregional Input-Output model

With the Environmentally Extended IO analysis we can observe the relationship between economic participation and connected environmental effects (Kitzes, 2013). EE MRIO is the most common method for calculating footprint indicators. Using the model, we can examine specific economic subjects and their share on footprints in detail. With the multiregional extension, the model is suitable for observing the phenomenon of the consequences of the international market on the environment (Ali *et al.*, 2018). The footprint approach with consumption data and the EE MRIO model has substantial results for forming global environmental policies (Wiedmann *et al.*, 2011).

The advantages of the model include the detailed description of international production and supply chains and the possibility to observe not only its environmental impacts, the possible use on forecasting and stable data collection at least on a national level. On the other hand, the model has limited sectors and production groups. For closer determination of local environmental impacts other data and models are necessary and the data is very limited in terms of time (Wiedmann *et al.*, 2011).

Many studies has been done using the EE MRIO model. Acquaye *et al.* (2017) and Zhang and Anadon (2014) used both production-based and consumption-based approaches. The first paper examines the carbon and sulphur oxide emissions and water use in electricity production and chemical industry for 33 countries while the second research focuses on water footprint of Chinese provinces and the virtual water flow between them. The consumption-based approach is used in the following studies from the Netherlands (Wilting, 2008), the United Kingdom (Yu *et al.*, 2010; Feng *et al.*, 2011), Spain (Cazcarro, Duarte and Sánchez Chóliz, 2013) or China and Northeast part of China respectively (Guo and Shen, 2015; Zhang *et al.*, 2020).

1.4.2 Hybrid EE MRIO

Ewing *et al.* (2012) present the adjusted EE MRIO model, here named as integrated MRIO-Footprint model, which connects the MRIO approach with the comprehensive WF accounts. This combination enables observation of the individual products together with a study of footprints across the supply chains. This method allows the unification of carbon footprint, ecological footprint, and WF. Also, the intermediate products can be distributed into final consumption and footprints of the service sector can be computed. The important aspect for the creation of this model is getting more detailed data, specifically the product categories, without the great data demanding decomposition of MRIO sectors (Ewing *et al.*, 2012; Steen-Olsen *et al.*, 2012).

The model allows us to observe the trade flows and interactions of economic subjects in more detail and better analysis of footprint indicators between each other. The production-based and consumption-based approaches, specifically described in Peters (2008), can be used. Possible shortcomings include the aggregation of products, primarily in environmentally significant sectors such as agriculture, forestry or fishing, or aggregation on the national level which can cause the lack of accuracy mainly in larger countries such as the United States, Canada or China (Ewing *et al.*, 2012).

Weinzettel *et al.* (2014) compare the results of the process analysis, standard MRIO model and the hybrid MRIO of computation of the ecological footprint. They summarise both methods are more accurate for specific information. The hybrid MRIO method provides more detail in primary products against the standard MRIO method and describes the supply chains and international trade more specifically than the process analysis. Another publication using the hybrid MRIO method is Weinzettel and Pfister (2019) focusing on the distribution of scarce water use from the production and consumption approach, who state that developed countries shift their need of scarce water use for consumption to developing countries. Chen *et al.* (2018) reached similar conclusions with water use and also with the use of agricultural land. Steen-Olsen *et al.* (2012) conducted a study based on a hybrid model showing the Carbon, Land and Water footprint of European member states. The GTAP 7 database for the year 2004 was used and the average consumption per EU habitant of blue water was conducted as 179 m^3. The Blue Water Footprint for the Czech Republic is below the average around 70 m^3. The study undertaken by Mach, Weinzettel and Ščasný (2018) is methodologically the closest to this thesis using the EXIOBASE 2 database and analysing the consumption of Czech households. The research identifies the amount of greenhouse gases, smog formation and acidification created by consumption pointing out the emissions are not allocated equally within the household expenditures.

3. Methodology and data description

2.1. Data description

The thesis is based primarily on three data sources for the year 2018. EXIOBASE 3 (Stadler *et al.*, 2021), which are a global Environmentally Extended Multi-Regional Input-Output Tables (EE MRIO), single-region Symmetric Input-Output Table (SIOT) for the Czech Republic (CZSO, 2018) and non-publicly available Czech households consumption data obtained from the consumer expenditure survey (CES) of Czech households for 2018. EXIOBASE 3 database contains information about 44 countries including 28 members of the EU, 16 major economies and the rest of the world is collated into 5 world regions. The tables are presented in basic prices in units of millions of Euros (EUR) and the data are divided into 200 product classifications. Information about water consumption is split by blue and green water into 103 and 13 product classifications respectively. The water accounts are stored in millions of m^3. Specifically, the tables with final use, intermediate consumption, technical coefficients and production-based water accounts were used. Single-region SIOT data for the Czech Republic shows financial flows between 90 Classification of Products by Activity (CPA) product categories in current, basic prices in millions of Czech Koruna (CZK). CES collects data about expenditures from 2899 Czech households disaggregated into 293 Classification Of Individual Consumption by Purpose (COICOP) categories in CZK purchasers' prices. Besides the consumption data, the demographic characteristics of each household are obtained such as a number of members of the household, age, education, employment etc.

Furthermore, to link the COICOP and CPA classifications the publicly available contingency and bridge matrix are used. This bridge made from 2010 data is composed for 64 CPA product groups and 47 COICOP categories. For the following conversion of purchasers' prices to basic prices we will use data acquired from the supply and use table for 2018 (CZSO, 2018), specifically vector of domestic production with imports, vectors of margins, taxes and subsidies.

2.2. Methodology

With the aim of computing the WF of consumption of Czech households we can divide our procedure into three-steps. First, the hybrid EE MRIO analysis is applied to EXIOBASE 3 and the domestic SIOT database. In general, EE MRIO models are commonly used for computation of environmental pressures created by worldwide production. The model describes global trade relationships and thus offers a detailed analysis of the entire market chains (Kitzes, 2013; Mohan *et al.*, 2021). Second, the expenditure data for the Czech households are bridged, in detail described by Cai and Rueda-Cantuche (2019) into product groups, converted to basic prices and connected with the computed WI to get the outcomes of WF in m^3. Lastly, the results are collapsed into 12 main COICOP categories and further investigated by statistical methods. Subsequent figures are presented on yearly basis per household member.

2.2.1. Hybrid EE MRIO

The hybrid method of input-output analysis was developed to combine the higher quality of data collected in single-region input-output table with a more comprehensive structure of EE MRIO tables. By this connection, we can use more detailed national data together with more accurate estimations of the water footprint for imported products (Mach, Weinzettel and Ščasný, 2018).

To compute the WF and WI for each product group we proceed according to research by Mach, Weinzettel and Ščasný (2018). This procedure can be divided into two parts, where in first we compute the total WF of imported products consumed by Czech households, and in the second part, we derive WF connected to household consumption from domestic production. To get the footprint of imports we use the EXIOBASE 3 database, especially imported intermediate inputs, final demand, technical coefficient matrix A_{MR} and water intensity matrix WI_{MR}. Footprint of imports is calculated as follows:

$$F_{impreg} = WI_{MR}(I - A_{MR})^{-1}\widehat{m}_{MR}$$

where I is unit matrix, $\widehat{m}_{MR}$ is diagonalized vector of sum of final demand and products imported for intermediate use and $(I - A_{MR})^{-1}$ is usually called the Leontief matrix. This matrix describes the water necessary for all the layers of trades between the production groups. Simply it counts the water need not just for output of industry but also the inputs which are coming to the industry. In matrix F_{impreg} the data are specified not only by product groups, but also by origin of imported production which was used for different technical coefficients and now cannot be used any further. Thus the F_{impreg} is summed to the matrix F_{imp} holding the information only about the product group.

Matrix F_{imp} is then transformed to the grouping of domestic IOT. Specifically, 200 groups are aggregated into 90 groups by summing the more detailed multiregional data categories and dividing footprint by the ratio of imports for categories more comprehensive for domestic data. Afterwards, the water intensities of imported products with higher product precision in domestic IOT are compared with water intensities for domestic production and those with a difference larger than 20 % are labelled. In our case, only two domestic groups fulfil both criteria but after closer analysis we found out this was caused by zero WI in domestic production and thus we suggested using the WI from multiregional data instead.

In the next point, we need to distribute the WF of imported produce to the domestic users of the products. It is used in intermediate consumption or directly. To do this distribution we utilize the national IO table for import (Z_{imp}) containing the data about trade structure and inversed diagonalized vector of total imports m.

$$F_{impsect} = F_{imp} * (\widehat{m})^{-1} Z_{imp}$$

The WF of products which are consumed directly by households is computed as follows:

$$F_{impyhh} = F_{imp} * (\widehat{m})^{-1} * (\hat{y}_{hhimp})$$

where $\hat{y}_{hhimp}$ is a vector describing the final consumption of imports of the households. For the next step, the technology coefficient matrix A_{dom} is derived from the single region IO table (Z_{dom}) for domestic production.

$$A_{dom} = Z_{dom}(q - m)^{-1}$$

where q stands for the vector of total domestic and imported supply and m is total imported supply. The imported products which are used in intermediate consumption are then allocated to the final demand of households by the Leontief method.

$$F_{impsecthh} = WI_{impsect} * (I - A_{dom})^{-1} * (\hat{y}_{hhdom})$$

for $$WI_{impsect} = F_{impsect} * (q - m)^{-1}$$

and $\hat{y}_{hhdom}$ stands for a vector of final household consumption from domestic production. Therefore, the WF of imported products consumed by households can be derived as the sum of directly consumed imports and processed products by intermediate consumption used in the end by households.

$$F_{imphh} = F_{impyhh} + F_{impsecthh}$$

To compute the WF of domestic production consumed by households we used the data about water accounts from the EXIOBASE 3 database which were summed by product groups and divided by total output to get the WI. These data had to be then transformed by the matrix from the 200 product groups to the 90 CPA groups applied in single-region IO tables.

$$F_{domhh} = WI_{dom} * (I - A_{dom})^{-1} * (\hat{y}_{hhdom})$$

Finally, to compute the WF of the total household consumption, we need to sum the WF from consumed imports F_{imphh} and domestic products F_{domhh}.

$$F_{hhtotal} = F_{imphh} + F_{domhh}$$

The water intensity of the product groups essential in further analysis for the calculation of WF connected to the household expenditures and consumption is afterwards simply computed as:

$$WI_{hhtotal} = F_{hhtotal} * (\hat{y}_{hh})^{-1}$$

where y_{hh} is the vector of total household consumption and final WI is in m^3/EUR.

2.2.2. Calculation of water footprint for household expenditures

To connect the calculated WI from the hybrid EE MRIO model with the data based on consumption survey we use in addition to the procedure described in Mach, Weinzettel and Ščasný (2018) also the method presented in Cazcarro *et al.* (2022). To link the computed WI in CPA categories with household expenditures from CES data in COICOP classification the bridge matrix is utilised. But since the bridge matrix is assembled for 64 CPA product groups and 47 COICOP categories the data have to be adjusted to this shape. 90 CPA categories were merged into 64 categories, product groups which needed to be divided were split by the coefficient of total supply. In the case of COICOP classification original 293 groups were converted into 47 categories. After regrouping the bridge matrix is used on CES data.

After the transformation of COICOP classification to the CPA nomenclature, we need to converse the CES data from purchasers' prices to the basic prices. We will proceed according to the description in Mach, Weinzettel and Ščasný (2018). To modify the data, we need to subtract imposed taxes, given subsidies and the margins connected with transport and trade which are afterwards reallocated to the respective product groups. The detailed vectors with data are acquired from the supply and use table (CZSO, 2018). The basic prices are calculated as follows:

$$E_b = E_p \times (\widehat{c^t} + c^m)$$

where E_b and E_p represent the matrix of expenditures in basic and purchasers' prices respectively. $\widehat{c^t}$ is diagonal matrix which is created to deduct the taxes and margins from the purchasers' prices for all product groups. Vector c^m reallocates the margins to the providing product groups. The vector c^t is derived as:

$$\{c_i^t\} = \left\{\frac{p_i}{p_i + r_i + |t_i + s_i|}\right\}$$

where p_i stands for domestic production with imports, r_i is in our case sum of trade and transport margin, t_i are taxes and s_i are subsidies for each product group i. Therefore, from the mathematical foundations clearly follows for the product groups without any production and imports, i.e. $p_i = 0$ the $\{c_i^t\} = 0$.

The computation of c^m matrix can be written as:

$$\{c_{ij}^m\} = \left\{\frac{r_i}{p_i + r_i} \times \frac{r_j}{\sum_j r_j}\right\}$$

for all product groups i and j where groups j in this case mean the providers of margins. Thus, for product groups i with $r_i = 0$ and for product groups j, which are not suppliers of margins and $r_j = 0$ applies $\{c_{ij}^m\} = 0$.

The trade margin is incorporated into three product groups by its origin. The first group is wholesale, retail trade and services of vehicles, another group is another retail trade services and the last group with the highest transferred margin is another wholesale trade services. The transport margin is divided also into three groups of land and pipelines, water and air transport services.

The adjusted households expenditures in basic prices are then divided by the average exchange rate for the euro for 2018 (CNB, 2018) and multiplied by the total water intensity $WI_{hhtotal}$. By this computation we will get the total WF for each household.

2.2.3. Detailed household water footprint

Data from the expenditure survey are usually collected for two months during which the questionnaire is filled out. Data are thus rearranged to values per year and also grouped into 12 main COICOP categories for a better presentation of results. The CES data include the weights of representation of examined households in the Czech population and thus, the average values are calculated as the weighted average for overall Czech inhabitants. The results are presented for blue and green WF separately. Since the expenditures of households vary especially by the number of persons, the results are presented per member of the household. The WF is analysed in connection with the total expenditures. As in Mach, Weinzettel and Ščasný (2018) the double-log model is used for the computation:

$$\ln WF_{ij} = \beta \ln X_i + \mu_i$$

Where index j by WF is for the jth consumption group ($j=\{1,2,....,12\}$), X is absolute expenses per household member for ith household and β is the estimated coefficient. The WF is furthermore examined by the Lorenz curve and the associated Gini coefficient.

3. Results

By the connection of resulting water intensities from hybrid EE MRIO with the data about household expenditures we got the water footprint of consumption of examined Czech households. The results are divided for blue and green WF to better reflect the water source and diversity through the consumption categories. Since some of the consumption categories have long complex name, we will set the abbreviated names which will be used in further presentation of results. Category food and non-alcoholic beverages will be labelled as “food”, Alcoholic beverages, tobacco and narcotics as “addictives”, clothing and footwear as “clothing”, housing, water, electricity, gas and other fuels just as “housing”, Furnishing, household equipment and routine household maintenance as “household goods” and miscellaneous goods and services as “other services”. For the rest categories we will use the official COICOP names.

For the total WF per weighted household member we obtained 214.3 m3 of blue water and 2544 m3 of green water per year. The specific average WF for each consumption group is shown in Table 1 and graphically illustrated by pie charts in Figure 1. For better graphic clarity five of the twelve categories with very small representation are for this pie charts merged together as category other services. Even so, they do not embody more than 3 % of overall WF. In both cases the category food holds the largest share in WF, specifically 57,7 % and 75,3 % for blue and green water respectively. On the contrary, the smallest contribution has the education sector. Three categories which are connected with the foodstuff, thus first, second and eleventh category are together responsible for 85,8 % of blue WF and 84,9 % of green WF. In the comparison of blue and green water, we can see significant changes in ratios in three categories, specifically food, addictives and recreation and culture.

Table 1: Average WF per household member per year

	Blue WF (m^3)	Green WF (m^3)
Food	123.6	1916.2
Addictives	58.5	229.4
Clothing	8.76	37.6
Housing	0.41	1.5
Household goods	6.81	22.5
Health	0.19	0.9
Transport	0.93	5.4
Communication	0.11	0.5
Recreation and culture	8.29	306.1
Education	0.004	0.03
Restaurants and hotels	1.82	13.5
Other services	4.88	11.1

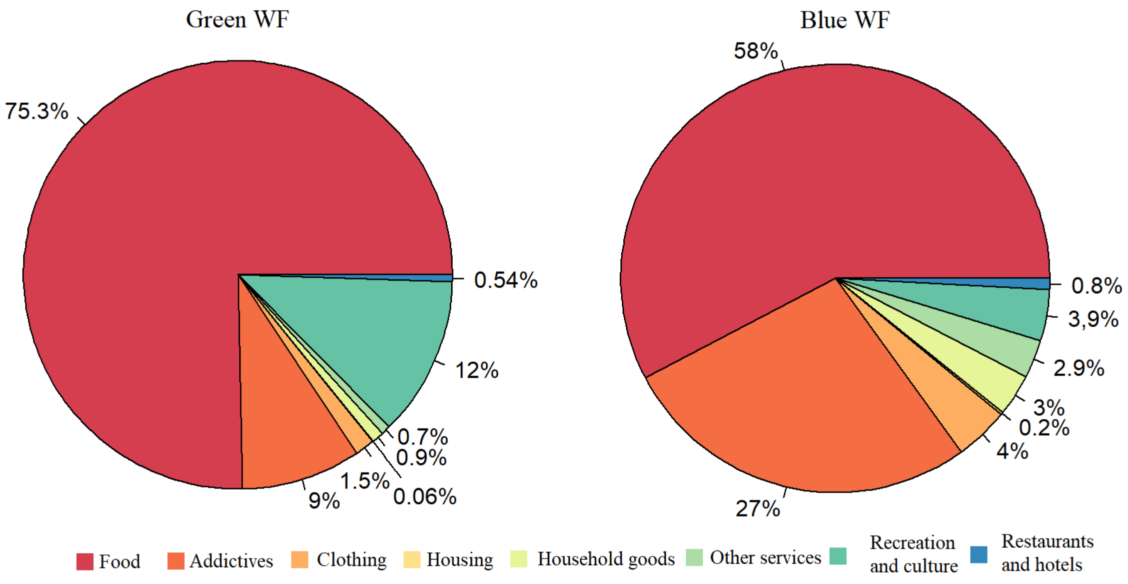

Figure 1: Average WF per household per year for eight merged consumption categories

The households on average spend 11 124 EUR (285 271 CZK) per year and in terms of household member the expenditures are 5 332 EUR (136 729 CZK) per year. The weighted household member has the mean expenses 5 093 EUR (130 606 CZK) per year with the standard deviation of 1 680 EUR (43 071 CZK). The average WI and expenditures for 12 COICOP categories are reported in Table 2. The high difference can be occurred in intensities through the consumption groups. The highest intensities are for both blue and green water for the food category 0.27 m3/EUR and 7,19 m3/EUR respectively. The smallest WI per one euro is also for both WFs in same category of education, 4.7×10^{-5} m^3/EUR and 3.6×10^{-4} m^3/EUR respectively. The average household member spends the most on housing followed by food category. On the other side of expenditures stand education and health groups. This, in comparison to other groups, low expenditures on education and health are most likely caused by Czech public expenditure system which covers many services as free education in public schools or medical checks. Expenditures of most categories are moving between 300 – 500 euros per year. The highest standard deviation can be occurred in transport category. Overall, the standard deviation of expenditures is relatively high which can demonstrate considerable expenditure differences between the poorest and the richest. Despite the fact the food category stands behind the 12 % of average yearly expenditures per household member in terms of total average WF is responsible for 74 %.

Table 2: Average expenses per household member per year with respective standard deviation in brackets. WI for twelve categories.

	Expenditure (EUR)	Blue WI (m^3/EUR)	Green WI (m^3/EUR)
Food	627 (746)	0.274	7.194
Addictives	304 (351)	0.090	0.602
Clothing	181 (485)	0.035	0.151
Housing	1342 (2161)	0.013	0.059
Household goods	406 (1449)	0.052	0.149
Health	131 (635)	0.002	0.008
Transport	413 (3596)	0.052	0.083
Communication	228 (387)	0.001	0.005
Recreation and culture	564 (1815)	0.046	1.286
Education	68 (813)	0.00005	0.0004
Restaurants and hotels	378 (1316)	0.005	0.036
Other services	450 (1055)	0.044	0.094
Total expenditure/mean intensity	5093 (1680)	0.048	0.806

Looking at WF in terms of responsibility we found uneven distribution through the households. The lowest decile is behind 3,98 % and 4,03 % of blue and green WF respectively with the 2,96 % of expenditures. On the contrary the top decile uses 25,09 % of expenditures to produce 17,63 % and 18,10 % of WF respectively. Over all households the expenditures are the most unevenly allocated (Figure 2). The Gini coefficient for expenditures is 0.333, blue and green WF acquire the same value of Gini coefficient 0.289. The blue WF ranges from the first to the tenth decile in values from 55 933 m^3 to 247 723 m^3 and green WF scales from 675 440 m^3 to 3 033 185 m^3 for the upper decile. The highest gap is for expenditures and both WFs same between the ninth and tenth deciles.

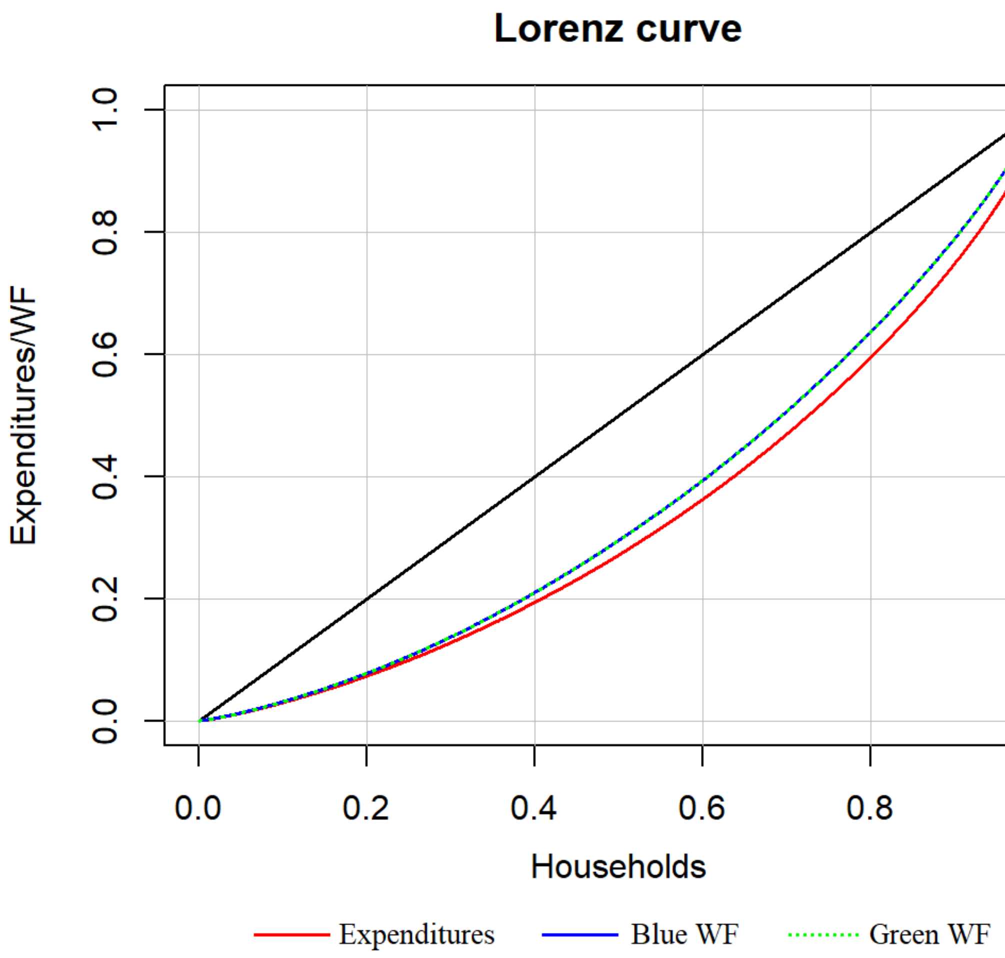

Figure 2: Lorenz curve of allocation of expenses, blue and green WF with Gini coefficients 0.333, 0.289 and 0.289 for cluster of 2899 households.

We also analysed relationship between the both WFs and the expenses per household member by the linear log-log model. Since we are using this model, we can present the estimated coefficients straightforwardly as the elasticity of WF with respect to the expenditures. The results are shown in Table 3: Linear model of expenses and footprints. The estimated elasticity β, R2 as coefficient of determination and CI as confidence interval in confidence level 95 %. divided for blue and green WF computed for 12 consumption categories and totals. The estimates shown in Table 3: Linear model of expenses and footprints. The estimated elasticity β, R2 as coefficient of determination and CI as confidence interval in confidence level 95 %. are statistically significant at the level of statistical significance α = 0.01. The coefficient of determination varies greatly through the categories from 0.07 up to 0.49. The estimates for blue WF varies between 0.46 to 2.60 and for green WF acquire values from 0.49 to 2.71. For blue WF the overall elasticity is 0.56 and for green WF 0.54. In terms of consumption categories eight of the twelve categories have elasticity higher than one, including the restaurants and hotels category with expenditure elasticity equal to 2.60 and 2.71 for blue and green WF respectively. With the elasticity higher than one the categories are elastic, thus the rise of expenses will increase the emissions relatively more. The estimates of the rest four categories are located below the one, with the lowest elasticities for food and addictives groups for both blue and green WF.

Table 3: Linear model of expenses and footprints. The estimated elasticity β, R^2 as coefficient of determination and CI as confidence interval in confidence level 95 %.

	Blue WF			Green WF		
	β	R^2	CI	β	R^2	CI
Food	0.48	0.29	± 0.027	0.51	0.31	± 0.028
Addictives	0.46	0.25	± 0.029	0.49	0.30	± 0.027
Clothing	1.68	0.17	± 0.135	1.68	0.17	± 0.135
Housing	0.99	0.49	± 0.037	0.93	0.49	± 0.035
Household goods	1.21	0.40	± 0.054	1.28	0.38	± 0.059
Health	1.45	0.38	± 0.067	1.42	0.38	± 0.065
Transport	1.40	0.38	± 0.066	1.45	0.31	± 0.078
Communication	1.23	0.24	± 0.079	1.19	0.25	± 0.075
Recreation and culture	0.67	0.46	± 0.027	0.54	0.33	± 0.028
Education	1.07	0.07	± 0.148	1.07	0.07	± 0.148
Restaurants and hotels	2.60	0.08	± 0.327	2.71	0.08	± 0.346
Other services	1.01	0.36	± 0.049	1.07	0.40	± 0.048
Total	0.56	0.40	± 0.025	0.54	0.35	± 0.027

4. Discussion

4.1. Limitations

Several limitations in our study were observed. The EE IO analyses are nowadays commonly used tool for research in a field of environmental footprints. Their advantage is high detail in financial flows between the industries and countries (Mohan *et al.*, 2021). But this analysis has also some limitations which we have to reckon with. Having low class resolution can lead to problems with homogeneity in model and in general to issues connected with highly aggregated data. Since we are using the hybrid method, we are aggregating the EXIOBASE data to classification structure of Czech SIOT and we lose detail of the world database. Another limitation can be found in activities which are unable to be captured in the analysis such as grey economy. Besides the data compilation are not in nations standardised and it is difficult to get the data for all the nations (Kitzes, 2013). As in our case of EXIOBASE data for 44 countries including the EU members and other major economies and the rest is connected into 5 world regions, we lose by these important details. For most of the specified countries the aggregation to regions do not have to cause high discrepancies but for aggregated countries e.g. states of Africa or South America the data are missing important details in trade structure.

Next limitation in our analysis can be the lack of data from domestic sources about water accounts and WI. This information was utilized from EXIOBASE database for Czech domestic trade. The aggregation of product groups and relatively smaller accuracy of data compared to national databases could cause the imprecisions in final results.

Another, regarding the connection of CES and IO tables data the homogeneity assumption can be violated. The aggregation of data tables with distinct category grouping can cause inconsistent reallocation to new groups (Mach, Weinzettel and Ščasný, 2018).

Given the collection procedure of the household expenditure data, the household surveys generally undervalue the real expenses (Weber and Matthews, 2008; Cazcarro *et al.*, 2022). To get the proportion of representation of household surveys data we analysed the relationship between the expenditures of weighted household member from CES data and expenses calculated per average member from final consumption expenditures from SIOT. We got the results that CES average data demonstrate 63.2 % of expenses in national SIOT.

Lastly, the household surveys data often undervalue certain consumption groups. It can be the categories of products connected with social negatively accepted behaviours, such as alcohol, tobacco products or narcotics. Other option for undervaluation is products which are borrowed or resaled or also used without any fee (e.g. public goods).

4.2. Discussion of the results

The research about WF usually focuses on consumption or production data from IO systems and rarely connect the household expenditure survey data to calculate the WF. Many papers study the WF globally and individually describe footprints for the biggest countries. The analysis which study the WF from the view of households are usually conducted for Asian countries such as China or Indonesia (Weber and Matthews, 2008; Chai *et al.*, 2020; Liu and Zhang, 2022). Thus, it is complicated to compare the results from other studies, but it can be compared in terms of volumes.

Firstly, in comparison with the study from Chai *et al.* (2020) investigation the data for China in 2018, the average blue WF was for Czech data higher. Specifically, 176 m^3 in China compared to 214.3 m^3. The study from China also noted the rise in WF between 2012 and 2018 by 12 %.

The research made by Steen-Olsen *et al.* (2012) worked with the database from 2004 and studied, among others, the WF for EU countries. The average EU blue WF was determined to 179 m^3. The blue WF for Czech Republic was about 70 m^3 which is less than 35 % of calculated blue WF from our calculations. This can be caused by possible rise in WF between 2004 and 2018 or different study approach since the study uses consumption responsibility approach and do not utilise the household consumption survey data.

Lastly, the results of household expenditures are compared with the results in Mach, Weinzettel and Ščasný (2018). The weighted average household member expenditures rose from 4310 EUR in 2010 to 5093 EUR in 2018. This grow could be explained by the inflation rates. The Gini coefficient for expenditures rose from 0.231 in 2010 to 0.333 in 2018. This change shows the increasing unequal distribution which could indicate the growing gaps between the poorest and richest households.

5. Conclusion

The thesis focuses on water footprint connected to expenditures of Czech households. Closer examination of spending behaviour of households and individuals is important aspect of reducing overall water consumption. Since the human population is still growing the pressures on environmental system will be rising. Together with the highly water demanding consumer society behaviour it is essential to familiarize the individuals with the natural costs of their decisions. Since more than 65 % of water footprint is connected to food and beverages consumption, this category could be a key aspect in reduction of individual WF (Mekonnen and Gerbens-Leenes, 2020).

The average Czech household member WF is calculated using the hybrid EE MRIO method introduced by Ewing *et al.* (2012). Resulting water intensity is then connected with the Czech household survey data. The resulting consumption is 214.3 m^3 of blue water and 2544 m^3 of green water per year per household member. From twelve presented consumption groups, the greatest share in WF has food category with 57,7 % and 75,3 % for blue and green WF respectively. Merging the three categories connected to food and beverages, share of this group on both WFs is around 85 %. The highest water intensities presented in m^3/EUR are for both WFs also for food category. The average household member uses the greatest share of expenditures on housing and food categories. Even as a second biggest expense group, food represents the 12 % of mean yearly expenses nevertheless in terms of WF is accountable for 74 %.

The expenditures and WF are distributed unevenly with Gini coefficients 0.333 and 0.289 respectively. The lowest decile of households is responsible for 3,98 % and 4,03 % of blue and green WF respectively, whereas upper decile of households is behind 17,63 % and 18,10 % of WF respectively. The elasticities estimated by linear regression are statistically significant ranging from 0.48 to 2.60 for blue WF and from 0.49 to 2.71 for green WF.

Literature using the IO models together with household expenditure surveys is limited and together with specification on WF even more narrow. Most of these studies are specified for countries of considerable size or fundamentally affected by lack of the water. For the Czech Republic data this method was already used but not for WF. In thesis we derive the total WF attributable to consumption of Czech households for twelve categories from COICOP classification. Thesis also determined the inequality of distribution of WF across the Czech households. The possible use of results can be found for informing the general public about individual environmental pressures or in the preparation of government measures.

Work can be possibly extended by maintaining more production groups through to whole process of modelling to get more precise and specific results. This extension would be good to make for group of food products to identify major products which stand behind a high proportion of the WF connected to diet. Finally, the linear regression analysis could be processed for more demographic characteristics connected to households and their members.

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