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CHALLENGES OF SUSTAINABLE FOOD TECHNOLOGY - A REVIEW

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ABSTRACT

Over the last decades due to rapid development of human civilization along with revolution in technology, some burning issues about generation of environmental contaminant, management of by-products from technologies, high consumption of natural resources and conservation of natural resources have been dramatically raised. Without any contradiction, impacts in overall ecosystem as well as human civilization have negative effects. These evoked lots of scientific and industrial researches, and implemented several stricter environmental legislations on the development of sustainable ecosystem. Thus, sustainability has become an emerging topic all over the world, as evidenced by the growing body of scientific publications in the last 20 years with one order of magnitude increase since the start of the new century. The study attempts to perform a review of the sustainable development from the food industry's perspective. At present, the agro-food sector produces high amount of carbon dioxide, food waste, packaging waste, wastewater, etc. and it is still consuming a lot of water, land, oxygen and energy. Furthermore, taken into consideration the increasing number of the world's population, there has been an enhancing interest experienced towards sustainable development among food manufacturers in the last decades. The article highlights the paramount areas of sustainable production, which offers new directions towards the increasing number of human beings for the future survival. The paper also gives an overview of the main perspectives contra constraints of sustainable food production, offers innovative food products from sustainable food waste and by-product, and focuses on the growing importance of sustainable food production in life cycle assessment methodology as well.

Keywords: Sustainable food technology, LCA method, Protein, Waste valorisation

1.INTRODUCTION

Social and economic importance of natural resources is unquestionable at all times from the aspect of humanity. Economical management of resources against wasteful and careless utilization – which is able to protect the decrease of biodiversity – became an essential topic on corporate, national, regional and global levels. In the early periods of economics natural resources were considered as permissible goods exposed unlimitedly to the society. Fig 1. summarizes the social and environmental aspects and economic costs of emergent foods for evaluating long-term sustainability [1].

The accelerated pace of population growth and the intensified production and growing consumption in the 20th century, increased the utilization of natural resources exponentially [2]. Concern about climate change and scarcity of resources has brought environmental and sustainability issues into focus both on political agenda and in the consciousness of the general public [3]. Sustainable development such as the decreasing of the emission of greenhouse effect gases, protection of forests, saving and caring of biological diversity and the management of energy resources should be in focus [4]. Sustainable development is a sort of development which ensures the satisfaction of present generation's demands without the threat of endangering future generations' chances to satisfy their demands [5].

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2. MATERIALS AND METHODS

Most relevant scientific publication have been collected and used in the study, proceeding towards scientific literature synthesis throughout the work as methodology. Furthermore examination of the set of hypothesis discussed in the following chapter for the different topics in the article was carried out.

Hypothesis
Nulhypothesis are being set in the different chapters of the article to determine whether the following statements are veridical or not concerning the context of the different areas in food production.

Hypothesis 1.

Waste minimalization and valorisation are significant methods in order to ensure sustainable food production on an economic, environmental as well as social level.
H_0= The statement is acceptable. Waste minimalization and valorisation are significantly applicable methods for sustainable food production.
H_1= These methods are not significant for sustainable food production according to some previous researches.

Hypothesis 2.

Alternative protein source**s** are needed for future sustainability, other than animal-based protein sources with negative impact on the environment.
Current research has been moving towards new directions of protein sources from animal-based through plant-based to insect-based due to a more sustainable environment.
H_0= The statement is true. The plant-based protein has a positive effect on environmental, as well as new researches can be found as an additional protein source of insects for human.
H_1= Animal-based protein source is sufficient for a long time for human nutrition.

Hypothesis 3.

There is an increasing need for laboratory measurements, to meet sustainab**i**lity, safety and health requirements in the field of food production, especially in protein analysis. Intensive growth in numbers of private laboratories providing external measurements can be experienced in the market.

H_0= There is a strong connection to be detected- between laboratory measurements and safety as well as health requirements in the food industry.
H_1= There is no connection between laboratory research activities and safety requirements.

2.1. The perspectives and constraints of sustainable food production

The long-term prospects for sustainable food production are being questioned increasingly by resource and policy analysts [6]. The world population is expanding rapidly and is likely to grow from 6 billion to 10 billion by 2050. It leads to exploitation of natural resources by greenhouse gas emissions, water consumption and deforestation, contributing to world's ecological insufficiency and climate change. There is an urgent need for a change of global food and agriculture systems in order to sustainably increase food production.

The food sector has been reported to utilize around 30% of the World's total energy consumption and 22% of total Greenhouse Gas emissions [7]. The water resources of our Earth are also reducing drastically, and

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require us to restructure our diet. The amount of the needed water to produce 1 kg of food is 13000 l in case of cattle; 5520 l in case of chicken; while only 50 l in case of peas or lentils [8]. So it leads to a significant increase in the price of food of animal origin, which implies to significantly reduce the proportion of these in our diet.

Food security, sustainable agriculture has limited availability of further water resources, arable land and crop yields.

Especially in the developing countries, poor soil fertility, soil erosion and low level of mineral nutrient in soil are major constraints contributing to food security, also the well-being of humans without harming the environment [9]. Climatic change can ultimately threaten the long-term adequacy of food production systems as well [10].

The conclusions are to maintain yield while protecting the environment, conserving natural resources and the need for agricultural expansion and productivity growth are so important [11] [1] .

Plant nutrition research provides sustainable ways as main priorities to meet human needs for food. Brklacich and co-workers [12] drew the attention that environmental degradation, competition for resources, increasing food demands, and the integration of agriculture into the international economy threaten the sustainability of many food production systems.

According to Hekstra and Liverman [10] the concept of sustainable food production technology systems remains unclear, and recent attempts to appraise sustainability have been hampered by conceptual inconsistencies and the absence of workable definitions. In their work six perspectives were introduced and considered individually to underpin the concept, namely:

1. environmental accounting
2. sustained yield
3. carrying capacity
4. production unit viability
5. product supply and security
6. equity.

These perspectives provide a basis for proposing a comprehensive definition of sustainable food production systems. Van der Goot [13] emphasized that the current way of producing food is not sustainable due to inefficiencies in food production, increased use of products of animal origin, inefficient use of food products once produced, and the current set-up of food process.

According to Jagustovica et al. [14] climate-smart-agriculture (CSA) is seen as a relevant solution for tackling sustainable increases in food production. CSA integrates the social, economic and environmental dimension of food production and aims to simultaneously achieve the triple goals of (a) ensuring food security through a sustainable increase in productivity and income, (b) adapting to climate change and (c) reducing greenhouse gas emissions. New technologies, as better alternatives than conventional methods, improve quality attributes as well as shelf life, contribute to resource savings and also to decreasing energy consumptions [15] [16]**.** According to Töpfl and co-workers [17] more than half of the population in developed countries do not prefer highly processed foods and lean towards organic production and food produced locally rather than obtain products from global food flows.

Fig.1. summarizes the social and environmental aspects and economic costs of emergent foods for evaluating long-term sustainability.

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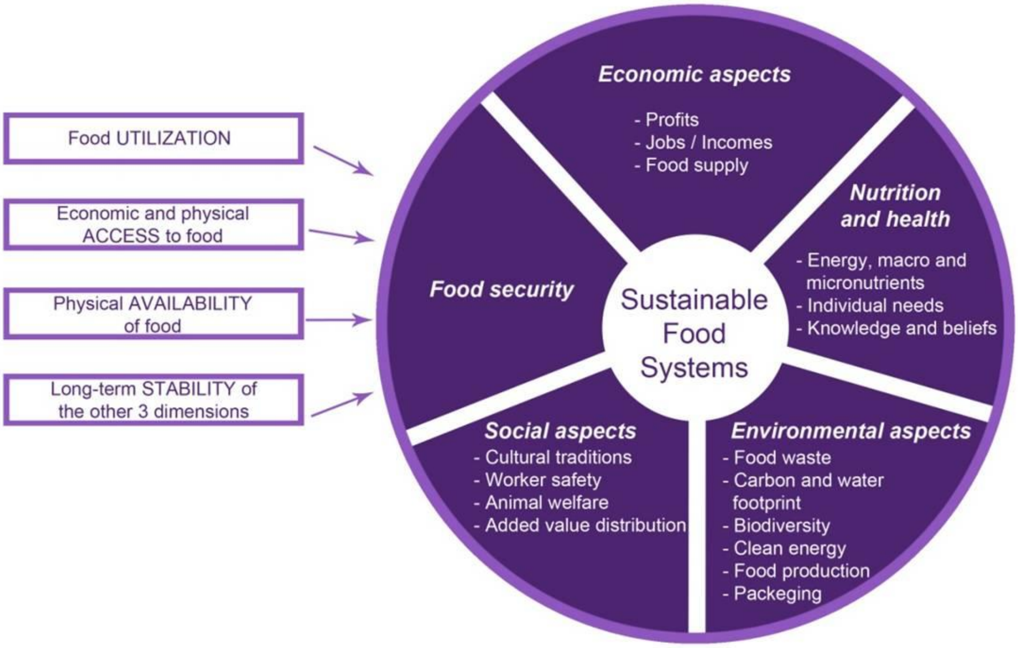

Figure 1. Sustainable food systems dimensions [1]

2.2 Food sustainability by waste and by-product

Food processing industry in the EU annually generated around 100 Mt of food waste and residues, and more than its 38% happens due to processing. Significant amounts of compounds with potential for valorisation for high added-value products are lost [18]. As food waste does not cause severe environmental threat, this subject has not received much attention yet [19].
Since the food production challenges for growing population are common issues, global food waste at retailers, consumers, production, and supply chains level should be reduced by 2030 [20]. Food wastes are today considered as a cheap source of valuable components since the existent technologies (conventional, emerging) and the commercialized applications allow the recovery of target compounds and their recycling inside food chain as functional additives in different products with low production costs [21]. By-products' sources can have high fibre, protein content, other beneficial bioactive components, so they can be good food additive eg. to improve protein content, biological value/nutritional quality and some techno-functional properties as water binding capacity and balance texture in processed food, or to modify the structure of proteins with decreasing the allergenic proteins and to manage medical problems as well.
A lot of biomass continues to be disposed that are harmful to the environment even though it still contains valuable ingredients. Extracting and refining these ingredients requires processes that are sufficiently gentle, energy efficient and cost-effective across a value chain to benefit from them. The process and end products must meet strict industry-specific regulations. Major contributors to biomass waste are rapeseed, olive oil production, the processing of citrus fruits and vegetables, such as tomatoes, considered to be low-value, although containing valuable compounds, as extraction was either too difficult, too costly.
Stone and co-workers [22] introduced the unavoidable food waste reduction/management through food and drink manufacturers by the means of reclaiming as much value as possible, by conversion to valuable products, so called "valorisation" performed in a sustainable manner. Potential valorisation options as well

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as selecting appropriate indicators for environmental, social and economic performance are indentified, using Cost-Benefit Analysis (CBA), Life Cycle Assessment (LCA), and Variation on Multi-Criteria Decision Analysis (MCDA), respectively. The given results highlighted that overall valorisation strategy is optimal for offering superior economic return, environmental performance as well as technological readiness level.
Ekman et al. [3] examined the contingency of the transition to a bio-economy by the efficient utilisation of biomass resources – e.g from wastes and by-products - with good environmental performance in bio-refineries in order to generate extra value (energy, chemicals) [23].
Summarizing the highlighted articles and research works in this section, it can be clearly stated that Hypothesis 1. is an acceptable as food waste reduction and by-product valorisation are significant methods in sustainable food production.

2.3. Towards emergent food proteins

Finding solutions for sustainable food production is an increasingly pressing task nowadays. One possible direction is to exploit the potential of non-conventional raw materials. The increasing demand for animal protein cause serious concerns. Resources were needed to convert vegetable matter into animal-derived proteins, such as meat or milk proteins. The adaptation of a more sustainable production of conventionally used proteins and by that, starting to rebalance the contributions between animal and plant proteins, thus contributing to the sustainability of food systems and to a more efficient distribution of high–quality proteins for the entire world population has a key role. Europe has a protein deficit that should be increased by production of plant- rather than animal-based proteins as the latter leave a large carbon foot-print [17]. There has been an increasing demand for sustainable and alternative protein sources, such as vegetables (beans, peas, broad beans, lentils, etc). According to Henchion et al. [24] there has been an increased demand for animal-based protein in particular which was expected to have negative environmental impact, generating greenhouse gas emissions, requiring more water and more land. Different vegetable protein sources make a positive contribution to the environment and climate change. If the nitrogen-binding properties of legumes are used differently, they require 30-70% less synthetic fertilizer, furthermore increase soil strength and have a beneficial effect on soil. It is also known that due to nutrient transformation losses, for the production of 1 kg of animal protein min. 6-16 times more hectares of arable land are needed. In addition, the carbon footprint of the production of foods of animal origin, especially beef-based food, is about 10- times that of plant-based foods. Henchion et al.'s research [25] emphasizes the role of livestock as part of the solution to greenhouse gas emissions, and indicates that animal-based protein has an important role as part of a sustainable diet and as a contributor to food security.
Plant-based foods have lower greenhouse gas emissions and tend to be less resource-intensive and environmentally destructive than animal husbandry. In addition, vegetable proteins reduce the risk of spreading diseases [26]. Besides plant-based protein source, there is greater focus on identifying less expensive and less resource-intensive alternatives, including non-GMO options, which yield proteins without the use of extensive heat, solvents and harmful chemicals.
It is worth to mention that other alternative protein sources nowdays in attention as sustainable protein sources: single-cell proteins from microorganisms (microalgae, yeasts, filamentous fungi, bacteria), seaweeds in saltwater, duckweed species on the freshwater surface and various insect species from different stages of their development. The protein content of each source can vary significantly, depending on the species and cultivation technology and nutrient supply. Novel proteins require the development of new value chains, and attention to issues such as production costs, food safety, scalability and consumer acceptance [24].
The European food consumption structure characterized by 59% of the daily protein intake is originated from animal protein sources (meat, fish, milk) and only 41% is from plant-based proteins. More than 50% of the latter is wheat protein, while the intake of legumes (including soy protein) is only 3%. As a result,

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some cereals (wheat, corn, rice) may have become staple foods, leading to geographical homogeneity of foods, dietary homogeneity, and nutritional imbalances, increasing micronutrient deficiencies, overweight, and pathological obesity, as well as the risk of NCDs (Non-Communicable Diseases)**,** including cardiovascular disease, stroke, cancer, and diabetes [27].

Based on all this, it is becoming increasingly important to map and study plant and other alternative protein sources that can contribute to meeting the protein needs of an increasing number of humanity and to addressing their unbalanced nutritional status.

More recently, insects have been identified as an alternative source of protein for the Western world [28] supported by the European Commission. Insects as food and feed are receiving much attention lately. The academic interest of using insects as food or feed is exponentially increasing. This is exemplified by the increasing numbers of scientific publications and private enterprises engaged in producing insect products [28]. Significantly, they argue that insects do not compete for land, require less water and emit lower levels of greenhouse gases and NH_3 than regular livestock. They can be reared on organic side-streams thus creating value from and reducing waste products [29]. Many insects also have a favourable nutritional profile for humans, with most being highly digestible (77–98%), high in protein (crude protein 40–75% on a dry weight basis) [30] and a good source of essential amino acids, high in vitamins B_1, B_2 and B_3 and the minerals iron and zinc [31].

On the basis of processed articles we can confirm that Hypothesis 2 H_0 is accepted. Insects can be an alternative source for humans in the future, with less environmental impact.

2.4. Evaluation sustainability for food processing technologies (LCA method)

There are several tools and methods for evaluating sustainability for food processing technologies in order to source food ingredients produced by best practice, reducing food loss in the processing line. Meynard and co-workers [32] offered that the improvement of technology in the food process is a possible option to reduce sustainability footprint. Woodhouse and co-workers [33] introduced a tool of a qualitative sustainability checklist, based on Life Cycle Assessment (LCA) theory. LCA is a standardized methodology, the most recognised environmental assessment method, which allows quantifying the environmental impacts of a product, a process or a service along its whole life cycle. The approach is widely used for food production systems [34]. Woodhouse and co-workers' article was a pioneer research study from the aspect of using qualitative sustainability checklist for food processing development. Their publication was structured to cover the three pillars of sustainability: environmental, social and economic, all in a life cycle approach. Silva and Sanjuán [35] also highlighted the importance of applying LCA in food processing. The authors attempted to examine - through case studies - the technological developments from some methodological aspects in food processing. According to them, the improvement made in food processing in the last decades, are under two axes: plurality (conventional technologies co-existing with new alternatives) and sustainability (jointly with efficiency, quality and safety). LCA was recognised to be a powerful method permitting the assessment of the environmental load of food products throughout their entire life cycle, confirmed by a high number of scientific studies published. Silva and Sanjuán [35] classified the examined LCA studies, in their systematic literature review of LCA in alternative food processing technologies publication, into two main types of LCA, namely attributional and consequential. While most of the LCA studies apply an attributional perspective (A-LCA), with reference to a steady state of the internal flows of a specific production system, the consequential LCA (C-LCA) aims to evaluate the environmental consequences of a decision, quantifying the indirect effects of the decision. According to Huit [25] a life cycle assessment is a widely accepted method to quantify greenhouse gas (GHG) emissions, and other environmental parameters, such as land or fossil energy use. Parameters are then quantified along the entire life cycle of a product. This is called an attributional life cycle analysis. Insects-based protein source determination, referring to section 2.3 is also using a life cycle analysis approach,

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research revealed that mealworm had lower greenhouse gas emissions, and used less land and water than common production animals [36] [37].

Another approach by Stone and co-workers [22] seeks to extend LCA principles of measuring the environmental life cycle impact of a product to include impacts on people and prosperity, which brings LCA in line with the Brundtland Report [1987]. The authors pointed out that there are several publications in which LCA tenets had been applied to selection of food waste valorisation strategies, such as explore the suitability of vegetable waste produced by food industry for use as animal feed.

2.5. Transition towards sustainability through information and communication technologies

Food sustainability transition refers to transformation processes to move towards sustainable food system [38]. One of the most important ongoing transformation processes is digitalization. The authors explored the contribution of information and communication technologies (ICTs) to transition towards sustainability in food production by providing new ways of measuring impacts, communicating necessary changes and connecting food chain actors. The role of ICTs in increasing system efficiency is a central theme and has been used to improve resource efficiency and productivity in food systems.

2.6. Methodology in the laboratory field

2.6.1. The essential role of laboratory field in the support of food industry

Food laboratories have high responsibilities for ingredients compliance in analytical method process for sustainable food products as well as the evaluation of the environmental impact might caused by the raw material used in the production. Secchi et al. [39] review in their survey that R&D acitivities in the field of food and pharmaceutical ingredients have been focusing on sustainable environmental development of the final products. The study reveals that food and pharmaceutical ingredients producers' activities have significantly more environmental impacts than basic chemical production in a kilogram-per-kilogram basis.

2.6.2. Analytical laboratory instruments and measurements in food industry

ÉMI-TÜV SÜD has decades of analytical experience in the food industry. The services are in full compliance with the requirements of the Hungarian National Food Standards – Codex Alimentarius Hungaricus and the applicable legal regulations. The services are based on laboratory tests, which are performed in a laboratory equipped with modern methods and instrumentation. The laboratory also acts as the TÜV SÜD Group's competence center in Central and Eastern Europe. The experienced experts perform the tests in a laboratory accredited according to the MSZ EN ISO / IEC 17025: 2005 standard.
Multinational food companies have their own research laboratories, while smaller companies from the small and medium-sized enterprises sector (SME) either having smaller laboratories, not so well equipped, with some basic, general laboratory devices, or outsourcing their analytical measurements to contract laboratories. Several private as well as governmental research laboraties (in Hungary: Balint Analitika, Wessling Hungary, part of the Wessling-Group, SGS Hungaria Kft. National Food Chain Safety Office (NÉBIH) has an extensive laboratory network) are responsible for carrying out external contractual measurements or executing research activities having less negative environmental impact, more safety for humans, less damage to the environment, revealed by the authors through deep interviews carried out by laboratory managers.
Laboratory measurements can be classified according to the type of examination:

- chemical measurements;
- physical tests
- microbiology measurements;

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- stability measurements;
- allergen measurements;
- organoleptic tests.

In order to determine protein analysis methods (quantitative, qualitative, structure and molecular weight) different types of laboratory instruments are needed. In Tab 1 all analytical instruments and the different methods are gathered to demonstrate the analyses of direct and indirect protein determination and extraction. Amino acid analysis is one of the analytical principles for protein determination [41]. The second most frequently used methods for food protein determination are based on analysis of the total nitrogen content in the samples, such methods are the Dumas method and the Kjeldahl method. The third common analytical technique for protein analysis is spectrophotometry [42].

Table 1. Analysis Methods in protein determination

Protein Analysis Methods			
Quantitative	**Qualitative**	**Structure**	**Molecular weight**
Lowry	One/two dimensional electrophoresis	X-ray crystallography	Dynamic Light Scattering
Bradford	Native gel electrophoresis	Protein NMR	Ozmometer
Kjeldahl	Immunoelectrophoresis	Cryo-electron microscope	
Spechrophoto-metrical	Isoelectric focusing	Small X-ray scattering	
ELISA	Western blot		
Biuret	Protein immunoprecipitation		
	HPLC		
	LC/MS		

Tab. 1 shows the importance as well as the wide range of equipments in research laboratories for an efficient analytical methodology of protein determination in the food industry.
Hypothesis 4. clearly determines the acceptance of the null hypothesis in Chapter 2.3., due to growing population, the number of laboratories as well as the demand for protein sources in food industry are intensively increasing. The trend seems to be consequent.

2.6.2 Comparative ratio figures for the food industry

Determining the distribution ratio for the recent food industry market size for natural, organic versus conventional food products as well as the alternative protein source examination, and further the number of analytical laboratory equipments for food products measurements as well as R&D activities the following comparative figures are proposed:

$$C(o) = \frac{\text{Organic food products}}{\text{Total food products}} \cdot 100\ (\%)$$

$$C(\square) = \frac{\text{Hypoallergen products}}{\text{Total food products}} \cdot 100\ (\%)$$

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C (o) and C(h) ratios define the market presence in percentage of organic and hypoallergen food products.

$$C(p,p) = \frac{\text{Plant} - \text{based protein source}}{\text{Total protein source}} \cdot 100\ (\%)$$

$$C(p,i) = \frac{\text{Insects} - \text{based protein source}}{\text{Total protein source}} \cdot 100\ (\%)$$

C (p,p) and C(p,i) ratios examine the alternative protein source possibilities for the fast growing world population.

$$C(lab) = \frac{\text{Laboratory equipments for food measurements}}{\text{Total laboratory eqipments}} \cdot 100\ (\%)$$

$$C(research) = \frac{\text{R\&Đ in food industry field}}{\text{Total R\&Đ}} \cdot 100\ (\%)$$

C(lab) and C(research) ratios determine the growing importance of research activities in food industry by the increasing number of laboratories, supporting the production of organic as well as food waste and by-product in food production.

3. FUTURE OUTLOOK: AWARENESS AND SOLUTIONS

Food systems need a radical transformation to become sustainable. Reviewing a great body of scientific publications on food production sustainability contrasting different technologies, it can be determined that the technological approach plays an important role in the challenge of seeking the environmental sustainability of food processing [35]. There is an urgent need for a change of global food and agriculture systems in order to sustainably increase food production, in view of today's 795 million hungry and the additional 2 billion people expected by 2050 [43]. According to Jagustovica et al. [14] climate-smart-agriculture (CSA) is seen as a relevant solution for tackling sustainable increases in food production. CSA integrates the social, economic and environmental dimension of food production and aims to simultaneously achieve the triple goals of

a) ensuring food security through a sustainable increase in productivity and income
b) adapting to climate change
c) reducing greenhouse gas emissions.

New technologies, as better alternatives than conventional methods, improve quality attributes as well as shelf life, contribute to resource savings and also to decreasing energy consumptions [14] [16]. New technologies do not always imply an environmental improvement and reducing the environmental impact does not necessarily imply changing the technological base (which implicitly entails the need for large capital investments [35]. El Bilali and Sadegh Allahyari [38] denoted that ICTs can contribute to food sustainability transition by providing new ways of measuring impacts, communicating necessary changes and connecting food chain actors. Actions in policy, science and innovation are necessary to encourage the development of affordable, locally appropriate, and sustainable ICT infrastructure and applications.
Following examination and careful consideration of the set hypothesis the results give a clear indication on the food industry trends concerning several aspects. The results of the set hypothesis show a reflection towards problematic field of food market to be solved, such as carrying out complex survey on alternative protein sources by the ever growing number of population, concerning sustainable environment as well as human safety. The introduced comparative ratio figures for the food industry in Section 2.8.3 could be appropriate for deeper investigation on the constitutions of food industry. Data collection is needed for further examination.

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3. CONCLUSION

Especially in the last century the intensive and uncontrolled food production caused serious damages in the environment, but the processed publications in current work present many new endeavours concerning food production towards sustainability taking into account the perspective of the three main indicators of sustainability, such as economic, social and environmental. However, there are still much more improvements as well as researches to be left for a more sustainable way of food production. Therefore sustainable food industry deserves to get prime attention. The change has begun on both the producers and consumers side although financial support and tender opportunities can be help of food manufacturers to follow sustainability during production. There are also several new directions to be found in processing waste food and by-product which leads to less environmental loading, as well as taking into consideration the fast growing population, new approaches are found for alternative protein sources with less footprint, such as insects-based sources. However this new sector is still in starting phrase, with new emerging investment thrive by innovations [44]. As well, analytical laboratories play key role in regard of new research technology for analytical methods in the food production procedure. The authors introduced the range of laboratory instruments for protein analysis, which is one of the main research directions in the food industry today. Yet, numerous studies show that each new research of organic components in food industry towards sustainable production has to be evaluated from all aspects of any environmental, social and economic impacts. Therefore, more complex laboratory researches must be carried out in the future in order to assist sustainable food innovation on a higher level align with more sophisticated laboratory equipments as well as developing new analytical methods on a wider scale in the food research.

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