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Scenario Analysis of Changes in the Food Supply Chain

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The aim of this study is to identify possible alternative scenarios in food production and consumption that would lead to a more balanced supply of locally produced food and a reduction in the environmental impact of agricultural production. The analysis of food consumption and agricultural land distribution in Slovenia showed that a significantly larger proportion of land area is used for food production for animals than for humans. Several potential changes in the distribution of agricultural land, in milk consumption and production, in the use of fertilizers and in people's eating habits towards lower consumption of red meat were identified. Analysis of the scenarios showed the potential to increase food self-sufficiency by 15 %, reduce greenhouse gas emissions by 35 %, and reduce nitrogen intake by 30 % by 2050. Reducing red meat consumption could shift intensive feed-based livestock production to grass-based production and produce more plant-based food for humans. This could increase the amount of local food and make food production less harmful to the environment. Preliminary research has shown that there are several influencing factors in the food supply chain that have conflicting effects on key food supply parameters and environmental indicators. It is therefore necessary to move towards a systematic multi-criteria optimization of the food supply chain in order to achieve the objectives of the European and national strategies on agriculture and climate change.

1. Introduction

The food chain is an extremely complex system that is exposed to many negative factors, such as increasing demand for food due to population growth, increasing consumption of meat, dairy and eggs in developed countries, increasing specific diseases due to excessive consumption of red meat and processed meat products (Godfray et al., 2018), large amounts of greenhouse gas (GHG) emissions from food production, the use of food crops for biofuels (Cassidy et al., 2013), exposure to uncertainties in weather, demand and prices (Ray, 2021). Projections regarding food security are not optimistic for the future, as the gap between food supply and demand is expected to widen (Tian et al., 2021). A large proportion of agricultural land is used for the production of animal feed. At the same time, in meat production, the ratio of calories from meat products to calories consumed is only 10 % (Godfray et al., 2010). The increase in food production was achieved in the past through intensive use of fertilizers and plant protection products, but the EU's Farm-to-Fork Strategy requires that the use of fertilizers must be reduced at least by 20 % and pesticides at least by 50 % by 2030 (European Commission, 2020). Optimization of agricultural land is necessary to improve food production and distribution (Põldaru et al., 2018). However, further measures need to be planned to ensure food security and reduce emissions, even as the population grows. These are changes in food structure (Willett et al., 2019), organic and conservation agriculture (Król-Badziak et al., 2021), aquaponics (Li et al., 2018), the movement of livestock from intensive farming to grazing (Hayek and Garrett, 2018) etc. Food waste should be managed appropriately (Woon, 2021). Slovenia is one of the smallest EU countries. Its food market is small and very sensitive to food imports from neighboring countries. The terrain is hilly with a small share of flat land, there are many protected areas. Food production is rather unbalanced, there is a lot of cattle breeding in the lowlands, production of vegetables and pork is low. Changing eating habits, especially in Generation Z, are moving towards much lower meat consumption and higher vegetable consumption (Bumbac et al., 2020). These factors require a redistribution of cultivated land and a different composition and quantity of food produced. The aim of this research was to apply systematic methods in the agricultural supply chain to achieve a more balanced supply of healthy, locally produced food. Data were collected for the Republic of Slovenia (Zagorc et al., 2020), then aggregated

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accordingly and included in a model to calculate various indicators. Several scenarios of changes in agricultural policies and dietary habits were evaluated in terms of food self-sufficiency, greenhouse gas emissions, nitrogen inputs, use of arable land, etc.

2. Methods

Data were collected on the area used for food and feed production, yields per hectare, composition and consumption of different feeds for a given livestock, conversion factors expressed as mass of feed per unit mass of animal food, food consumption per capita, etc. Different types of food/feed were included in the analysis, divided into human food and animal feed, such as cereals, potatoes, grass, green fodder, fruits, vegetables, meat and meat products of pigs, cows and poultry, milk, eggs, honey. Some scenarios have been developed to study the impact of changes in land policies and dietary habits on the key parameters to be monitored.

2.1 Key evaluation parameters

The changes caused by the measures introduced in each scenario were quantified using seven key parameters.

a) ***Total level of food self-sufficiency***. It is the ratio of all food produced to all food consumed and includes plant foods for human and animal consumption, and foods of animal origin.
b) ***Level of self-sufficiency for human food***. It is the ratio between all domestically produced and consumed food of plant and animal origin for human consumption.
c) ***Greenhouse gas (GHG) emissions***. It represents the amount of greenhouse gasses, expressed in terms of mass of CO2-equivalents, produced in the production of all food of plant and animal origin.
d) ***Nitrogen inputs from animal manures***. It is the input of nitrogen to the soil through livestock manures.
e) ***Mineral fertilizers used***. It represents the annual consumption of mineral fertilizers to produce plant human food and plant animal feed.
f) ***Area of agricultural land to produce human food and animal feed***. These indicators measure the extent of agricultural land used to produce human food and animal feed.
g) ***Annual food consumption per capita***. It represents the total mass of food from plant and animal origin consumed by a person in a year.

2.2 Scenarios

Scenario 1. The first scenario considers population growth in Slovenia until 2030 and 2050, projected using the tool Forecast Sheet in Excel. This is an Excel feature that can forecast future values based on historical data. At the same time, a change in the dietary habits of the population is foreseen in accordance with the guidelines for a healthy diet, as the average per capita consumption of meat and meat products in Slovenia is significantly higher than the EU average (88 kg per capita per year in Slovenia compared to 68 kg per capita in EU). Therefore, by 2030, annual consumption of red meat and meat products would be reduced by 10 kg per capita for pork and 5 kg per capita for beef, bringing us closer to the EU average and reducing overall meat consumption per capita by 17 %. By 2050, the consumption of red meat and other meats should be further reduced to approach healthy diet guidelines. The total consumption would achieve about 50 kg per capita, from which 17.8 kg of pork, 8.6 kg of beef, 22.3 kg of poultry, and 1 kg of lamb.

It was assumed that beef production would decline by 20 % until 2030 and by 50 % by 2050 from current levels. Since the self-sufficiency level of pork meat in the country is very low, it was assumed that the production of pork and pork products would increase by 20 % by 2030 and then remain unchanged by 2050. The freed-up agricultural land where plant foods were grown for animal feed would be used to produce plant foods for human consumption, with priority given to crops with high consumption and low self-sufficiency, such as wheat, potatoes, vegetables.

Scenario 2. In the second scenario all the changes from the first scenario were included and further examined the individual effects of the following changes: a) lower consumption of dairy and dairy products, b) lower consumption of fertilizers for plant food production, and c) production of some of the vegetables in greenhouses. Considering that feed-based dairy production is a major driver of GHG emissions, and that the OECD projects a decrease in the consumption of fresh dairy products in the EU (OECD/FAO, 2019), dairy consumption was assumed to decrease by 15 % by 2030 and by 25 % by 2050 compared to the current situation. As the self-sufficiency level for dairy in Slovenia is over 100 %, it was assumed that production would decrease by 10 % and 25 % by 2030 and 2050, respectively. The reduced need for feeding cow herds would free up some pastures and meadows that could be used for grass-based production of beef.

According to European Green Deal and Farm-to-Fork Strategy, it was assumed that fertilizer use would decrease by 10 % by 2030 and by 25 % by 2050 compared to the current situation. Considering conventional farming technologies, the reductions in yields per hectare of -5 % by 2030 and -12.5 % by 2050 were assumed, as well as reductions of GHG emissions of -5 % and -12.5 %. For vegetable production, a redistribution to

greenhouses of 15 % by 2030 and 35 % by 2050 compared to the current situation was assumed. The yield per hectare in greenhouses was very conservatively assumed to be about twice as high as in traditional production.

Scenario 3. The third scenario combines all the changes considered in scenario 1 and all the variants of scenario 2, thus representing a "super-scenario" of agricultural and dietary changes considered in this work.

3. Results and discussion

Total level of food self-sufficiency. The current overall food self-sufficiency level is about 84.6 %. Despite population growth, it could be increased to 86.6 % by 2050 (Figure 1) through appropriate food policies in Scenario 1. The most favorable scenario for this indicator is 2c, in which, in addition to reduced meat consumption and increased plant food production for human consumption from Scenario 1, part of vegetable production is shifted to greenhouses. In this scenario, the overall self-sufficiency level could reach 87.9 %. In scenarios 2b and 3, the use of fertilizers decreases, resulting in lower yields per hectare. This leads to a decrease in the amount of food produced and consequently to a decrease in the value of the overall self-sufficiency level in the future.

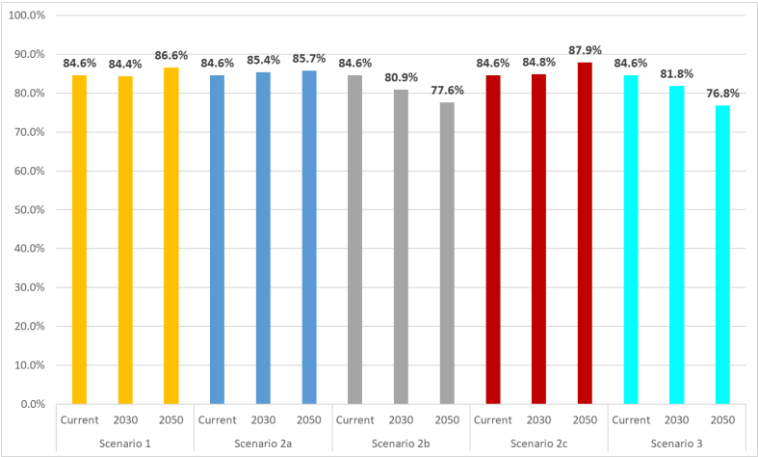

Figure 1: Total level of food self-sufficiency

Level of self-sufficiency for human food. The current level of self-sufficiency for human food is 76.2 % and could increase up to 87.2 % by 2050 under Scenario 1 (Figure 2). Again, the most favourable scenario is 2c, where in addition to changes of Scenario 1, part of the vegetable production is allocated to greenhouses. In this case, up to 91 % of people's food demand could be met by local production. Scenario 2a, in which the production and consumption of cow's milk are reduced, and the freed-up meadow and pastureland is used for the more environmentally friendly grass-based production of beef and its products, also proves to be very favourable.

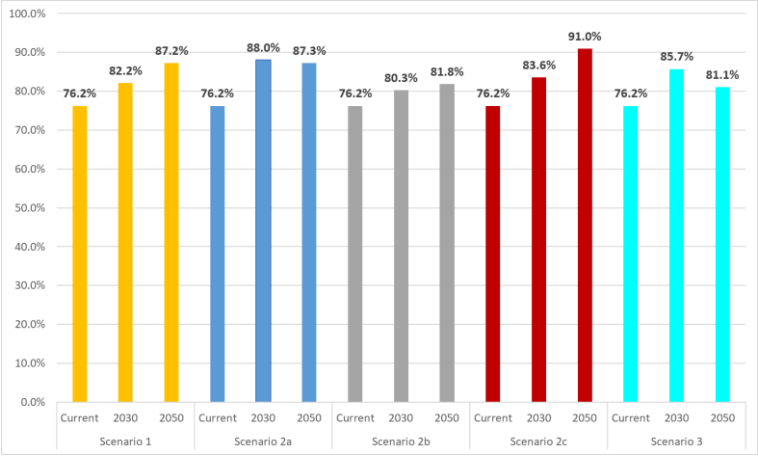

Figure 2: Level of self-sufficiency for human food

Greenhouse gas emissions. Food production in Slovenia causes 1,466 kt CO2-equivalent emissions per year, of which the largest shares come from the production of beef and beef products (31 %) and from milk production

(35 %). The level of GHG emissions is reduced under all envisaged scenarios (Figure 3). The highest reduction is achieved in Scenario 3 as a synergistic result of reduced meat and dairy production, increased share of agricultural land devoted to human food, and reduced use of fertilizers. However, the quantities of food produced decrease and so does the level of self-sufficiency for this scenario (Figures 1 and 2). The second most favorable scenario is 2a, which includes lower milk production and consumption and increased grass-based production of beef and beef products.

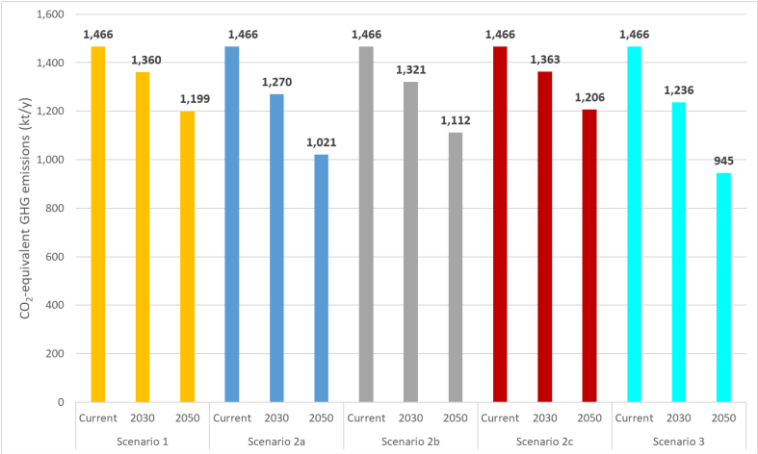

Figure 3: GHG emissions expressed in CO_2-equivalent

Nitrogen inputs from animal manures. Changes in nitrogen inputs to soil from livestock manure under different scenarios are shown in Figure 4. In all scenarios, a large reduction in nitrogen inputs to the environment was achieved, mainly through a decrease of cattle breeding. In scenarios 2a and 3, where milk production is also reduced, the mass of nitrogen input to the environment is reduced the most (for 30 %).

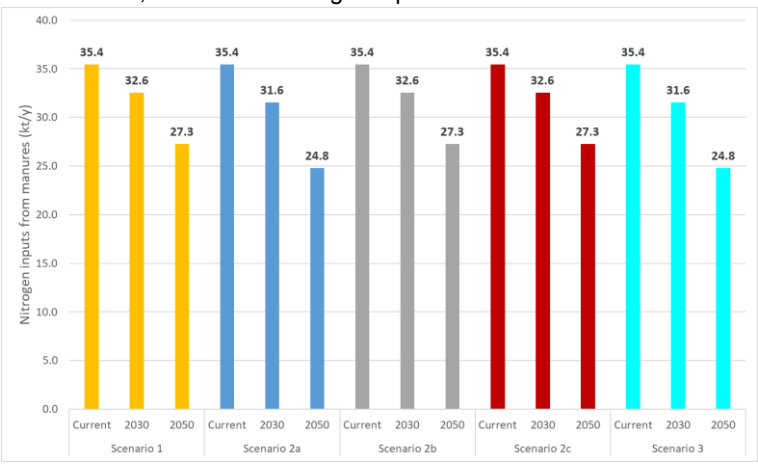

Figure 4: Mass of nitrogen inputs from manures

Mineral fertilizers used. The amount of fertilizers used per hectare was reduced in scenarios 2b and 3 (Figure 5). However, this results in a lower level of food self-sufficiency than in the other scenarios, as shown in Figures 1 and 2. In scenarios 1, 2a and 2c, the amount of fertilizer increases slightly due to the redistribution of agricultural land.

Area of agricultural land to produce human food and animal feed. The distribution of agricultural land used for production of human food and animal feed is shown in Figure 6. The lower part of the columns represents the land used for animal feed production, and the upper part the land used for human food production. Figure 6 shows that the production of animal feed takes up a considerably larger share of arable land than the production of plant food for humans. In all five scenarios, the area for human food production increases by about the same percentage, with scenarios 2a and 3 standing out slightly.

Annual food consumption per capita. Each inhabitant of Slovenia consumes on average 775 kg of food per year, of which 42 % is food of animal origin and 58 % is plant food. The changes in the amount of food consumed

per capita are shown in Figure 7. The lower part of the columns represents the amount of food of plant origin consumed per capita, which did not change in this study. The upper part represents the amount of food of animal origin, which is decreasing in all scenarios. This is favourable as currently more than half of the Slovenian population is overweight and such changes in diet could be beneficial for human health and the environment.

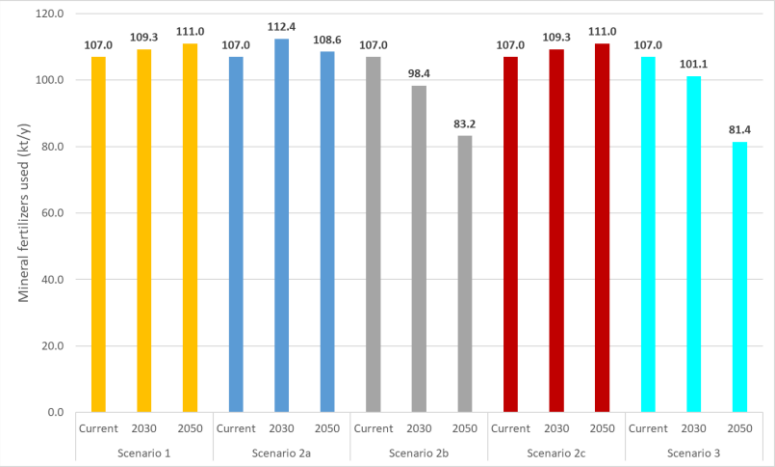

Figure 5: Amount of mineral fertilizers used

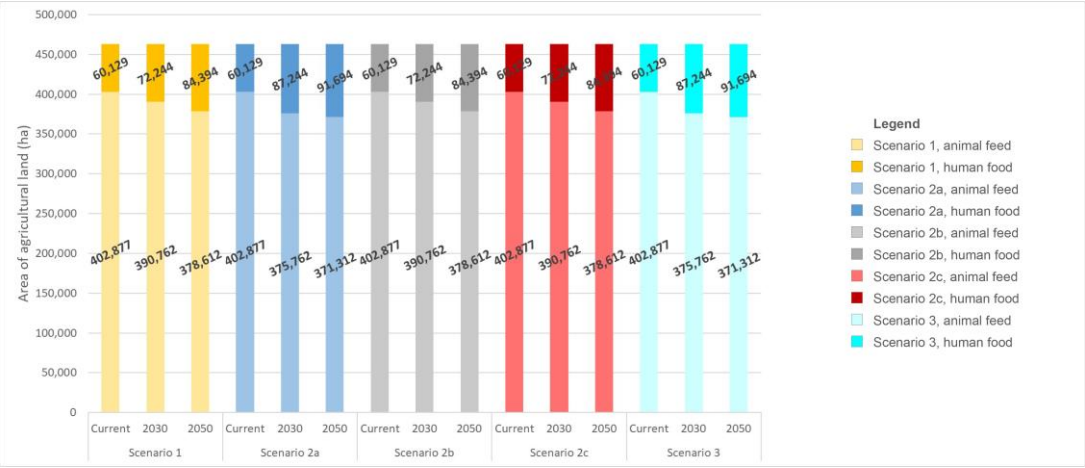

Figure 6: Area of agricultural land to produce human food and animal feed

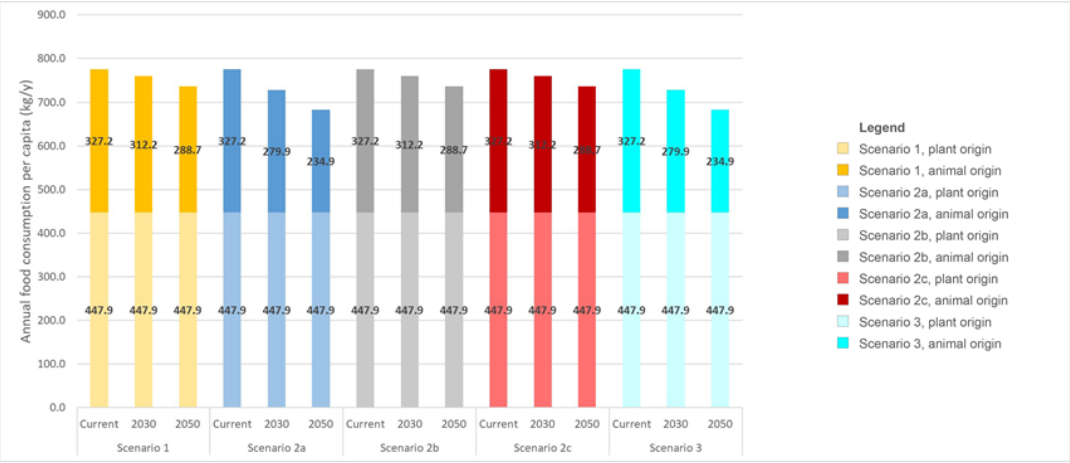

Figure 7: Annual food consumption per capita

4. Conclusions

This study illustrates the effects of changes in food production and eating habits of humans on food consumption, self-sufficiency level, GHG emissions, nitrogen input, fertilizer use, and arable land distribution. The results showed that the proposed scenarios have the potential to improve self-sufficiency for human food by up to 15 %, reduce GHG emissions by 35 % and nitrogen input by 30 %. However, the effects of the changes are often opposite, i.e., scenarios in which the amount of GHG emissions is greatly reduced are the least favorable in terms of reducing food self-sufficiency. Slovenian agriculture could become more sustainable through strategic agricultural policy decisions by shifting part of food production from livestock to vegetable and plant-based food production.

This represents a motivation for the development of a multi-criteria optimization model in further research to achieve the objectives of the European Green Deal, the Farm-to-Fork Strategy, and other commitments. The possibility of adopting alternative farming systems will be also considered, such as conservation agriculture, where the use of mineral fertilizers could be reduced by up to 50 %, while the yield per hectare is comparable to conventional agriculture.

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