The Potential for Reducing Environmental Footprints by Substituting Meat for Alternatives in the German Diet

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The German National Nutrition Survey II

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Synopsis

This research evaluated the environmental impact of food consumption in Germany, using data from the German National Nutrition Survey II (2005-2007). In this sample of 12,915 German adults, the average meat consumption was 127.7 grams/day. On days when individuals consumed meat, their diets had higher greenhouse gas emissions at 6.3 kg CO_2-eq/day, compared with 4.1 kg CO_2-eq/day on days without meat. Similarly, land use was higher on days with meat consumption, reaching 7.6 m^2·year/day, compared to 4.2 m^2·year/day on days without meat.

If individuals replaced meat with alternatives such as legumes, nuts, seeds, eggs, and meat analogues in their daily diets, their dietary greenhouse gas emissions could be reduced by 1.6 kg CO_2-eq/day (a 23.9% decrease), while land use could be reduced by 2.1 m^2·year/day (a 23.4% decrease). Therefore, lowering meat consumption in Germany has the potential to reduce the environmental impact of food consumption.

Background

Our current food production and consumption practices exert a substantial impact on the environment, putting planetary ecosystems at risk. Globally, food systems are responsible for approximately 30% of total greenhouse gas emissions and 40% of global land use (Willett, 2019). Meat and dairy products are among the biggest contributors to this environmental impact (Biesbroek, 2014). It is therefore urgently needed to shift to a diet with less meat and dairy while increasing plant-based foods – a change that may significantly alleviate environmental impact and promote planetary health.

Germany’s newest food-based dietary guidelines (German Society for Nutrition, 2024) recommend eating foods that are 'colorful and healthy while protecting the environment,' with at least 75% of plant-based foods and a maximum of 25% of animal-based foods. This research, using data from the German National Nutrition Survey II (2005-2007), evaluated the greenhouse gas emissions and land use resulting from the daily diets of German adults on days they consumed meat or no meat. Additionally, this research estimated the potential reduction in environmental impact if individuals replaced meat with meat substitutes in their diets.

Research Results and Interpretation

Consumption Levels of Meat and Meat Substitutes

In this population sample of German adults (18-80 years), a total of 12,915 participants recorded detailed information on food consumption on a total of 25,825 days. Of all consumption days, the average total meat consumption was 127.7 grams/day, with breakdowns for red meat of 40.7 grams/day (31.9%), processed meat of 54.0 grams/day (42.3%), white meat of 14.7 grams/day (11.5%), seafood of 16.4 grams/day (12.8%), and meat/fish from composite dishes of 1.8 grams/day (1.4%) (**Figure 1a**). The average total meat substitutes consumption was 20.7 grams/day, which consisted of legumes of 5.2 grams/day (25.1%), eggs of 11.3 grams/day (54.6%), nuts/seeds of 4.0 grams/day (19.3%), and meat analogues of 0.1 grams/day (0.5%) (**Figure 1b**). Of the total 25,825 days of dietary assessments for 12,915 participants, 2631 (20.4%) participants had at least one day that they did not consume meat, accounting for 3087 (12.0%) meat-free days (**Table 1**). A meat day refers to an individual who consumed meat and/or fish on a record day; while a meat-free day refers to an individual who did not consume meat and/or fish on a record day.

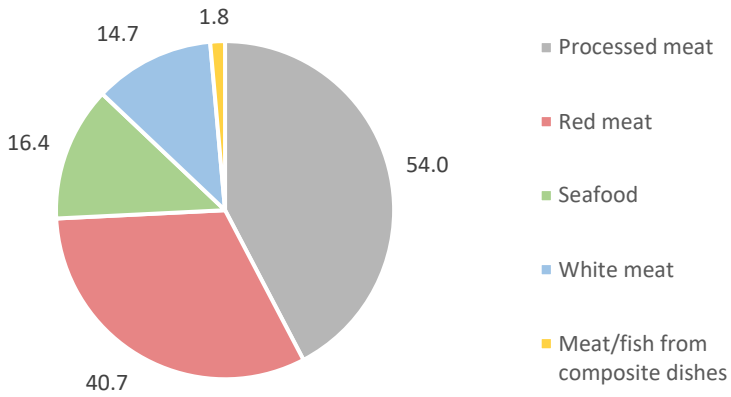
Table 1 – Numbers of participants and days with or without meat consumption

	Participants, n (%)	Days of dietary records, n (%)
Meat days	10,284 (79.6%)	22,738 (88.1%)
Meat-free days	2631 (20.4%)[a]	3087 (12.0%)
Total	12,915	25,825

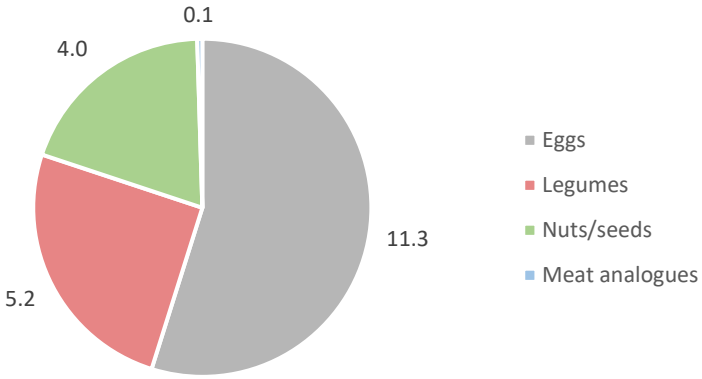
[a] Participants had at least one day that they did not consume meat.

Figure 1 – Average consumption of meat (a) and meat substitutes (b) in grams per day of the study population

(a) Meat consumption



(b) Meat substitutes consumption



Environmental Impact of Daily Diets

The dietary environmental impact of German adults is shown in **Table 2**, separated into meat days and meat-free days. The dietary environmental impact was higher on meat days compared with meat-free days. Greenhouse gas emissions reached 6.3 kg CO_2-eq/day on meat days and 4.1 kg CO_2-eq/day on meat-free days. Land use amounted to 7.6 m^2·year/day on meat days, compared with 4.2 m^2·year/day on meat-free days

Eating larger food quantities generally lead to higher calorie intake and greater dietary environmental impact. Individual food preferences or health considerations, on the other hand, may reduce calorie consumption from specific foods. Some participants may have also underreported or omitted certain foods, resulting in a lower observed energy intake. Considering the difference in energy intake between meat days (2034 kcal/day on average) and meat-free days (1551 kcal/day on average), the observed environmental impact for each individual was scaled to 2000 kcal/day energy intake. This approach enhances the comparability of environmental impact across different consumption days. On meat-free days, the environmental impact of 2000 kcal/day-scaled diets was higher than the observed values (**Table 2**), which was due to the low reported energy intake. However, the environmental impact (scaled to 2000 kcal/day) on meat-free days remained consistently lower than meat days, with 7.8% lower greenhouse gas emissions and 23.7% lower land use.

In addition to energy intake, age and gender may also influence the environmental impact of diets. It is important to gain deeper insights into the extent to which meat consumption contributed to the dietary environmental impact, irrespective of these factors. To calculate this, regression models were applied. Results from the regression models showed that, of all consumption days, meat consumption was estimated to contribute to 1.2 kg CO_2-eq/day of greenhouse gas emissions and 2.1 m^2·year/day of land use. Further details of this regression analysis can be found in section **Methods and Explanation**.

Table 2 – Dietary environmental impact and energy intake on meat days and meat-free days[a]

	Total	Meat days	Meat-free days
Number of days, n	25,825	22,738	3087
Energy intake, kcal	1976 (830)	2034 (823)	1551 (757)
Greenhouse gas emissions, kg CO_2-eq/day			
Observed	6.0 (2.9)	6.3 (2.8)	4.1 (2.1)
Per 2000 kcal	6.3 (2.6)	6.4 (2.2)	5.9 (4.7)
Land use, m^2·year/day			
Observed	7.2 (4.1)	7.6 (4.2)	4.2 (2.7)
Per 2000 kcal	7.4 (3.5)	7.6 (3.3)	5.8 (3.8)

[a] Data are presented as mean (standard deviation).

Reducing Environmental Impact by Replacing Meat by Meat Substitutes

Replacing meat by meat substitutes has the potential to alleviate dietary environmental impact. Hence, substitution analyses were performed to estimate the potential reduction in greenhouse gas emissions and land use if individuals replaced meat with alternatives in their daily diets. Meat substitutes included eggs, legumes, nuts/seeds, and meat-analogues and plant-based meat substitutes only includes legumes, nuts/seeds, and plant-based meat-analogues.

Table 3 and **Figure 2** show the estimated average reduction per person in dietary environmental impact that would be achieved if individuals replaced meat with meat substitutes. In the figures, the total height of each stacked bar represents the observed values of environmental impact on meat days and meat-free days, while the shadowed areas denote the estimated reduction in environmental impact that would be achieved by replacing meat by meat substitutes. If individuals replaced meat by meat substitutes, greenhouse gas emissions would decrease by 1.6 kg CO_2-eq/day (11.4 kg CO_2-eq/week, 23.9% decrease), and land use would decrease by 2.1 m^2·year/day (14.5 m^2·year/week) by 23.4%. This reduction would slightly increase to 1.7 kg CO_2-eq/day (11.9 kg CO_2-eq/week) by 25.0% for greenhouse gas emissions and 2.1 m^2·year/day (14.9 m^2·year/week) by 24.1% for land use per person on average, if meat was replaced by plant-based meat substitutes.

Table 3 – Estimated reduction in environmental impact if individuals replaced meat by meat substitutes in their daily diets[a]

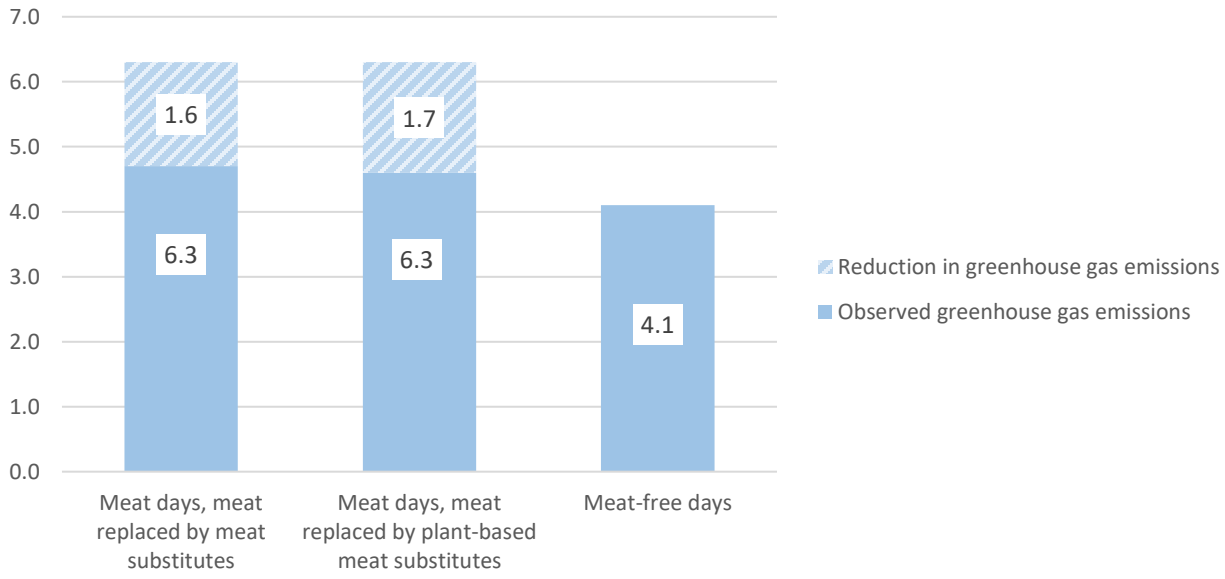
	Meat substitutes[b]	Plant-based meat substitutes[b]
Greenhouse gas emissions, kg CO_2-eq		
With 1 day change	1.6 (1.8)	1.7 (1.8)
With 1 week change	11.4 (12.5)	11.9 (12.9)
Percentage reduction, %	23.9 (18.2)	25.0 (18.8)
Land use, m^2·year		
With 1 day change	2.1 (2.7)	2.1 (2.7)
With 1 week change	14.5 (18.8)	14.9 (19.1)
Percentage reduction, %	23.4 (19.6)	24.1 (20.0)

[a] Data are presented as mean (standard deviation).

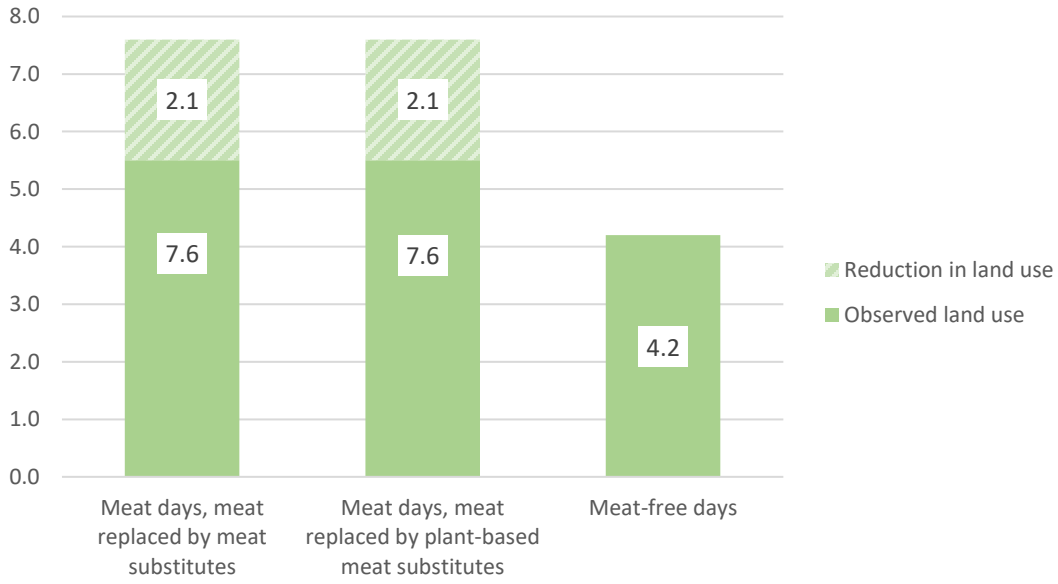
[b] Meat substitutes included eggs, legumes, nuts/seeds, and meat analogues; plant-based meat substitutes included legumes, nuts/seeds, and plant-based meat analogues.

Figure 2 – Dietary environmental impact on meat days, meat-free days, and potential reduction in environmental impact by replacing meat with meat substitutes on meat days[a]

(a) Greenhouse gas emissions (kg CO_2-eq/day)



(b) Land use (m^2·year/day)



[a] Meat substitutes included eggs, legumes, nuts/seeds, and meat analogues; plant-based meat substitutes included legumes, nuts/seeds, and plant-based meat analogues.

Methods and Explanation

Study Population

Data on daily food consumption was obtained from the German National Nutrition Survey II (2005-2007), conducted by the Max Rubner-Institut on behalf of the German Federal Ministry of Food, Agriculture and Consumer Protection (Straßburg, 2019). This data was shared via the European Food Safety Authority (EFSA) as part of the Comprehensive Food Consumption Database. For this research, data of 12,915 German adults were used, with a total of 25,825 days of dietary records. The survey sampling aimed to create a representative population sample in Germany concerning age and gender. In short, a two-stage sampling process was applied. First, all municipalities were stratified by district and rural/urban classification and 500 sample points were randomly selected, which reflected the population distribution. Subsequently, addresses for interviewees were randomly drawn from local population registries at each sample point, stratified by gender and age. Non-German speaking was an exclusion criterion (Straßburg, 2019). Demographic characteristics of the study population are presented in **Table 4**.

Dietary consumption was assessed with two 24-hour dietary recalls on two non-consecutive days. Telephone interviews were conducted by trained interviewers to inquire about participants' food and beverage consumption from the previous day. EPIC-SOFT software (IARC, Lyon, France) was used to record the types of food and portion sizes consumed. The EPIC-SOFT software system included control questions and integrated quality checks. The assessment days were randomly selected, consisting of 75% weekdays and 25% weekends (Straßburg, 2019). All food items were further classified according to the FoodEx2 food classification system developed by EFSA. Dietary consumption data were linked to the German Nutrient Database (version 3.02, https://www.blsdb.de/) to calculate nutrient and energy intake. In this research, meat is defined as red meat, white meat, processed meat, fish/seafood, and meat/fish from composite dishes.

Table 4 – Demographic characteristics of the study population[a]

Participants, n	12,915
Female, n (%)	7158 (55.4)
Days of dietary assessments, n	25,825
Age, years	48.2 (15.8)
Weight, kg	76.8 (13.8)
Height, cm	170.0 (8.8)
BMI, kg/m^2	26.5 (4.1)

[a] Data are presented as mean (standard deviation) if not specified.

Environmental Impact Indicators

The dietary environmental impact was calculated using the SHARP Indicators Database (SHARP-ID), which includes estimates of European average greenhouse gas emissions and land use of food items. The SHARP-ID was developed as part of the EU-funded SUSFANS project (H2020-SFS-2014-2, grant number 633692). In short, attributional life cycle assessment was applied to quantify the environmental impact throughout the entire life cycle of a food product, including primary production, primary packaging, transport, food losses/waste, and food preparations at home. The life cycle assessment data were adjusted for consumption amount using available conversion factors for production, edible portion, cooking losses and gains, and food losses and waste. The life cycle assessment data were available for 957 FoodEx2 coded foods, based on 182 primary food products, and were extrapolated to European countries. Missing values were preferably supplemented with estimates for similar food items, comparable in production method and/or ingredient composition. Alternatively, the mean value of the same (and if not available higher) level of the FoodEx2 classification was used. Furthermore, recipes were created for missing values of composite dishes based on a combination of food items if no suitable alternative was available. In this study, the environmental impact for greenhouse gas emissions and land use was linked to the German National Nutrition Survey II data using the FoodEx2 food classification codes (Mertens, 2019). Other environmental impact indicators, such as water use and biodiversity loss are not available, and therefore not included in this study. It is important to investigate the environmental impact of these indicators when data become available.

Composite Dishes in German Diet

The food consumption data from the German National Nutrition Survey II (2005-2007) included 13 types of meat-based composite dishes. Examples of these composite dishes are pizza, meat soup, pasta with minced meat, and German stew dishes (such as Eintopf). Quantities of meat consumed in these composite dishes were originally not quantified separately. To calculate the meat content in these composite dishes, recipes were created for each dish based on individual food items to determine the proportion of meat in each dish. Similar composite dishes were also used as a reference for creating recipes if available. Subsequently, the quantity of meat consumed in grams per day was calculated. Similarly, for environmental impact, recipes were created for each composite dish based on individual food items. The environmental impact of each food item was adjusted according to its weight in the recipe and then summed. Detailed recipes created for the 13 types of meat-based composite dishes can be found in **Appendix**.

As shown in **Figure 1**, the average consumption of meat and fish from composite dishes was estimated to be 1.8 grams per day. This low level of consumption suggests that while most of the meat and fish in daily diets was documented separately in the survey data, composite dishes were recorded instead when necessary in certain situations. This could be due to participants not remembering the recipes or the consumption of ready-to-eat foods from supermarkets. Out of the total 616,495 food records in the survey data, only 4059 (0.7%) are composite dishes. Therefore, this low amount of meat consumption from composite dishes are not expected to affect the overall meat consumption level and the proportion of meat in the total diet, and thus the results and conclusions of this study. Nonetheless, future advancements in dietary data collection are crucial for gaining clearer insights into the consumption level of meat in composite dishes and its associated environmental impact.

Potential Changes in Meat Consumption

This study used data from the German National Nutrition Survey II (2005-2007). There is currently no updated national nutrition survey in Germany. The latest German National Nutrition Survey III is ongoing and is expected to be completed next year.

Although this study is based on a cross-sectional food consumption survey using data between 2005-2007, the calculations provide a reasonable estimate of how a meat-free day could help reduce dietary environmental impact. Since there is currently no available newer food consumption data representative of the German population, it is impossible to further evaluate potential changes in meat consumption since the last survey. Previous research has shown that in the Netherlands and Denmark, the proportion of different types of meat consumed relative to total meat consumption has remained basically unchanged over the past 15 years (Heerschop, 2022; Duan, 2024a; Duan, 2024b). Substantial changes in meat consumption since the last survey in Germany are not expected. The results from this study substantiate that eating meat-free (by replacing meat with meat substitutes) may contribute to a lower dietary environmental footprint. Substantial long-term benefits in reducing the dietary environmental impact may be achieved if individuals switch to more plant-based dietary patterns for an extended period. Contemporary changes in diet and their associated environmental impacts should be studied once new data become available.

Regression Models

Meat consumption contributes substantially to dietary environmental impact. Age and gender may also influence food consumption patterns and thus the environmental impact of diets. Therefore, two linear regression models were applied to assess the specific contribution of meat consumption to dietary environmental impact, regardless of these factors. Taking greenhouse gas emissions as an example, in the first model, the values of dietary greenhouse gas emissions were set as the dependent variable, while age, gender, energy intake, and meat consumption (both amount and consuming meat on an assessment day or not) were set as the independent variables. The second model was identical but variables representing meat consumption were left out, i.e., it included age, gender, and energy intake as the independent variables. The sum of the difference of the greenhouse gas emissions predicted by these two models thus estimated the part of dietary greenhouse gas emissions that can be attributed to meat consumption. For land use, the same approach was applied.

Table 5 shows the estimated environmental impact attributed to meat consumption. Of all consumption days, meat consumption was estimated to account for 1.2 kg CO_2-eq/day of greenhouse gas emissions and 2.1 m^2·year/day of land use.

It should be noted that other factors, such as education and income, could influence meat consumption and the environmental impact of daily diets. Unfortunately, these factors are not included in the current research data, so their influence could not be examined in this research.

Table 5 – Predicted dietary environmental impact on meat days and meat-free days[a]

	Meat days	Meat-free days	Environmental impact attributed to meat consumption[b]
Greenhouse gas emissions, kg CO_2-eq/day			
Models considering meat consumption[c]	6.1 (2.7)	3.7 (1.1)	
Models not considering meat consumption[d]	5.9 (2.5)	4.8 (1.9)	
Difference	0.2 (1.1)	1.0 (0.8)	1.2
Land use, m^2·year/day			
Models considering meat consumption[c]	7.2 (4.0)	3.6 (1.3)	
Models not considering meat consumption[d]	6.9 (3.6)	5.3 (2.6)	
Difference	0.4 (1.8)	1.7 (1.3)	2.1

[a] Data are presented as mean (standard deviation) except for the environmental impact attributed to meat consumption.

[b] The sum of the difference in predicted values between the two models indicate the environmental impact attributed to meat consumption.

[c] Values predicted by models considering meat consumption, age, gender, and energy intake.

[d] Values predicted by models considering age, gender, and energy intake.

Other Considerations

This research estimated the potential reduction in dietary environmental impact if individuals replaced meat with meat substitutes. Underreporting of food consumption and energy intake is inevitably present, especially on meat-free days. Previous studies have shown that potential underreporting in the German National Nutrition Survey II was approximately 16% for 24-hour dietary recalls. Food items with a high chance of underreporting include pastries, ice cream, and sweets, likely because of social desirability and food preferences (Straßburg, 2019). However, the underreporting of these food items is not expected to substantially influence the outcomes of this study. This study results illustrates that the main difference in dietary environmental impact is attributed to meat consumption, and there is no evidence of systematic underreporting of meat consumption. By scaling the environmental impact to diets of 2000 kcal/day and applying the regression models, the potential impact of underreporting on dietary environmental impact is likely mitigated.

Additionally, sufficient intake of nutrients should be guaranteed when switching to more plant-based diets. Animal-based foods are good dietary sources of iron, calcium, vitamin B1, vitamin B12, and vitamin D, while in plant-based foods these nutrients are in general limited (Tso, 2021).

Moreover, the environmental impact indicators used in this research are based on current estimates related to existing production systems. This research applied average EU data for greenhouse gas emissions and land use. However, the environmental footprints of diets in Germany may differ from these EU averages. The environmental footprints of food items will be reduced when animal and plant/crop production systems become more environmentally sustainable.

Conclusions

In this research, the dietary environmental impact of German adults was assessed, and the potential reduction in this impact was estimated if individuals replaced meat with meat substitutes. Among all participants, the average meat consumption was 127.7 grams/day. Out of the 25,825 days of dietary assessments, 3087 days (12.0%) were meat-free. Meat days showed higher dietary environmental impact compared with meat-free days. If individuals replaced meat with meat substitutes, the average reduction would be 1.6 kg CO_2-eq/day (a 23.9% decrease) in greenhouse gas emissions and 2.1 m^2·year/day (a 23.4% decrease) in land use. These findings highlight the significant environmental benefits that could be achieved by reducing meat consumption among German adults.

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Appendix – Recipes for Composite Dishes in the German National Nutrition Survey II used in this Study

Composite dishes	Main ingredients with weight ratios
Fish balls	50% fish; 25% flour; 15% oil; 8% vegetables; 2% condiments
Fish/seafood-based dishes	20% fish/seafood; 40% pasta; 30% vegetables; 8% water; 2% condiments
Fish gratin	40% fish; 30% water; 25% vegetables; 4% cheese; 1% condiments
Seafood salad	15% fish; 50% vegetables; 25% pasta; 8% sauce; 2% condiments
Meat-based dishes	20% processed meat; 40% potatoes; 30% vegetables; 8% water; 2% condiments
Meat in aspic	20% red meat; 75% water; 4% vegetables; 1% condiments
Sandwich with processed meat	25% processed meat; 50% bread; 15% vegetables; 9% sauce; 1% condiments
Pizza with processed meat	10% processed meat; 50% pizza dough; 15% tomatoes; 15% cheese; 7% tomato puree; 3% condiments
Pasta dishes with meat	10% meat; 40% pasta; 30% vegetables; 12% sauce; 6% cheese; 2% condiments
Meat soup	5% red meat; 50% vegetables; 43% water; 2% condiments
Meat and vegetable soup	3% red meat; 55% vegetables; 40% water; 2% condiments
Fish soup	5% fish; 50% vegetables; 43% water; 2% condiments
Clear meat soup	5% red meat; 93% water; 2% condiments

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