CHANGES IN NUTRIENT AND FOOD CONSUMPTION OVER TIME IN POPULATIONS AROUND THE WORLD

CHANGES IN NUTRIENT AND FOOD CONSUMPTION OVER TIME IN POPULATIONS AROUND THE WORLD

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Lay Abstract

As diet changes are related to chronic diseases and malnutrition, it is necessary to estimate and compare diet trends around the world. Three projects were conducted. First, intakes from published studies investigating trends in macronutrients and foods between 1950-2019 in 47 countries were combined. We found that carbohydrate intake decreased, and fat intake increased in Asia, while the opposite occurred in North America. In Europe, fat consumption decreased, while carbohydrate intake was unchanged. Second, we investigated the change in food intakes over 15 years in 16 low-, middle-, and high-income countries in the international PURE prospective cohort study, observing generally modest changes. Low-income countries had increases in milk, poultry, fish, and fruit intake. Vegetable consumption decreased in most regions. Third, compared to diet directly measured from participants, we found that diet changes estimated from national supply data were comparable to population changes in macronutrients, but not energy intake.

Abstract

Background: Comprehensive assessments of diet trends are warranted as changes have implications for non-communicable diseases and malnutrition. This thesis aimed to estimate and compare changes in energy, macronutrients, and foods, over the long term (1950-2019) and short term (2007-2022).

Methods: A systematic review and meta-analysis examined changes in energy, macronutrients, and foods per decade from 1950-2019 by geographic and income regions using linear mixed-effects models. In sixteen low-, middle-, and high-income countries participating in the Prospective Urban Rural Epidemiology (PURE) Study, changes in foods were assessed (2007-2022) using mixed-effect models. In a small methodological project, we used correlation coefficients to compare trends in food supply data to dietary changes collected using individual-level diet assessments.

Results: Findings from the systematic review and meta-analysis show a pattern of decreased carbohydrate and increased fat intakes in Asia; the opposite was found in North America. In Europe, fat consumption decreased, but little change was found in carbohydrate intake. By the end of the covered time period (in the 2000s), fruit, vegetable, nut, and legume intakes were below recommended intakes in most regions. In the PURE cohort, dietary changes were modest. In low-income countries, milk, chicken, fish, and fruit intakes increased, with little change to vegetable intake. Fruit decreased in high- and middle-income countries, and vegetables decreased in most regions. Food supply data overestimated individual-level intakes, especially in higher-income countries. Diet changes estimated from supply data corresponded with changes from individual-level assessments for macronutrients, but not energy intake.

Conclusions: Based on our systematic review, consumption of fruits and vegetables, nuts, and legumes remain below recommendations in most world regions. Similarly, in PURE, consumption of fruits and vegetables has not improved in most regions in recent years (i.e., 2007-2022). This work helps to identify targets for nutritional policies and interventions in different world regions.

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List of Abbreviations

% energy	Percent of total energy
CHHS	Canadian Community Health Surveys
CI	Confidence interval
E.g.	Exempli Grati
FAO	Food and Agriculture Organization
FFQ	Food frequency questionnaire
g	grams
GBD	Global Burden of Disease Study
GDD	Global Dietary Database
GDP	Gross domestic product
GENuS	Global Expanded Nutrient Supply Model
HICs	High-income countries
IQR	Interquartile range
LICs	Low-income countries
MICs	Middle-income countries
MUFA	Monounsaturated fatty acids
NHANES	National Health and Nutrition Examination Survey
NOS	The Newcastle-Ottawa Scale
PDS	Public Distribution System
PHRI	Population Health Research Institute
PROSPERO	The International Prospective Register of Systematic Reviews

PUFA	Polyunsaturated fatty acids
PURE	Prospective Urban Rural Epidemiology
r_s	Spearman Correlation Coefficient
SD	Standard deviation
s/day	Servings per day
SE	Standard error
SFA	Saturated fatty acids
sFFQ	Short food frequency questionnaire
UN	United Nations
USDA	United States Department of Agriculture
WHO	World Health Organization

Declaration of Academic Achievement

The doctoral dissertation contained herein is a "sandwich" thesis, which includes three main chapters, one of which has been published in a peer-reviewed nutrition journal (Chapter 2), and two manuscripts prepared for submission to peer-reviewed journals (Chapter 3 and Chapter 4). I am the first author of all manuscripts included in this dissertation. The details of my contributions to each chapter are listed below.

Chapter 2: Changes in energy, macronutrient, and food consumption in 47 countries over the last 70 years (1950-2019): a systematic review and meta-analysis

This project was published in *Nutrition*. My contributions include involvement in the project conception, design, project administration, data acquisition, data analysis, data interpretation, drafting of the manuscript, critical revision of the manuscript for important intellectual content, providing final approval of the published version, having full access to the data, and responsibility for ensuring the integrity of the work. My co-authors were involved in project conception and design, data acquisition, data interpretation, critical revising of the manuscript, and providing final approval of the published version.

Chapter 3: Dietary changes over a 15-year period in 16 countries: findings from the PURE prospective cohort study

This manuscript is prepared for submission. My contributions include involvement in the project conception, data analysis, data interpretation, drafting of the manuscript, critical revision of the manuscript for important intellectual content, and responsibility for ensuring the integrity of the work. Prior to submission for publication, the manuscript will be updated with the most recent version of the dataset. My co-authors were involved in project conception, design, project administration, project supervision, data acquisition, data interpretation, and critical revising of the manuscript.

Chapter 4: Comparison of individual-level and supply-level estimates of dietary intake over a 50-year period (1961-2011) in 18 countries in Asia, North America, and Europe

This manuscript is prepared for submission. My contributions include involvement in the project conception, design, project administration, data acquisition, data analysis, data interpretation, drafting of the manuscript, critical revision of the manuscript for important intellectual content, having full access to the data, and responsibility for ensuring the integrity of the work. My co-authors were involved in project conception and design, project supervision, data interpretation, and critically revising the manuscript.

Chapter 1

Introduction

Background

Over the past few decades, changes to dietary patterns have occurred globally, in parallel with several changes in socioeconomic development, increased efficiency in modern trade systems, use of fertilizers and pesticides, food industry marketing, food processing, increased supply at lower prices, and public health policies (1-2). There are limited prior systematic assessments of trends in energy, macronutrient, and food intakes in different countries around the world (3-4). The investigation of diet patterns and distributions over time, as well as heterogeneity in these patterns by country and region, is warranted.

Dietary changes have important implications for malnutrition and its consequences, including prevention of premature mortality and morbidity, wasting, stunting, anemia, cognitive impairment, infectious diseases, and reduced economic productivity (5). The World Health Organization recognizes that malnutrition can present as undernutrition, inadequate micronutrient consumption, and as overweight and obesity (5). Malnutrition is common globally as all countries experience at least one form of malnutrition, of which 59% have high levels of two forms and 29% have high levels of all three, with increasing burden in low- and middle-income countries, especially in Africa (5). Diet is also a potentially modifiable risk factor for cardiovascular and metabolic diseases, and about one-fifth of adult mortality is linked to poor diet (6-7). Moreover, monitoring nutritional changes is essential to assess if dietary intakes align with nutritional guidelines. A better understanding of changes in food intake over time can help track and plan public health nutrition initiatives and policies.

Sources of data for monitoring dietary trends

Three main sources of dietary data can be used when examining national trends, including supply-level, household-level, and individual-level data. Each source of dietary data has its merits, depending on research objectives. Supply-level dietary data is the most common (8). Supply-level dietary data is calculated based on the total quantity of food produced and imported in a country minus the food exported, fed to animals, or not available for human consumption, divided by the population size (8-9). While supply-level data represent a crude estimate of food intakes, it is a low-cost method with high accessibility to study trends in food availability in almost all countries worldwide (8). However, supply-level estimates provide data about average availability per person, not the actual amount of food consumed per person (10). As a result, compared to other dietary assessments, it may overestimate intakes, as it does not consider factors such as food wasted, unequal access to food (e.g., across seasonal variations or socioeconomic levels), weight loss during cooking, and practices such as fat trimming (10-11). Moreover, supply-level data for low- and middle-income countries may be less reliable as the national input data is often poor quality (12). Household-level dietary data capture information on household food availability, typically by calculating the proportion of total income spent on various food items during a specific period (13). Household-level dietary assessments are not designed to measure individual intake, but rather broader household expenditures and apparent food intake (13).

There are well-established tools for collecting dietary data at the individual level, including 24-hour dietary recall, diet records, and food frequency questionnaires. For the 24-hour dietary recall, a trained interviewer asks participants to recall and report all foods and beverages consumed over the preceding 24 hours (13-14). The diet record method relies on participants to self-record food consumption for a specific period of time, typically three to seven days (13-14). The food frequency questionnaire (FFQ) uses a detailed checklist of foods to capture the frequency and quantity of food consumed over a period ranging from one week to one year (13-14). For monitoring dietary changes, individual-level dietary assessments are typically collected through repeat cross-sectional studies, and less frequently in long-term prospective cohort studies. In higher-income countries, repeat cross-sectional national nutrition surveys are commonly conducted, providing invaluable data on changes in actual food consumption. However, many countries, particularly lower-income countries, do not have the resources to conduct repeat individual-level nutrition surveys. As a result, most prior investigations of global dietary trends rely in part or fully on food supply estimates, which may not be reflective of actual individual-level consumption (8-12).

Thesis rationale and objectives

This thesis aims to provide comprehensive longitudinal analyses of energy, macronutrients, and food intakes around the world using data from multiple dietary assessment methods, including supply-level data, repeat cross-sectional studies, and prospective cohort studies. Our objectives are:

1. To conduct a systematic review and meta-analysis to estimate energy, macronutrient, and food trends around the world from 1950 to 2019 using individual-level dietary assessments (Chapter 2).
2. To assess dietary changes from 2007-2022 using the Prospective Urban Rural Epidemiology (PURE) cohort study, a large international population of various low-, middle-, and high-income countries from seven geographic regions: North America and Europe, South America, the Middle East, South Asia, China, Southeast Asia, and Africa (Chapter 3).
3. To compare dietary trends from individual-level dietary assessments (Chapter 2) to supply-level estimates from 1961 to 2011 in 18 countries in Asia, Europe, and the United States. Considering that many lower-income countries rely on supply-level data when crafting policies and recommendations, it is important to assess the degree of error between supply- and individual-level dietary trend data. The degree to which supply-level data can replace or complement individual-level assessments is not well known.

Chapter 2

Changes in energy, macronutrient, and food consumption in 47 countries over the last 70 years (1950-2019): a systematic review and meta-analysis

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Review

Changes in energy, macronutrient, and food consumption in 47 countries over the last 70 years (1950-2019): a systematic review and meta-analysis

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ABSTRACT

Objectives: We aimed to systematically examine trends in dietary energy, macronutrient, and food consumption in different geographic regions.
Methods: We searched Medline, Embase, CINAHL, and organizations for studies and reports using individual-level dietary assessments from 1950 to 2019 (PROSPERO CRD42022302843) and quantified changes using multivariable linear mixed-effects models.
Results: We identified 109 articles and reports from 47 countries, including Europe and Australasia (47% of studies), Asia (30%), Latin America (13%), the Middle East (6%), and North America (4%). In Southeast and East Asia, carbohydrate intake decreased, whereas fat consumption increased; the opposite pattern occurred in North America; and fat decreased while carbohydrate intake remained stable in Europe and Australasia. Consumption of carbohydrate and fat were stable in South Asia, Latin America, and the Middle East, but data were limited in these regions. A greater increase in national gross domestic product over time was associated with decreased carbohydrate and increased fat and protein intake. Dietary saturated fatty acid intake decreased in Northern and Eastern Europe and was stable in other regions. Changes in food varied by region; East and Southeast Asia increased meat, fish, dairy, egg, fruit, and vegetable consumption and decreased intake of grains, roots and tubers, legumes, whereas North America decreased dairy and red meat but increased eggs, nuts, poultry, and vegetable oil intake. Intakes of fruits, nuts, legumes, and roots and tubers were below recommendations in most regions.

Author contributions are as follows: Claudia Sikorski: conceptualization, data curation, formal analysis, methodology, project administration, resources, software, supervision, validation, visualization, writing—original draft, and writing—reviewing and editing; Shuling Yang: data curation, investigation, resources, validation, and writing—reviewing and editing; Rosain Stennett: data curation, investigation, resources, validation, and writing—reviewing and editing; Victoria Miller: supervision and writing—reviewing and editing; Koon Teo: conceptualization, methodology, project administration, supervision, and writing—reviewing and editing; Sonia S. Anand: conceptualization, methodology, project administration, supervision, and writing—reviewing and editing; Guillaume Paré: conceptualization, methodology, project administration, supervision, and writing—reviewing and editing; Salim Yusuf: conceptualization, methodology, project administration, supervision, and writing—reviewing and editing; Mahshid Dehghan: conceptualization, methodology, supervision, and writing—reviewing and editing; and Andrew Mente: conceptualization, methodology, project administration, supervision, and writing—reviewing and editing.

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Conclusions: Our findings indicate regional variations in dietary trends and identify countries that would benefit from nutritional policies aimed at decreasing lower-quality carbohydrate foods and increasing consumption of fruits, vegetables, nuts, legumes, and dairy.

Introduction

Diet is considered a modifiable risk factor for cardiovascular and metabolic diseases. Both a systematic analysis of global dietary intake and a large international, prospective cohort study estimated that 10% to 20% of adult mortality was attributable to poor diet [1,2]. Low- and middle-income countries have the highest burden of mortality and disability from cardiovascular disease (CVD), diabetes, and malnutrition, whereas higher-income countries have higher burdens from cancer [1,3,4]. Over the past few decades, changes to dietary patterns are likely to have occurred in many countries, coinciding with a variety of changes in socioeconomic development, increased mechanization, more efficient modern trade systems, food industry marketing, increased supply at lower prices, and modified public health policies [5,6]. Low- and middle-income countries are believed to be experiencing the most marked diet changes [7–9].

Dietary changes have important implications for overall health, malnutrition, and chronic diseases [3–6]. Globally, 671 million (13%) adults were obese in 2016, up from 100 million in 1975, as estimated by the Non-communicable Disease Risk Factor Collaboration [10]. The global prevalence of diabetes increased from 108 million in 1980 to 537 million (10.5%) in 2021 [11,12]. A better understanding of changes in nutrient and food intakes over time is essential for assessing whether progress is being made to meet nutritional guidelines and for the development of country-specific interventions, guidelines, and policies to improve diets of populations.

There are few prior systematic assessments of the time trends in energy, macronutrient, and food intake in different countries around the world. Most prior investigations of dietary trends rely on food supply estimates or household surveys, typically in a few countries within a single geographic region [13–17]. However, estimates from supply (e.g., United Nations Food and Agriculture Organization Food Balance Sheets) and household surveys do not necessarily reflect the levels of individual consumption and often overestimate consumption [16–18]. For instance, supply-level data include inedible portions (e.g., meat bone and nut shells) and do not account for food wasted, weight loss during cooking, and practices, such as fat trimming [16–18]. The specific objectives of this study are 1) to examine whether intake of energy, macronutrients (fat, carbohydrate, and protein), types of fat (saturated, monounsaturated, and polyunsaturated), and foods (meat, eggs, fish, dairy, fruit, vegetables, roots and tubers, legumes, nuts, fats and oils, grains and cereals, and sweets and foods containing added sugars) have changed over time in different geographic regions based on individual-level dietary assessments and 2) to assess if the trends over time differ across economic regions grouped based on country per capita gross domestic product (GDP).

Methods

Search strategy and selection criteria

This systematic review and meta-analysis included all studies and reports that assessed dietary trends in energy, macronutrients, and foods using at least one individual-level dietary assessment (food frequency questionnaires, 24-h dietary recall, and diet records). If individual-level surveys were not available, household-level estimates were considered if they reported consumption (i.e., percent energy, grams per day). We included studies providing dietary estimates from ≥2 different years of data collection in community-based, national, subnational, or multinational populations with a sample size of ≥100 participants/year. Studies that reported intakes as a percent change or servings per day without the serving size (i.e., in kilocalories or grams per day), in specific populations (e.g., people with type 2 diabetes mellitus), exclusively focused on dietary trends in children and/or adolescents, or based on projections were excluded.

The literature search was compiled from Medline, EMBASE, CINAHL, key organizations, institutes of nutrition, and government websites up to February 16, 2022 (Supplementary Tables 1 and 2). Hand searching of the reference lists of identified articles was performed. We also contacted the authors of articles and international study investigators with existing collaborations with the Population Health Research Institute to request individual-level dietary assessment estimates not publicly available. The study protocol was registered (PROSPERO CRD42022302843).

At least two authors (two of the authors C. S., S. Ya., and R. S) reviewed titles, abstracts, full texts (κ values = 0.57–0.65 and agreement = 87.5–87.8%) and assessed risk of bias using a modified version of the Newcastle-Ottawa scale for cohort studies [19]. We applied a scoring system to assess risk of bias (low, medium, and high risk) in our models (Supplementary Table 3). Discrepancies were resolved by group discussion or contacting a third author. Data extraction of full-text articles was independently assessed (by two of the authors C. S., S. Ya., and R. S.) using a standardized form (Supplementary Table 4).

Data analysis

Objective one

Energy, macronutrients, and foods were standardized to common definitions (Supplementary Tables 5 and 6). Countries were grouped into nine regions based on similar food cultures and geography (Supplementary Table 7). Trend lines for energy, macronutrients, specific types of fat, and foods were plotted by country and by region. The change in energy (change in kilocalories per day per decade), macronutrients (change in percent of total energy per day per decade), and foods (change in grams per day per decade) was estimated using a linear mixed-effects model, with random slopes and intercepts for region, accounting for the clustering of country. The linear mixed-effects models were adjusted for median age over time (to adjust for changes in population age distributions over time), dietary assessment method, and year of initial data collection. Sensitivity analyses compared estimates of unadjusted models, by population type (adult versus all ages), survey population (national versus subnational versus community-level), study design (cross-sectional versus cohort), and risk of bias (e.g., low versus medium risk). Data on the national median age from 1950 to 2019 were obtained from the United Nations [20].

Objective two

Countries were grouped based on their changes in economic level using the World Bank analytical classifications, available from 1987 to 2019 [21]. We grouped countries into five regions based on their GDP transition between 1987 and 2019: 1) remained high income, 2) upper-middle income transitioned to high income, 3) lower-middle income transitioned to upper-middle or high income, 4) low income transitioned to lower-middle income, and 5) low income transitioned to upper-middle income. The change in energy, macronutrients, and food intakes per decade were estimated using a linear mixed-effects model, with random slopes and intercepts for GDP region, accounting for country clustering.

Results

The literature search identified 51 328 articles from peer-reviewed journals and 323 from key organizations and websites (Fig. 1). Overall, 109 studies and reports were included, across 47 countries in Europe and Australasia (only Australia and New Zealand) (46.8%), Asia (29.8%), Latin America (12.8%), the Middle East (6.4%), and North America (4.3%) (Table 1; Supplementary Table 7). Studies on individual-level dietary trends were not identified for many countries in the Caribbean, Africa, Latin America, and the Middle East. Most studies were nationally representative (74.5%), repeat cross-sectional surveys (80.9%), and measured diet using 24-h recalls (29.8%) (Table 1). Trends were generally consistent across different countries within regions (Supplementary Figs. 1–20).

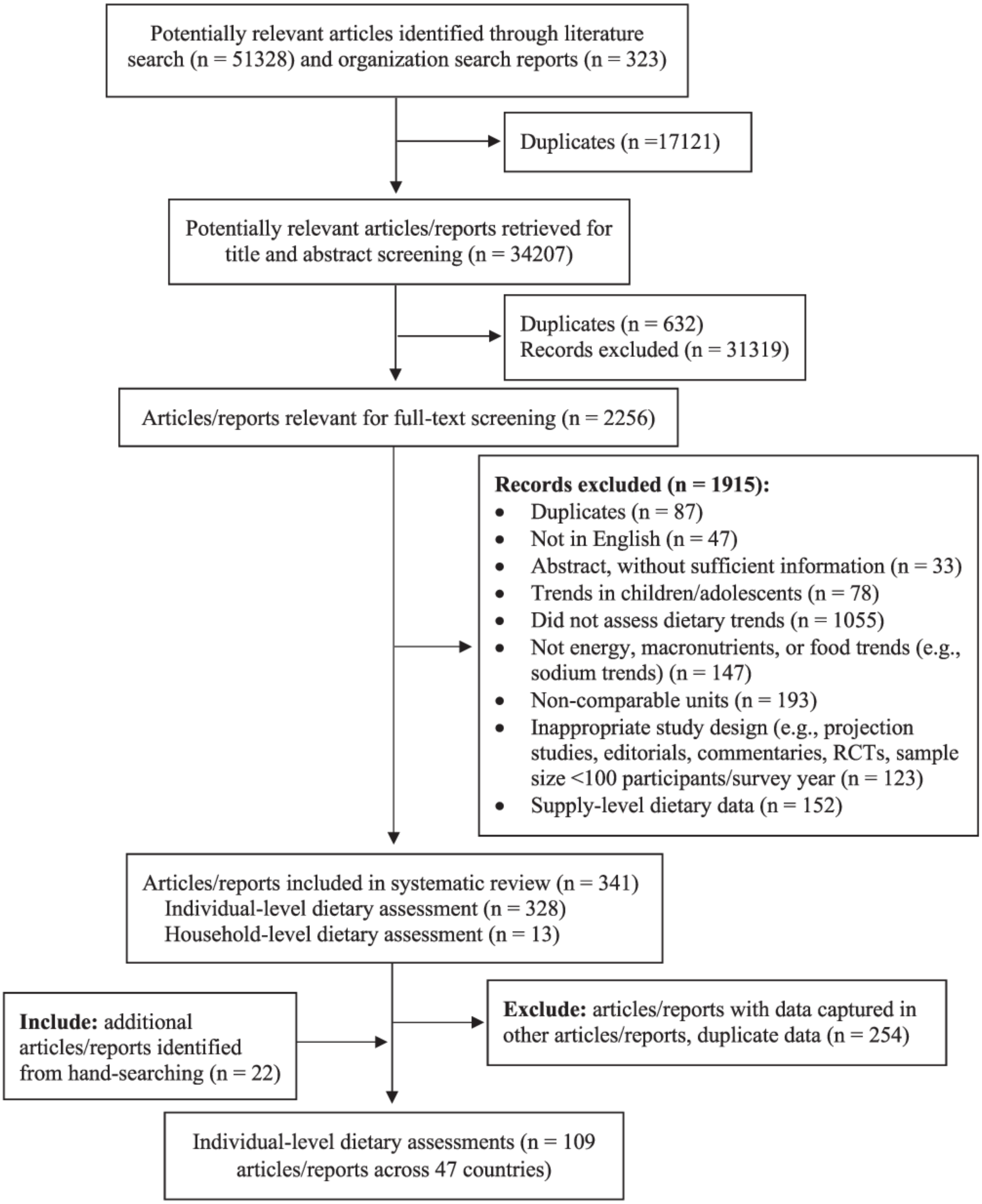

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow chart of peer-reviewed and gray literature search.

Dietary trends in energy, macronutrients, and types of fat in different world regions

Total energy increased in North America by 92.9 (95% CI, 25.6–160.1) kcal/d/decade, decreased in Western Europe and Australasia (−97.4; 95% CI, −153.7 to −41.1), Northern Europe (−89.8; 95% CI, −137.1 to −42.5), and Eastern Europe (−74.1; 95% CI, −147.6 to −0.6) and was stable in South Asia, East Asia, Southeast Asia, Latin America, and the Middle East (Fig. 2). Carbohydrate intake decreased by 1.9% of energy per decade (95% CI, −2.8 to

Table 1
Characteristics of studies using individual-level dietary assessments (n = 47 countries)

Characteristics	No. countries (%)
Region[†]	
East Asia	5 (10.6)
South Asia	2 (4.3)
Southeast Asia	7 (14.9)
Western Europe and Australasia	9 (19.1)
Northern Europe	8 (17.0)
Eastern Europe	5 (10.6)
North America	2 (4.3)
Latin America	6 (12.8)
Middle East	3 (6.4)
Type of study	
Repeat cross-sectional surveys	38 (80.9)
Cohort studies (repeat assessments in same participants)	9 (19.1)
Population of interest	
Nationally representative	35 (74.5)
Subnational (e.g., 1 province in country)	6 (12.8)
1–2 Cities or counties	6 (12.8)
Population age	
Adults (≥18 y)	35 (74.5)
All ages	12 (25.5)
Type of dietary assessment	
24-h recall	14 (29.8)
1-d, 3-d, 7-d diet records	10 (21.3)
FFQ	7 (14.9)
Combination of 2 or more techniques (e.g., 24-h recall and FFQ)	9 (19.1)
Household budget surveys	7 (14.9)
Study-level adjustments	
No adjustments	32 (68.1)
Adjustment for sociodemographic variables (e.g., age, sex, education, and ethnicity) at each time point	10 (21.3)
Age standardized	5 (10.6)
Risk of bias	
Low	29 (61.7)
Medium	18 (38.3)
Type of dietary assessment	
Energy intake	42 (89.4)
Fat intake	42 (89.4)
Carbohydrate intake	40 (85.1)
Protein intake	38 (80.9)
Specific fat intake (saturated, monounsaturated, and polyunsaturated fat)	23 (48.9)
Food intake (e.g., grains, fruits, and dairy)	33 (70.2)

FFQ, food frequency questionnaire
[†]East Asia: China, Japan, South Korea, Taiwan, and South Africa; South Asia: India and Pakistan; Southeast Asia: Indonesia, Malaysia, Philippines, Singapore, Thailand, Vietnam, and Fiji; Western Europe and Australasia: Germany, Netherlands, Switzerland, Italy, France, Spain, Greece, Australia, and New Zealand; Northern Europe: Denmark, Finland, Ireland, Lithuanaia, Norway, Sweden, the UK, and Estonia; Eastern Europe: Russia, Czech Republic, Poland, Slovak Republic, and Bulgaria; North America: Canada and the United States; and Latin America: Guatemala, Mexico, Argentina, Brazil, Costa Rica, and Chile; Middle East: Iran, Lebanon, and Morocco.

−0.9) in Southeast Asia and 1.6% (95% CI, −2.6 to −0.7) in East Asia, increased by 2.0% (95% CI, 0.6–3.3) in North America, and was stable in Western Europe and Australasia, Northern Europe, Eastern Europe, South Asia, Latin America, and the Middle East (Fig. 2). Protein consumption increased in Northern Europe and Southeast Asia (0.7% of energy per decade [95% CI, 0.5–0.9] and 0.5% [95% CI, 0.4–0.7], respectively), decreased by 0.4% (95% CI, −0.7 to −0.1) in North America, and was stable in other regions (Fig. 2).

Fat consumption decreased by 2.5% energy per decade (95% CI, −3.8 to −1.1) in Eastern Europe, 1.4% (95% CI, −2.5 to −0.3) in North America, 1.2% (95% CI, −2.1 to −0.3) in Western Europe and Australasia, and 1.0% in Northern Europe (95% CI, −1.8 to −0.3). Fat intake increased by 1.3% of energy per decade (95% CI, 0.5–2.0) in Southeast Asia and 1.0% (95% CI, 0.2–1.8) in East Asia, and was stable in South Asia, Latin America, and the Middle East (Fig. 2). Overall, the decreased fat intake in Eastern and Northern Europe was driven by decreased saturated fatty acid (SFA) intake (1.3% energy per decade [95% CI, −2.0 to −0.6] and 1.0% [95% CI, −1.6 to −0.4], respectively) but varied between countries over time. For instance, SFAs intake decreased in Finland and the UK (from 19% to 12.5% energy between 1982 and 2007, and 17% to 12% between 1986 and 2018, respectively), but in Poland, decreased between 1984 and 2001 (from 15.5% to 12.7% of energy), followed by an increase in 2012 to 14.6% of energy (Supplementary Fig. 5). Monounsaturated fatty acid (MUFA) consumption increased in Southeast Asia, East Asia, and Northern Europe (1.4% of energy per decade [95% CI, 0.3–2.4], 0.9% [95% CI, 0.4–1.3], and 0.6% [95% CI, 0.1–1.2], respectively) and was stable in other regions (Fig. 3). Although overall total fat intake was stable in North America, polyunsaturated fatty acids (PUFAs) increased by 0.8% energy per decade (95% CI, 0.2–1.3), whereas SFAs and MUFAs were stable (Fig. 3). PUFAs also increased by 1.2% energy per decade (95% CI, 0.8–1.7) in East Asia.

Dietary trends in foods in different world regions

The greatest increase in intake of meat was found in Eastern Europe and Southeast Asia (21.7 and 21.1 g/d per decade, respectively), followed by East Asia, Western Europe and Australasia, and the Middle East (12.8, 7.1, and 4.5 g/d/decade, respectively). Meat intake decreased in North America (−5.2 g/d/decade) and was stable in Northern Europe and South Asia (Fig. 4). Egg intake increased modestly (3.0 to 3.9 g/d/decade) in Northern Europe, North America, East Asia, and Southeast Asia but did not change significantly in the other regions (Fig. 4). Fish consumption increased modestly in all regions except South Asia, where fish intake was stable, with the largest increase found in Eastern Europe (10 g/d/decade; 95% CI, 5.3–14.7) (Fig. 4). Dairy intake decreased by ~42 g/d/decade in North America and Northern Europe and by 18 g/d/per decade in the Middle East. By contrast, dairy intake increased in Western Europe and Australasia, East Asia, and Southeast Asia (27.2, 18.8, and 13.3 g/d/decade, respectively) (Fig. 4). Notably, in the UK, although total dairy consumption did not significantly change, whole milk intake decreased at the same rate that skim milk increased (Supplementary Figs. 10 and 11). Fat and oil intake decreased in all European regions (−3.2 to −9.0 g/d/decade), in the Middle East (−2.2 g/d/decade), slightly increased in Southeast and East Asia (0.8–1.2 g/d/decade), and was stable in North America (Fig. 4). Vegetable oils displaced animal fats in some countries (Supplementary Fig. 19). For example, in South Korea, vegetable oil increased from 3.5 to 7.5 g/d, whereas animal fat decreased from 3.8 to 0.1 g/d between 1969 and 1995 (Supplementary Fig. 19). In France, consumption of vegetable oils increased from 6 to 22 g/d between 1998 and 2007, whereas animal fat intake remained stable at ~15 g/d (Supplementary Fig. 19). Fruit consumption increased in Southeast and East Asia (44.9 and 13.3 g/d/decade, respectively) and Northern and Western Europe and Australasia (26.7 and 15.8 g/d/decade, respectively); decreased in Eastern Europe (−107.3 g/d/decade); and remained stable in South Asia, North America, and the Middle East (Fig. 4). The greatest increase in vegetable consumption occurred in the Middle East and Northern Europe (19.7 and 20.5 g/d/decade, respectively), followed by East Asia, Western Europe and Australasia, and North America (9.6, 5.5, and 4.4 g/d/decade, respectively). Vegetable intake decreased 19.2 g/d in Eastern Europe and 2.8 to 3.4 g/d in South and Southeast Asia (Fig. 4). Consumption of grains decreased in the Middle East, South and East Asia, and Western Europe and Australasia and remained stable in the other regions (Fig. 4). Intake of roots and tubers decreased in all regions, except for increases in South Asia (13.4 g/d/decade), and remained stable in the Middle East (Fig. 4).

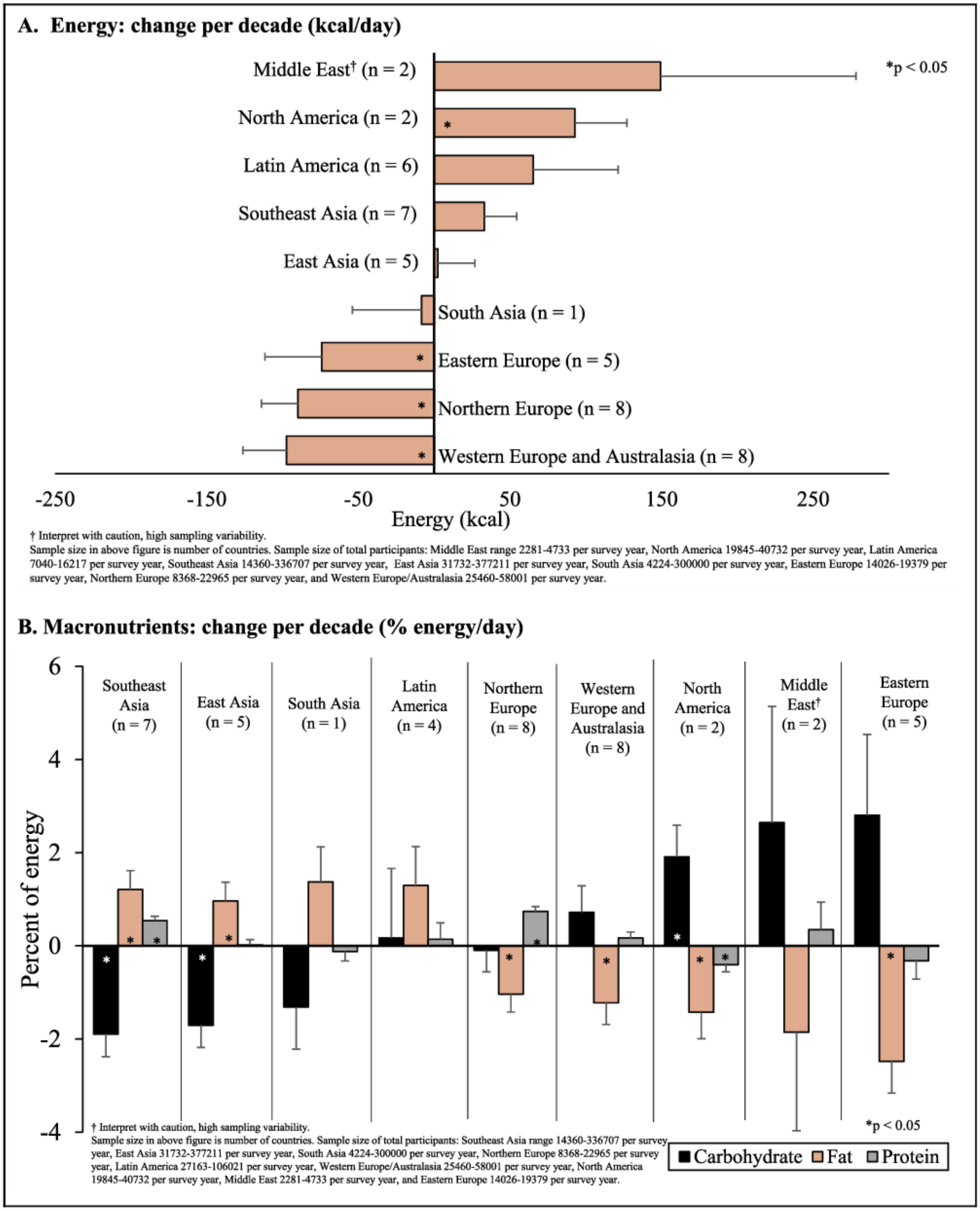

Fig. 2. Changes (SE) in energy and macronutrient intakes, per decade, by region, 1950–2019, adjusted for median age over time, method of dietary assessment, and initial year of collection

Recent consumption in different world regions

Intakes of fruits, nuts, legumes, and roots and tubers were below recommendations in most regions (Table 2). Despite decreased carbohydrate intake, South Asia and Southeast Asia remain the highest consumers of carbohydrate (62–69% of energy), and the lowest consumers of fat (20–23% energy) and protein (11–14% energy) (Table 2; Supplementary Fig. 21).

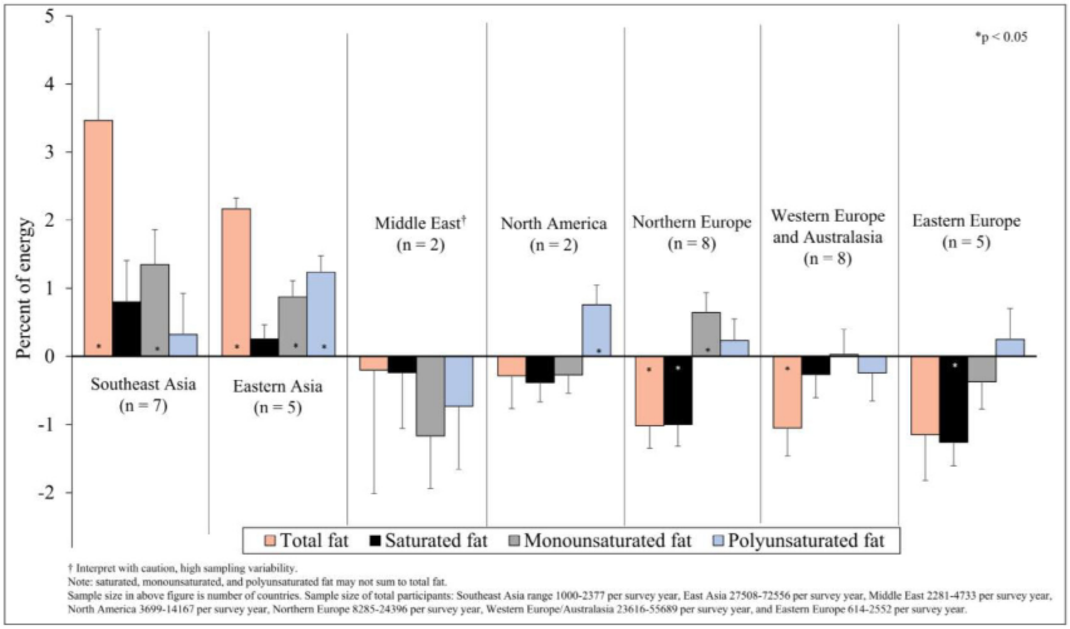

Fig. 3. Change (SE) in fat and its types, per decade, by region, 1964–2019, adjusted for median age over time, method of dietary assessment, and initial year of collection. Types of fat not available for Latin America and South Asia.

Northern Europe and Western Europe and Australasia consumed the most SFAs and MUFAs (13.4–13.8% and 12.8–14.8% energy, respectively), whereas PUFAs consumption was highest in North America and East Asia (7.6–8.7% energy) (Supplementary Fig. 21). Eastern Europe and Western Europe and Australasia were the top consumers of meat, dairy, fats and oils, fruit, and sweets; North America and Eastern Europe of eggs, vegetables, and roots and tubers; Southeast Asia of fish; and North America and the Middle East of nuts (Table 2; Supplementary Fig. 1). South Asia and East Asia consumed the most legumes, whereas grain intake was greatest in South Asia and the Middle East (Supplementary Fig. 21).

Dietary trends by GDP grouping in 1987 compared with grouping in 2019

Countries experiencing larger increases in GDP between 1987 and 2019 had larger decreases in carbohydrate intake and increases in fat and protein intake (Supplementary Fig. 22). For example, countries that were considered low income in 1987 but upper-middle income in 2019 decreased carbohydrate intake by 2.5% energy per decade (95% CI, −3.9 to −1.1) and increased fat and protein intake (1.5% [95% CI, 0.3–2.7] and 0.8% [95% CI, 0.6–1.0], respectively) (Supplementary Fig. 22).

Sensitivity analyses

Sensitivity analyses unadjusted and further stratified for risk of bias, population type (adult versus all ages), study design (cross-sectional versus cohort), and survey population (national versus subnational or community-level) did not materially change the results (<6% change).

Discussion

This systematic review and meta-analysis collated dietary trends measured at the individual level from 47 countries in Asia, Europe, North America, the Middle East, and Latin America across various years between 1950 and 2019. In Southeast Asia and East Asia, carbohydrate intake decreased and fat intake increased, whereas the opposite was found in North America. In Eastern Europe, Northern Europe, and Western Europe and Australasia, fat consumption decreased, but carbohydrate intake did not significantly change. Intakes of carbohydrate, fat, and protein were stable in South Asia, Latin America, and the Middle East, but data were limited in these regions. We found that the larger the increase in country GDP over time, the greater the decrease in carbohydrate intake and increase in fat and protein intake. Independent of changes to total fat over time, dietary SFA intake either decreased or was stable in all regions. Compared with the other regions, Southeast and East Asia had the largest decreases in carbohydrate intake and increase in fat intake, consistent with decreased grain and roots and tubers consumption and increased consumption of meats, dairy, eggs, and fats and oils. Estimates of the most recent intakes found that South and Southeast Asia and Latin America were the highest consumers of carbohydrate, with lower fat and protein compared with other regions. In contrast, Northern Europe and Western Europe and Australasia had the highest intakes of fat and protein and lowest intakes of carbohydrate. Many countries in the Caribbean, Africa, Latin America, and the Middle East did not have adequate individual-level dietary assessments of trends. Our findings have important implications, including recognizing gaps in dietary data around the world, identifying countries that would benefit the most from targeted nutritional interventions, and providing estimates of intake that can be used when measuring efficacy of policies.

Many countries in Southeast and East Asia have experienced rapid growth in GDP, which might account for why these regions had the largest decrease in carbohydrate and increase in fat intake [8]. These nutrient changes were driven by increased consumption of meat, eggs, dairy, nuts, and fats and oils. Even the lowest-income countries now have access to diets higher in fat, due to the increased availability of cheap vegetable oils and ultra-processed foods [2–5,10,22]. It was previously hypothesized that westernization of global diets would increase total dietary fat intake primarily

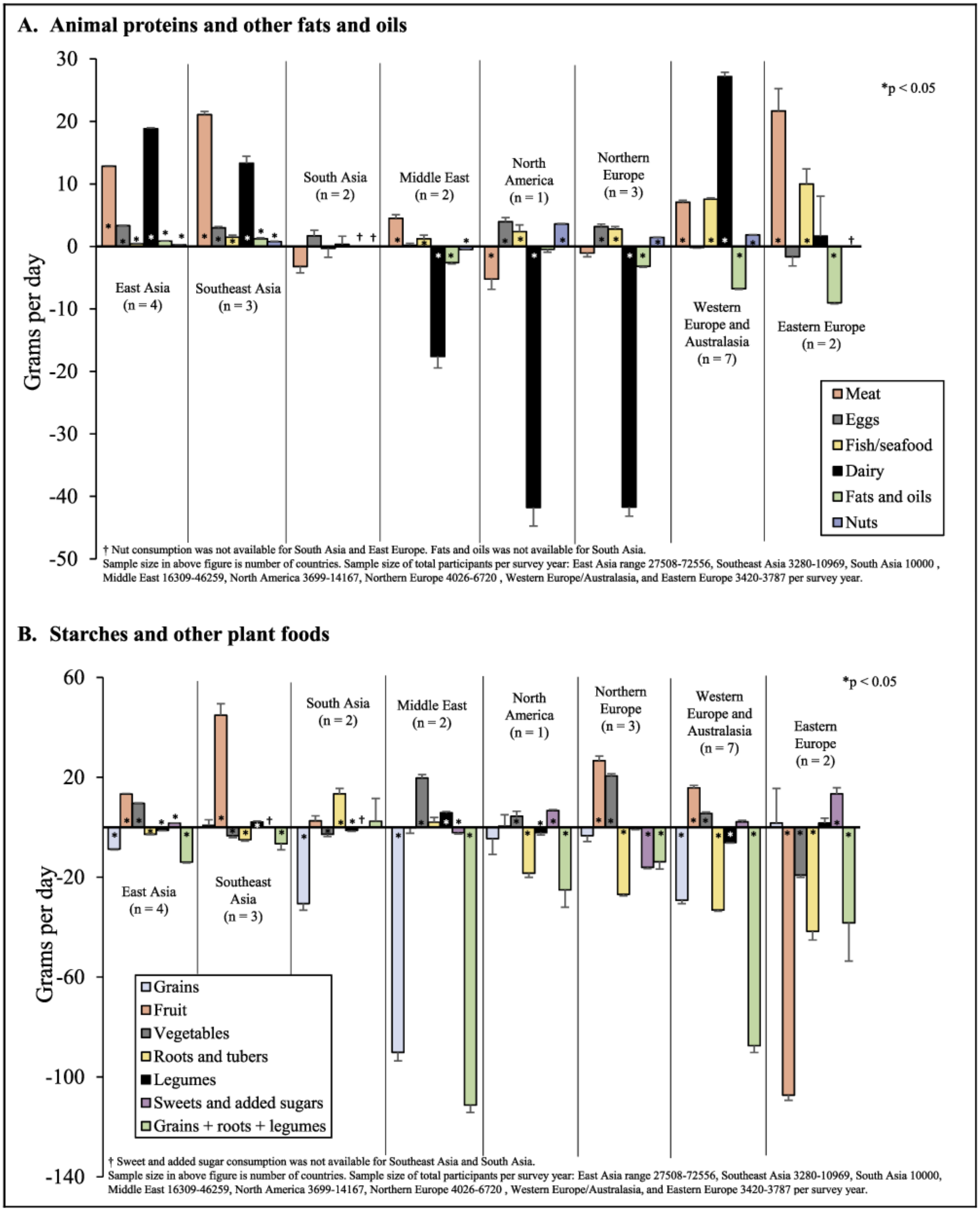

Fig. 4. Change (SE) in food intakes, per decade, by region, 1950–2019, adjusted for median age over time, method of dietary assessment, and initial year of collection. Foods not available for Latin America.

by increasing animal fat intake [23]. However, both supply- and individual-level data have found that the growing consumption of seed and vegetable oils contributes more energy than that of meat or animal fats [23]. The increased consumption of animal protein may be important for reducing iron deficiency, increasing lean muscle mass, and increasing intakes of priority micronutrients (e.

g., iron, zinc, vitamin A, and vitamin B_{12}) in the diet [24–26]. Despite decreased carbohydrate intake over time, many populations in Asian countries, including India, the Philippines, and Vietnam, who consumed 69% to 75% of energy from carbohydrate, would benefit from further reductions in carbohydrate intake. Both the Prospective Urban Rural Epidemiolog study of 135 335 individuals in 18 low-, middle-, and high-income countries and the Atherosclerosis Risk in Communities study of 15 428 individuals in the United States found that consuming >60% of energy from carbohydrate was associated with higher mortality [27,28]. In South and Southeast Asia, where egg consumption is low (<2 eggs/wk), a serving of eggs, in lieu of a serving of grains, may be one approach to reduce carbohydrate intake with a nutrient-dense and affordable food [29].

Across all regions in this review, intakes of fruits, vegetables, roots and tubers, legumes, and nuts were below optimal intakes or current recommendations (Table 2) [30–34]. Recent meta-analyses found that intakes of 200 to 300 g/d (2 to 3 servings/d) of fruit and

Table 2
Recommended intakes of nutrients and key foods, and regions meeting recommendations based on average daily intakes estimated in this review

	Recommended daily intake (USDA and WHO)	Regions where intakes align with, are above, or are below nutrition recommendations (average daily intake in 2000s, estimated based on results of this systematic review)
Energy*	~2250 kcal/d [54]	**Intakes align with recommendation:** Latin America (2169.3 kcal), Western Europe and Australasia (2116.5 kcal), South Asia (2109.7 kcal), Middle East (2079.7 kcal), Northern Europe (2059.2 kcal), East Asia (2087.6 kcal), North America (2014.6 kcal), and Southeast Asia (1956.7 kcal) **Intakes above recommendation:** Eastern Europe (2287.9 kcal)
Carbohydrate	45–65% total energy [54]	**Intakes align with recommendation:** Southeast Asia (61.9%), Latin America (59%), Eastern Europe (56.5%), East Asia (56.3%), Middle East (54.3%), Western Europe and Australasia (47.2%), North America (46.9%), and Northern Europe (45.9%) **Intakes above recommendation:** South Asia (68.9%)
Fat	<30% total energy [55] 20–35% total energy [56]	**Intakes align with recommendation:** North America (34.5%), Middle East (33%), Eastern Europe (33.3%), East Asia (27.4%), Latin America (26.7%), Southeast Asia (23.3%), and South Asia (20.3%) **Intakes above recommendation:** Northern Europe (37.2%) and Western Europe and Australasia (35.2%)
Protein	10–35% total energy [54]	**Intakes align with recommendation:** Western Europe and Australasia (16.2%), North America (16.1%), Northern Europe (15.6%), Middle East (14.9%), East Asia (14.3%), Southeast Asia (13.9%), Latin America (13.1%), Eastern Europe (11.9%), and South Asia (10.8%)
Saturated fat†	<10% total energy [54,55]	**Intakes align with recommendation:** Middle East (10.0%) and East Asia (7.5%) **Intakes above recommendation:** Eastern Europe (13.9%), Northern Europe (13.8%), Western Europe and Australasia (13.4%), Southeast Asia (12.1%), and North America (12.0%)
Meat (red meat, poultry)	26 oz Eq/wk (105.3 g/d)[54]	**Intakes above recommendations:** Eastern Europe (157.0 g), Western Europe and Australasia (152.8 g), and Northern Europe (127.6 g) **Intakes below recommendation:** North America (95.0 g), Southeast Asia (86.7 g), East Asia (78.2 g), Middle East (59.4 g), and South Asia (24.9 g)
Eggs	≤1 egg/d (~50 g/d) [57]	**Intakes align with recommendation:** Eastern Europe (32.0 g), North America (31.9 g), East Asia (29.2 g), Western Europe and Australasia (23.8 g), Northern Europe (20.7 g), Southeast Asia (13.8 g), Middle East (7.6 g), and South Asia (7.0 g)
Fish and seafood	8–10 oz/wk (30.4–40.5 g/d) [54]	**Intakes above recommendations:** Southeast Asia (80.1 g), Western Europe and Australasia (49.9 g), East Asia (47.2 g) **Intakes below recommendations:** North America (19.9 g), Northern Europe (16.4 g), Middle East (14.9 g), Eastern Europe (13.0 g), and South Asia (6.0 g)
Dairy‡	3 cups Eq/d (150–750 g/d) [54]	**Intakes align with recommendations:** Western Europe and Australasia (326.2 g), Northern Europe (299.2 g), North America (261.6 g), Eastern Europe (223.0 g), Middle East (180.8 g), and Southeast Asia (156.6 g) **Intakes below recommendations:** South Asia (128.0 g) and East Asia (90.6 g)
Added fats and oils	27–31 g/d [54]	**Intakes above recommendations:** Western Europe and Australasia (41.9 g), Eastern Europe (40.9 g), North America (34.9 g), and South Asia (33.0 g) Intakes below recommendations: Middle East (21.0 g), Northern Europe (20.9 g), East Asia (19.5 g), and Southeast Asia (10.9 g)
Nuts and seeds	5 oz/wk (20.2 g/d) [54]	**Intakes below recommendations:** Middle East (9.4 g), North America (8.0 g), Northern Europe (4.8 g), Western Europe and Australasia (4.7 g), East Asia (4.6 g), and Southeast Asia (3.5 g)
Fruit§	2 cups Eq/d (~250–360 g/d) [54]	**Intakes below recommendations:** Eastern Europe (226.8 g), Western Europe and Australasia (221.5 g), North America (181.8 g), Northern Europe (133.8 g), East Asia (130.5 g), Middle East (99.3 g), Southeast Asia (62.4 g), and South Asia (15.0 g)
Vegetables¶	2 cups Eq/d (~140–350 g/d) [54]	**Intakes align with recommendation:** Eastern Europe (293.7 g), North America (268.6 g), Middle East (242.5 g), East Asia (242.1 g), Western Europe and Australasia (198.5 g), Southeast Asia (141.9 g), and Northern Europe (141.8 g) **Intakes below recommendations:** South Asia (72.0 g)
Fruits and vegetables	At least 400 g/d (i.e., 5 portions) [55]	**Intakes align with recommendation:** Eastern Europe (520.6 g), North America (450.4 g), and Western Europe and Australasia (420.0 g) **Intakes below recommendations:** East Asia (372.6 g), Middle East (341.8 g), Northern Europe (275.6 g), Southeast Asia (204.3 g), and South Asia (87.0 g)
Roots and tubers‖	6 cups Eq/wk (~110–170 g/d) [54]	**Intakes align with recommendation:** Eastern Europe (129.0 g) **Intakes below recommendations:** North America (101.6 g), Western Europe and Australasia (91.0 g), Northern Europe (72.3 g), East Asia (36.7 g), Middle East (35.3 g), Southeast Asia (28.6 g), and South Asia (17.0 g)
Legumes**	2 cup Eq/wk (52.9 g/d) [54]	**Intakes below recommendations:** East Asia (48.8 g), South Asia (38.0 g), Middle East (28.4 g), Southeast Asia (23.1 g), Northern Europe (16.8 g), North America (15 g), Western Europe and Australasia (10.9 g), and Eastern Europe (4.0 g)

(continued)

Table 2 (*Continued*)

	Recommended daily intake (USDA and WHO)	Regions where intakes align with, are above, or are below nutrition recommendations (average daily intake in 2000s, estimated based on results of this systematic review)
Grains (whole and refined)	~180–200 g/d [54,55]	**Intakes align with recommendation:** Northern Europe (184.0 g) and North America (118.7 g) **Intakes above recommendations:** South Asia (483.0 g), Middle East (402.2 g), Southeast Asia (361.0 g), East Asia (356.8 g), Eastern Europe (309.0 g), and Western Europe and Australasia (218.0 g)

Eq, equivalent; USDA, US Department of Agriculture 2020–2025 dietary guidelines for Americans; WHO, World Health Organization
Saturated fat intake not available in South Asia, nut consumption not available in Eastern Europe and South Asia, and sweets not available in Southeast and South Asia; types of fat and foods not available for Latin America

*Generally recommend ~2000 kcal/d for women and 2500 kcal/d for men, therefore assuming average intake of 2250 kcal/d as recommended [54].

†No specific recommendations for monounsaturated and polyunsaturated fat. Overall recommendation to consume unsaturated fat over saturated fat [55].

‡Dairy 3 cup Eq/d, where 1 cup Eq = 1 cup (250 g) milk, 1 cup (125–170 g) yogurt, or 50 g cheese (range 150–750 g/d) [54,58].

§Fruit 2 cup Eq/d, where 1 cup Eq = 1 cup raw or cooked fruit, where 1 cup typically ranges from 125 to 180 g; therefore, 2 cup Eq/d ranges from 250 to 360 g/d. For example, 1 cup banana (150 g), 1 cup grapes (150 g), 1 cup watermelon (155 g), 1 cup apple (125 g), 1 cup pear (125 g), 1 cup orange (180 g), 1 cup mango (165 g), and 1 cup guava (165 g) (portion sizes from FoodData Central) [58].

¶Vegetables, fresh or raw, excluding roots and tubers, and legumes. Vegetables recommended at 2 cups Eq/d, where 1 cup Eq = 1 cup raw or cooked vegetables or 2 cups leafy salad greens; therefore, 2 cup Eq/d typically range from 140 to 350 g/d. Portion sizes of common vegetables: 1 cup cooked cabbage (155–175 g), 1 cup cooked Chinese broccoli (88 g), 1 cup cooked egglant (95 g), 1 cup cooked broccoli (160 g), 1 cup raw carrots (120 g), 1 cup cooked carrots (155 g), 1 cup cooked beets (170 g), and 2 cups raw romaine lettuce (70 g) (portion sizes from FoodData Central) [58].

||One cup roots and tubers can range between 130 and 200 g, and at recommended 6 cup Eq/wk this results in recommendation of ~111.4–171.4 g/d (1), for example, 1 cup cooked plantain (170 g), 1 cup mashed sweet potato (200 g), 1 cup boiled potato (160 g), 1 cup baked potato (130 g), 1 cup cooked taro (160 g), and 1 cup cooked yam (153 g) (portion sizes from FoodData Central) [58].

**One cup cooked legumes typically 185 g, and at recommended 2 cup Eq/wk this results in recommendation of 52.9 g/d of legumes (1), for example, 1 cup chickpeas (185 g), 1 cup lentils (185 g), 1 cup black beans (185 g), 1 cup kidney beans (185 g), 1 cup mung beans (185 g), 1 cup pinto beans (185 g), 1 cup fava bean (185 g), 1 cup split pea (185 g), and 1 cup soybeans (185 g) (portion sizes from FoodData Central) [58].

>400 g/d (>5 servings/d) of vegetables were associated with lower risks of stroke, CVD, cancer, and mortality [30,31]. In our review, fruit and vegetable consumption combined ranged from 87 g/d in South Asia to 521 g/d in Eastern Europe. Although still below optimal intakes, encouraging trends of higher intakes of fruit and vegetables in East and Southeast Asia, the Middle East, Northern Europe, and Western Europe and Australasia were observed. Increasing fruit and vegetable intake to the recommended 600 to 800 g/d may not be feasible for all countries, particularly lower-income countries, where fruits and vegetables may be unaffordable; however, a modest increase to 3 servings/d (375 g/d) has been found to lower the risk of mortality [35,36]. Previous meta-analyses also found that consuming >80 g/d of legumes was associated with significant decreases in CVD, coronary heart disease, hypertension, obesity, and mortality [32,33]. In our review, consumption of legumes slightly increased in Southeast Asia and the Middle East (to 20–30 g/d) but remained stable in East and South Asia (40–50 g/d), North America, and Northern and Eastern Europe (<15 g/d). Nut consumption was <10 g/d in all regions, with small increases (≤3 g/d/decade) in most regions. Our results found that nut consumption was below optimal intakes (5 oz/wk or 20.2 g/d), for reducing risk of CVD and mortality [34]. Although predominant in lower-income countries, micronutrient inadequacy remains a concern in higher-income countries, for instance, about one-third of the United States population are at risk of vitamin deficiency or are anemic [37–39]. An increase in fruits, vegetables, roots and tubers, legumes, and nuts could alleviate some of this burden [38,39]. However, several interventions focused on increasing availability, reducing waste without increasing consumer cost, and food fortification are warranted to achieve this goal [39,40]. These interventions are particularly important for lower-income countries but also for several higher-income countries where affordability is a concern. For example, the price of fruit in Japan is almost double that of the United States or Italy [41].

In our study, intakes of fruit and vegetables did not decrease in most regions, with little change to nut and legume intakes over time. The Global Dietary Database (GDD) and Global Burden of Disease study estimate that poor diet was responsible for 22% of all deaths among adults in 2010, increasing to 26% (12 million deaths) in 2018 [1,42]. Although fruit intake increased over time in most regions in our study, in the Global Burden of Disease study, globally, 4.5% of all premature deaths were attributable to diets low in fruit (<250 g/d) in 2018, up from 4.1% in 2010 [42]. Between 2010 and 2018, the burden of mortality from diets low in fruit increased the most in Oceania (2.7–3.6%), Asia (5.2–5.6%), and Africa (2.3–2.9%) [42]. Diets low in legumes (<60 g/d) were responsible for 1.9% of premature deaths in 2010, increasing to 2.1% in 2018, with the largest increases in Africa (1.1–1.4%) and Asia (2.1–2.3%) [42]. There was little change to the burden of mortality from diets low in vegetables (2.5–2.6%) and low in nuts and seeds (1.5–1.4%) between 2010 and 2018 [42]. Future work is needed to assess associations between dietary changes and changes in non-communicable disease rates in different world regions.

Our findings in Eastern Europe offer insight into diet changes in a state recently postwar (i.e., dissolution of the Soviet Union), evident by the variation in trends compared with Northern and Western Europe. Consistent with previous reports of historical patterns postwar, Eastern Europe increased consumption of meat, fish, and sugar, and reduced consumption of starchy staples (e.g., roots and tubers) [43,44]. This may be explained largely by the increased production, processing, and marketing of animal-source foods as well as the increased affordability of these foods [43,44]. Typically, fruit and vegetable consumption also increases as socioeconomic position improves, but our review observed decreasing trends of fruit and vegetable intake in Eastern Europe [43,44]. Extra disposable income is typically spent on food containing higher protein and fat (e.g., meats, fish, and processed foods), which may partly explain why meat and fish increased in Eastern Europe and was prioritized over further increasing fruit and vegetable intake [45–47].

Overall, our findings are consistent with trends estimated by the GDD between 1990 and 2018 (Supplementary Table 8) [48–51]. For example, both studies found decreased carbohydrate and meat intake in Southeast, East, and South Asia, decreased SFA intake in North America and Europe and Eastern Europe, increased protein and MUFAs consumption in Southeast Asia, and increased fish and nut consumption in all regions (Supplementary Table 8). Variations between our study and the GDD estimates may reflect differences in study time periods (GDD starts from 1990), the composition of countries within each region, the number and type of nutrition surveys included, the methods to harmonize the surveys, and different modeling techniques.

This study has several strengths and some potential limitations. Between studies, dietary trends were assessed at different time points, using various dietary assessment methods and sampling procedures. Within a study, the dietary assessment may change over time, as additional food items are added to questionnaires, food composition tables and databases, and the food supply. However, our findings were robust to sensitivity analysis by method of dietary assessment, population type, study design, and risk of bias. Although we searched peer-reviewed literature and various gray literature and contacted experts, we may have missed additional dietary trend data that were not publicly available. When examining results of this study by region, generalizability may be reduced as countries where dietary trend data were not available are not reflected in estimates. There are several lower-income countries and countries in Latin America, the Caribbean, the Middle East, and Africa that were not included in this review based on lack of individual-level data, highlighting the need for better national surveillance of dietary trends in these regions. Although we were able to examine data on energy, macronutrients, and key foods, many studies did not report consumption of ultra-processed foods and other foods eaten away from home, but previous studies of ultra-processed food and drink sales have examined these trends [52,53]. Most studies did not provide details on key foods groups (e.g., refined grains versus unrefined grains and skim milk versus whole milk). Despite these limitations, our work comprehensively compiled individual-level trends in dietary intakes across 47 countries, largely from national studies on energy, macronutrients, and key foods. We were also able to examine if changes in country income alter dietary trends as well as estimate variations in trends between higher- and lower-income groups. The GDD, which used bayesian methods to estimate intakes in countries where data were limited or not available, can be referenced for additional trend data [48].

Conclusions

Our findings indicate notable differences in dietary change over time across different world regions, with persistently higher intakes of carbohydrate in regions with lower GDP, despite decreases in carbohydrate consumption over time. Intakes of fruits, nuts, legumes, dairy, and starchy vegetables remain below recommendations in most world regions. Our findings help to identify countries where excessive carbohydrate consumption remains present, which would benefit from nutritional policies aimed at decreasing lower-quality carbohydrate foods and increasing consumption of fruits, vegetables, nuts, legumes, and dairy.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.nut.2022.111941.

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Supplementary Appendix

Supplement to: Changes in energy, macronutrient, and food consumption in 47 countries over the last 70 years (1950-2019): a systematic review and meta-analysis

Table of Contents

Supplementary Table S1. Search strategy, MEDLINE, EMBASE and CINAHL

Source	Search Strategy
MEDLINE (via OVID Medline Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE(R) Daily and Ovid MEDLINE(R) 1946 to 2019)	1. exp dietary fats/ or exp fats, unsaturated/ 2. exp Dietary Proteins/ 3. exp Dietary Carbohydrates/ 4. exp Energy Intake/ 5. exp diet/ 6. 1 or 2 or 4 or 5 7. (trend or trends or transition or transitions).ti,ab. 8. 6 and 7 9. ((food or foods or diet or dietary or diets or nutrient$ or nutrition or nutritional or calorie$ or carbohydrate$ or fats or fat or protein or proteins or macronutrient$ or dairy or milk or cheese or cream or yogurt or yoghurt or lard or butter or margarine or oil or oils or pork or chicken or poultry or beef or lamb or mutton or meat or meats or sausage$ or fruit$ or porridge$ rice or wheat or grain$ or bread$ or pasta or cereal$ or potato$ or yam$ or cassava or taro or corn or maize or vegetable$ or egg or eggs or legume$ or pulse$ or beans or bean or nuts or nut or seed or seeds or fish or seafood or sugar or sugars or dessert$ or confectioner$ or sweet$ or beverage$ or soda or pop or cola or soft drink$ or sugary drink$ or tonic) adj3 (trend or trends or transition or transitions)).ti,ab. 10. 8 or 9
EMBASE (via Ovid 1974 to 2019)	1. exp carbohydrate diet/ or exp carbohydrate intake/ 2. exp caloric intake/ 3. exp fat intake/ 4. exp diet/ 5. (trend or trends or transition or transitions).ti,ab. 6. 1 or 2 or 3 or 4 7. 5 and 6 8. ((food or foods or diet or dietary or diets or nutrient$ or nutrition or nutritional or calorie$ or carbohydrate$ or fats or fat or protein or proteins or macronutrient$ or dairy or milk or cheese or cream or yogurt or yoghurt or lard or butter or margarine or oil or oils or pork or chicken or poultry or beef or lamb or mutton or meat or meats or sausage$ or fruit$ or porridge$ rice or wheat or grain$ or bread$ or pasta or cereal$ or potato$ or yam$ or cassava or taro or corn or maize or vegetable$ or egg or eggs or legume$ or pulse$ or beans or bean or nuts or nut or seed or seeds or fish or seafood or sugar or sugars or dessert$ or confectioner$ or sweet$ or beverage$ or soda or pop or cola or soft drink$ or sugary drink$ or tonic) adj3 (trend or trends or transition or transitions)).ti,ab. 9. 7 or 8
CINAHL (via EBSCO host, 1981-2019)	1. (MH "Dietary Fats+") OR (MH "Fats, Unsaturated+") OR (MH "Dietary Carbohydrates+") OR (MH "Energy Intake") OR (MH "Food Intake+") OR (MH "Diet"+) OR (MH "Dietary Proteins+") 2. TI ((trend or trends or transition or transitions)) OR AB ((trend or trends or transition or transitions)) 3. (MH "Trend Studies") 4. 2 or 3 5. 1 and 4 6. TI ((food or foods or diet or dietary or diets or nutrition or nutritional or calorie$ or carbohydrate$ or fats or fat or protein or proteins or calorie$ or macronutrient$ or dairy or meat or meats or fruit$ or grain$ or cereal$ or vegetable$ or egg or eggs or legume$ or fish)) OR AB ((food or foods or diet or dietary or diets or nutrition or nutritional or carbohydrate$ or fats or fat or protein or proteins or consume or consumption or macronutrient$ or dairy or meat or meats or fruit$ or grain$ or cereal$ or vegetable$ or egg or eggs or legume$ or fish or beverage$ or soda or pop or cola or soft drink$ or sugary drink$ or tonic)) 7. 3 and 6 8. TI ((food or foods or diet or dietary or diets or nutrition or nutritional or calorie$ or carbohydrate$ or fats or fat or protein or proteins or calorie$ or macronutrient$ or dairy or meat or meats or fruit$ or grain$ or cereal$ or vegetable$ or egg or eggs or legume$ or fish) N3 (trend or trends or transition or transitions or change or changes or changing)) OR AB ((food or foods or diet or dietary or diets or nutrition or nutritional or carbohydrate$ or fats or fat or protein or proteins or consume or consumption or macronutrient$ or dairy or meat or meats or fruit$ or grain$ or cereal$ or vegetable$ or egg or eggs or legume$ or fish or beverage$ or soda or pop or cola or soft drink$ or sugary drink$ or tonic) N3 (trend or trends or transition or transitions or change or changes or changing)) 9. 5 or 7 or 8

The Head of Systems & Public Services and Coordinator of Research and Graduate Education Support at the McMaster University Health Sciences Library was consulted when building search strategy.

Supplementary Table S2. List of key organizations searched, resources reporting trends in energy, macronutient, and/or food intakes

Global or multinational

1. The Food and Agriculture Organization of the United Nations https://www.fao.org/home/en
2. Organisation for Economic Co-operation and Development https://data.oecd.org/
3. World Food Program https://www.wfp.org/
4. The World Bank https://www.worldbank.org/en/topic/health/publication/nutrition-country-profiles
5. World Health Organization https://www.who.int/health-topics/nutrition
6. Centre for Disease Control and Prevention https://www.cdc.gov/
7. UNSCN https://www.unscn.org/
8. CGIAR https://www.cgiar.org/
9. Eldis https://www.eldis.org/
10. Global Forum on Agricultural Research and Innovation https://www.gfar.net/
11. Global Alliance for Improved Nutrition https://www.gainhealth.org/homepage
12. Nutrition International https://www.nutritionintl.org/
13. National Institute of Agricultural Economics and Policy Research https://niap.icar.gov.in/contact.html
14. Project Concern International https://www.pciglobal.org/
15. International Food Policy Research Institute https://www.ifpri.org/
16. Institute for Agriculture and Trade Policy https://www.iatp.org/
17. International Food Information Council https://ific.org/
18. Health Research Web https://healthresearchweb.org/en/home
19. Global Dietary Database, The Global Nutrition and Policy Consortium https://globaldietarydatabase.org/
20. World Public Health Nutrition Association WPHNA https://worldnutritionjournal.org/index.php/wn
21. Global Nutrition Report https://globalnutritionreport.org/
22. The Food and Nutrition Technical Assistance III Project (FANTA) https://www.fantaproject.org/research
23. INFORMAS (International Network for Food and Obesity / Non-communicable Diseases (NCDs) Research, Monitoring and Action Support https://www.informas.org/countries/
24. Demographic and Health Surveys Program https://www.dhsprogram.com/
25. Global Hunger Index https://www.globalhungerindex.org/trends.html
26. Aga Khan Development Network https://www.akdn.org/
27. Statistics for Development Division https://sdd.spc.int/all-countries
28. Humanitarian Data Exchange (multinational) https://data.humdata.org/

Americas (North America, South/Latin America, Caribbean)

1. United States Department of Agriculture (United States) https://www.usda.gov/
2. United States Department of Agriculture, National Agricultural Statistics Service (United States) https://www.nass.usda.gov/
3. National Institute of Health (United States) https://www.nih.gov/
4. American Society for Nutrition (United States) https://nutrition.org/?s=trends
5. Canadian Agriculture and Food Industry Association (Canada) https://agriculture.canada.ca/en
6. Government of Canada (Canada) https://www.canada.ca/en.html
7. Statistics Canada (Canada) https://www.statcan.gc.ca/en/start
8. Dieticians of Canada (Canada) https://www.dietitians.ca/
9. Canadian Nutrition Society (Canada) https://cns-scn.ca/
10. Institute of Nutrition, Metabolism and Diabetes, CIHR (Canada) https://cihr-irsc.gc.ca/e/13521.html
11. Canadian Public Health Association (Canada) https://www.cpha.ca/
12. Pan American Health Organization (multinational) https://iris.paho.org/handle/10665.2/2956
13. Caribbean Epidemiology Center (CAREC) https://iris.paho.org/handle/10665.2/2961
    a) Caribbean Food and Nutrition Institute (CFNI) https://iris.paho.org/handle/10665.2/2969
    b) Latin American and Caribbean Center on Health Sciences (BIREME) https://iris.paho.org/handle/10665.2/2957
    c) Latin American Center for Perinatology, Women and Reproductive Health (CLAP) https://www.paho.org/en/latin-american-center-perinatology-women-and-reproductive-health-clap
    d) Caribbean Public Health Agency https://carpha.org/
14. The Government of Anguilla (Anguilla) http://www.gov.ai/statistics.htm
15. Ministry of Health (Antigua and Barbuda) https://ab.gov.ag/detail_page.php?page=29
16. Ministry of Health (Argentina) https://www.argentina.gob.ar/salud
17. Aruba Government (Aruba) https://www.government.aw/
18. Ministry of Health and Wellness (Bahamas) https://www.bahamas.gov.bs/wps/portal/public/Health%20Statistics/Health%20Statistics/
19. Barbados Information Service (Barbados) https://gisbarbados.gov.bb/blog/tag/caribbean-public-health-agency/
20. Ministry of Health (Barbados) https://www.gov.bb/Ministries/health
21. Government of Bermuda (Bermuda) https://www.gov.bm/
22. Ministry of Health (Brazil) https://bvsms.saude.gov.br/
23. Ministry of Health (Cayman Islands) https://www.gov.ky/news/press-release-details/dg-census-message-to-civil-service
24. Ministry of Health (Chile) https://www.gob.cl/en/ministries/ministry-of-health/ and https://www.minsal.cl/
25. Ministry of Health and Social Protection of Colombia (Colombia) https://www.minsalud.gov.co/English/Paginas/inicio.aspx
26. Ministry of Health (Costa Rica) https://www.ministeriodesalud.go.cr/
27. Ministry of Health (Cuba) https://salud.msp.gob.cu/language/en/welcome-to-the-official-website-of-the-ministry-of-public-health/
28. Government of Dominica (Dominica) https://dominica.gov.dm/
29. Ministry of Health (Ecuador) https://www.salud.gob.ec/
30. Ministry of Health (El Salvador) https://www-salud-gob-sv.translate.goog/?_x_tr_sl=es&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=nui,sc
31. Falkland Islands Government Public Health (Falkland Islands) https://fig.gov.fk/publichealth/ and https://www.fig.gov.fk/health/

32. Ministry of Health (Guyana) https://www.health.gov.gy/ and Department of Public Health https://dpi.gov.gy/
33. Bureau of Statistics of Guyana (Guyana) https://statisticsguyana.gov.gy/subjects/demography-vital-and-social-statistics/nutrition-guyana-2013-to-2017/
34. National Portal of the Government of Grenada (Grenada) https://gov.gd/
35. Ministry of Health (Guadeloupe) https://dpi.gov.gy/tag/guadeloupe/
36. Ministry of Health (Guatemala) https://www.mspas.gob.gt/
37. Ministry of Public Health and Population of Haiti (Haiti) https://www.mspp.gouv.ht/
38. Government of Honduras (Honduras) http://www.salud.gob.hn/site/
39. Ministry of Health & Wellness (Jamaica) https://www.moh.gov.jm/
40. Statistical Institute of Jamaica (Jamaica) https://statinja.gov.jm/Demo_SocialStats/Health.aspx
41. Jamaica Information Service (Jamaica) https://jis.gov.jm/information/get-the-facts/get-the-facts-understanding-nutrition-labels/
42. Secretariat of Health (Mexico) https://www.gob.mx/salud/en
43. National Public Health Institute (Mexico) https://www.insp.mx/insp-overview.html
44. Ministry of Health (Nicaragua) http://www.minsa.gob.ni/
45. Ministry of Health (Panama) http://www.minsa.gob.pa/
46. Ministry of Public Health and Social Welfare (Paraguay) https://www.mspbs.gov.py/index.php
47. Puerto Rico Department of Health (Puerto Rico) https://www.salud.gov.pr/
48. Government of Saint Kitts and Nevis (Saint Kitts and Nevis) https://www.gov.kn/
49. Government of Saint Lucia (Saint Lucia) http://www.govt.lc/ and http://health.govt.lc/
50. Ministry of Public Health (Saint Martin) http://www.sintmaartengov.org/GOVERNMENT/VSA/Pages/default.aspx and https://stmaartenehas.com/
51. Ministry of Health, Wellness and the Environment (Saint Vincent and the Grenadines) http://www.health.gov.vc/health/ and https://www.gov.vc/
52. Ministry of Health (Suriname) https://health.gov.sr/
53. Ministry of Health (Trinidad and Tobago) https://health.gov.tt/
54. Statistics Department Turks and Caicos Islands (Turks and Caicos Islands) https://www.gov.tc/stats/
55. Ministry of Health (Uruguay) https://www.gub.uy/ministerio-salud-publica/home

Asia and Pacific

1. Wellington: Ministry of Health (New Zealand) https://www.health.govt.nz/
2. The New Zealand Nutrition Foundation (New Zealand) https://nutritionfoundation.org.nz/about-us
3. Nutrition Australia (Australia) https://nutritionaustralia.org/
4. Australian Government, Department of Health and Australian Institute of Health and Welfare (Australia) https://www.awe.gov.au/ and https://www.aihw.gov.au/ and https://www1.health.gov.au/internet/main/publishing.nsf/Content/publications-Statistics
5. Australian Bureau of Statistics (Australia) https://www.abs.gov.au/statistics/health/health-conditions-and-risks/australian-health-survey-nutrition-first-results-foods-and-nutrients/latest-release
6. National Food and Nutrition Centre (Fiji) http://www.nutrition.gov.fj/
7. Ministry of Health & Medical Services (Fiji) http://www.health.gov.fj/publications/
8. Indian Council of Agricultural Research (India) https://icar.org.in/
9. National Institute of Nutrition Indian Council of Medical Research (India) https://www.nin.res.in/
10. Indian Diabetic Association (India) http://idaindia.com/
11. Nutrition Foundation of India (India) https://www.nutritionfoundationofindia.res.in/scientific-reports/
12. Badan Pusat Statistik (Indonesia) https://www.bps.go.id/
13. National Institute of Health and Nutrition (Japan) https://www.nibiohn.go.jp/eiken/
14. The Japan Diabetic Association (Japan) https://www.dietitian.or.jp/english/health/
15. Ministry of Health, Labour and Welfare (Japan) https://www.mhlw.go.jp/english/
16. Food and Nutrition Research Institute (Philippines) https://www.fnri.dost.gov.ph/index.php/19-nutrition-statistic/108-7th-national-nutrition-survey
17. Nutrition Center of the Philippines (Philippines) http://www.ncp.org.ph/
18. Philippine Statistics Authority (Philippines) https://psa.gov.ph/content/food-consumption-and-nutrition
19. Department of Health (Philippines) https://doh.gov.ph/search/node/nutrition
20. Health Promotion Board (Singapore) https://www.hpb.gov.sg/
21. Ministry of Public Health (Afghanistan) https://moph.gov.af/en/
22. Ministry of Health (Samoa) https://www.health.gov.ws/
23. Samoa Bureau of Statistics (Samoa) https://www.sbs.gov.ws/
24. The State Statistical Committee of the Republic of Azerbaijan (Azerbaijan) https://www.stat.gov.az/source/food_balances/?lang=en
25. Ministry of Health and Family Welfare (Bangladesh) http://www.mohfw.gov.bd/
26. Ministry of Health (Bhutan) https://www.moh.gov.bt/
27. The British Indian Ocean Territory Government website https://biot.gov.io/about/
28. Ministry of Health (Brunei Darussalam) http://www.moh.gov.bn/SitePages/Public%20Health.aspx
29. Ministry of Health of Cambodia (Cambodia) http://moh.gov.kh/?lang=en
30. National Institute of Public Health (Cambodia) https://niph.org.kh/niph/home/index.html
31. China National Nutrition Survey (China) https://www.cpc.unc.edu/projects/china
32. National Health Commission of the PRC (China) http://en.nhc.gov.cn/
33. Ministry of Health (China) http://www.china.org.cn/english/government/130468.htm
34. Te Marae Ora Cook Islands Ministry of Health (Cook Islands) https://www.health.gov.ck/
35. Guam Department of Public Health and Social Services (Guam) https://dphss.guam.gov/
36. Centre for Health Protection Department of Health (Hong Kong) https://www.chp.gov.hk/en/healthtopics/content/25/8800.html
37. Food and Health Bureau (Hong Kong) https://www.fhb.gov.hk/statistics/en/dha/dha_summary_report.htm
38. Department of Health (Hong Kong) https://www.dh.gov.hk/english/index.html
39. Ministry of Healthcare (Kazakhstan) https://www.gov.kz/memleket/entities/dsm?lang=en
40. Ministry of Health & Medical Services (Kiribati) https://mhms.gov.ki/

41. Kiribati National Statistics Office (Kiribati) https://nso.gov.ki/statistics/environment/food/
42. Ministry of Health and Welfare (South Korea) https://www.mohw.go.kr/eng/
43. Ministry of Health (Lao) https://moh-gov-la.translate.goog/?_x_tr_sl=lo&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=nui,sc
44. Ministry of Health (Malaysia) https://www.moh.gov.my/
45. Ministry of Health (Maldives) http://health.gov.mv/
46. Ministry of Health Republic Of Marshall Islands Majuro (Marshall Islands) https://rmihealth.org/
47. FSM Department of Health and Social Affairs (Federated States of Micronesia) https://hsa.gov.fm/health/ and https://www.fsmgov.org/index.html
48. Ministry of Health (Myanmar) https://www.mohs.gov.mm/page/7339
49. Ministry of Health (Nauru) http://naurugov.nr/government/ministries.aspx
50. Nepal Nutrition and Food Security Portal (Nepal) http://www.nnfsp.gov.np/
51. Ministry of Health and Population (Nepal) https://www.mohp.gov.np/eng/ and https://dohs.gov.np/
52. Nepal Public Health Association (Nepal) https://nepha.org.np/
53. Statistics Niue (Niue) https://niue.prism.spc.int/category/social/vital-statistics/
54. Ministry of National Health Services Regulations and Coordination, Government of Pakistan (Pakistan) https://nhsrc.gov.pk/
55. Ministry of Planning Development & Special Initiatives (Pakistan) https://www.pc.gov.pk/web/nutrition
56. National Institute of Health (Pakistan) https://www.nih.org.pk/
57. Ministry of Health (Palau) https://www.palaugov.pw/executive-branch/ministries/health/ and http://www.palauhealth.org/
58. Ministry of Health (Papua New Guinea) https://www.health.gov.pg/
59. Government of the Pitcairn Islands (Pitcairn Islands) https://www.government.pn/
60. Ministry of Health (Solomon Islands) https://solomons.gov.sb/ministry-of-health-medical-services/
61. National Statistics Office (Solomon Islands) https://www.statistics.gov.sb/
62. Medical Research Institute (Sri Lanka) http://www.mri.gov.lk/units/nutrition/survey-reports/
63. Department of Census and Statistics (Sri Lanka) http://www.statistics.gov.lk/Health/StaticalInformation
64. Ministry of Health (Sri Lanka) http://www.health.gov.lk/moh_final/english/ and https://hpb.health.gov.lk/en
65. Ministry of Health and Welfare (Taiwan) https://www.hpa.gov.tw/EngPages/Detail.aspx?nodeid=1077&pid=6201 and https://www.mohw.gov.tw/mp-2.html
66. Department of Health (Taiwan) https://english.doh.gov.taipei/Default.aspx
67. Government Portal of the Republic of China (Taiwan) https://www.taiwan.gov.tw/3866.php
68. Ministry of Health (Tajikistan) http://www.dushanbe.tj/index.php?lng=en&id=132
69. Ministry of Public Health (Thailand) https://ddc.moph.go.th/
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23. Ministère de la Santé Publique (Madagascar) http://www.sante.gov.mg/ministere-sante-publique/
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Supplementary Table S3. Risk of bias assessment scores, by country (n = 47)

Country	Selection	Comparability	Outcome	Total score
East Asia				
South Africa[1,2]	3	2	3	8 points (low risk of bias)
China[3–7]	3	2	3	8 points (low risk of bias)
Japan[8]	3	2	2	7 points (low risk of bias)
South Korea[9–12]	3	1.5	2	6.5 points (low risk of bias)
Taiwan[13]	3	1	2	6 points (low risk of bias)
South Asia				
India[14–16]	3	0.5	1.5	5 points (medium risk of bias)
Pakistan[17]	1	0.5	2	3.5 points (medium risk of bias)
Southeast Asia				
Indonesia[18–20]	3	1	2	6 points (low risk of bias)
Malaysia[21]	3	2	3	8 points (low risk of bias)
Philippines[22–24]	3	0.5	3	6.5 points (low risk of bias)
Singapore[25–28]	3	2	2	7 points (low risk of bias)
Thailand[29]	2.5	1	1	4.5 points (medium risk of bias)
Vietnam[30]	2.5	1	2	5.5 points (medium risk of bias)
Fiji[32,33]	2.5	0.5	1	4 points (medium risk of bias)
Middle East				
Iran[34]	3	2	2	7 points (low risk of bias)
Lebanon[35]	3	1.5	3	7.5 points (low risk of bias)
Morocco[36]	1	1	1.5	3.5 points (medium risk of bias)
Latin America				
Guatemala[37]	1.5	2	2	5.5 points (medium risk of bias)
Mexico[38,39]	2	2	3	7 points (low risk of bias)
Argentina[40]	1.5	2	3	6.5 points (low risk of bias)
Brazil[41,42]	1.5	1	3	5.5 points (medium risk of bias)
Costa Rica[43]	3	1	2	6 points (low risk of bias)
Chile[44]	2.5	1	2	5.5 points (medium risk of bias)
North America				
Canada[45–47]	3	2	3	8 points (low risk of bias)
United States[48–55]	3	2	3	8 points (low risk of bias)
Eastern Europe				
Russia[56,57]	3	1	3	7 points (low risk of bias)
Czech Republic[58,59]	2.5	1	2	5.5 points (medium risk of bias)
Poland[58–60]	2.5	1.5	1	5 points (medium risk of bias)
Slovak Republic[61]	3	1	2	6 points (low risk of bias)
Bulgaria[62]	3	1	2.5	6.5 points (low risk of bias)
Northern Europe				
Denmark[63,64]	3	2	1	6 points (low risk of bias)
Finland[65,66]	3	1	3	7 points (low risk of bias)
Ireland[67,68]	3	0.5	2	5.5 points (medium risk of bias)
Lithuania[69]	2	2	2	6 points (low risk of bias)
Norway[70–72]	2.5	0.5	1	4 points (medium risk of bias)
Sweden[73,74]	1.5	1.5	3	6 points (low risk of bias)
United Kingdom[75–80]	3	1	3	7 points (low risk of bias)
Estonia[81,82]	2	1	2	5 points (medium risk of bias)
Western Europe and Australasia (Australia and New Zealand)				
Germany[83,84]	2.5	2	2	6.5 points (low risk of bias)
Netherlands[85–87]	3	1	3	7 points (low risk of bias)
Switzerland[88]	3	2	2	7 points (low risk of bias)
Italy[89–94]	3	0.5	2	5.5 points (medium risk of bias)
France[95–98]	3	1.5	1	5.5 points (medium risk of bias)
Spain[99–102]	3	0.5	2	5.5 points (medium risk of bias)
Greece[103]	2	1	2	5 points (medium risk of bias)
Australia[104–106]	2.5	1.5	3	7 points (low risk of bias)
New Zealand[107–109]	3	1	2	6 points (low risk of bias)

The Newcastle-Ottawa Scale (NOS) risk of bias domains: Selection has 3 items, up to 3 points. Comparability has 2 items, up to 2 points. Outcome has 3 items, up to 3 points. Total possible score up to 8 points. Total number of points were converted into risk of bias assessments: 1-3 high risk of bias, 3.1-5.9 medium risk of bias, and 6-8 low risk of bias.

Supplementary Table S4. Data extraction form

Data item	**Articles…**
Title of paper	
Author(s)	
Journal	
Year of publication	
Year(s) of data conduction	
Study design	
Study location	
Sample size	
Age range and/or mean of participants	
Population type (e.g., nationally representative, community sample)	
Method of dietary assessment (e.g., food freqency questionnaire, 24-hour recall, diet records, household budget survey)	
Specific dietary exposures examined (e.g., energy, dairy, poultry)	
Operational definitions of dietary exposures (energy, macronutrients, and/or foods)	
Point estimates (consumption of energy, macronutrients, types of fat, and/or foods) at all time points	
Variables that study authors adjusted for in models	

Supplementary Table S5. Data standardization methodology

Energy intakes were converted to kcal, while all macronutrient intakes were expressed as a percentage of total energy. Food items were standardized to common definitions, in grams/day (Suppl. Table S4). Only food items that had comparable definitions across studies were included. Estimates of intakes only available stratified by age, sex, or urban/rural residence, were combined into a single average estimate, weighted by the sample size in each stratum. If not possible to combine estimates, the stratum with the most complete data was used. One survey or study reporting trends, with preference for those that are nationally representative, was selected per country, unless multiple surveys were standardized and combined in previous publication(s) or database(s). If multiple surveys were conducted in a single country, all surveys covering different time periods were included. If nationally representative surveys were not available, non-nationally representative surveys were selected to include as many years of data as possible. If trend data were only available in graphical format, a ruler was used to extract estimates.

Supplementary Table S6. Food group definitions

Food item	Unit	Main definition
Meat	g/day	Total meat, including chicken, beef, pork, mutton, game, bacon, salami, sausages, other processed meat To be separated into red meat, white meat, and processed meat if possible
Fish and seafood	g/day	Fish and seafood, including mackerel, shrimp, crab, oysters, octopus, etc.
Eggs	g/day	Eggs, including chicken, goose, duck, or quail eggs Unit will also be considered as eggs/day and eggs/week where 1 egg = 50 gram.
Dairy	g/day	Total dairy, including yoghurt, cheese, sour cream, cream cheese, buttermilk, milk, paneer, milk products, etc. Typically excludes: ice cream, non-dairy beverages To be separated into whole dairy vs low fat/skim dairy if possible.
Grains and cereals	g/day	Total grains and cereals, including rice, wheat flour, maize, pasta/noodles, breakfast cereals, crackers, millet, buckwheat, oats, rye, barley, sorghum, bulgur, etc.
Fruits	g/day	Total fruit intake, including fresh, frozen, cooked, canned, or dried fruit. Exclusions: fruit juice
Vegetables	g/day	Total vegetable intake, including fresh, frozen, cooked, canned, pickled. Exclusions: potatoes and other roots
Roots and tubers	g/day	Potatoes, yam, sweet potatoes, plantain, cassava, taro
Legumes and pulses	g/day	Total bean, legume, lentil, pulse intake, including fresh, frozen, cooked, canned, or dried. Typically excludes: nuts and seeds, tofu
Total starchy foods	g/day	Grains, cereals, roots and tubers, legumes, pulses
Nuts and seeds	g/day	Total nuts and seeds, including peanuts, tree nuts (e.g., walnuts, cashews), seeds (e.g., pumpkin seeds, sunflower seeds). Typically excludes: dried fruit
Added fats and oils	g/day	Butter, margarine, lard, vegetable/seed oils (soybean, canola, rapeseed, etc.), olive oil. To be separated into animal fats (butter, lard) and vegetable fats (seed oils, olive oil) if possible
Sweets and added sugars	g/day	Added sugars, ice cream, biscuits, pastries, candy, chocolate, cakes other confectionery. Typically excludes: fruit juice, sugar-sweetened beverages

Supplementary Table S7. Characterisitcs of studies and reports using individual-level dietary assessments, by region

Author, year, country	Data source	Study design	Sample size (% male)	Years of collection (total length)	Population age	Population type	Method of dietary assessment	Nutrients and food groups assessed	Adjustments
A. EAST ASIA (5 COUNTRIES)									
Wentzel-Viljoen et al., 2018, South Africa[1]	PURE-NWP-SA Study	Prospective cohort study	1154 (33.6%)	2005, 2010 (5 years)	35-70	Women and men, rural and urban Black South Africans in the North West Province, excluding those with energy > 7170 or < 717 kcal	FFQ	Energy, macronutrients, porridge, grains, vegetables, fruit, legumes, nuts/seeds, milk, animal protein, fats and oils, sugar/sweets, savoury snacks, alcohol	No
Steyn et al., 2016, South Africa, Cape Town[2]	BRISK Study and CRIBSA Study	Cross-sectional, randomly sampling frame based on BRISK Study, selected households, based on quotas for age and sex	544 (39.3%)	1990, 2009 (19 years)	19-64	Women and men, Black South Africans living in urban Cape Town (Langa, Gugulethu, Khayelitsha, Crossroads and Nyanga). Excluded pregnant or lactating women, those bedridden, on cancer treatment in last year, on TB treatment, antiretroviral therapy, or who lived in Cape Town < 3 months	24-hour recall using multiple pass method, same method used in both 1990 and 2009.	Energy, macronutrients, added sugar, types of fats (SFA, MUFA, PUFA)	Both surveys used the same sampling frame.
He et al., 2019, China[3]	China National Nutrition Surveys (CNNS)	Cross-sectional, stratified multi-stage cluster random sampling	Range 39008 to 58316 (45.9-49.7%)	1982, 1992, 2002, 2010-2012 (30 years)	20+	Nationally representative, men and women, covering 27-31 provinces (30-35% urban 1982-2002, 50% in 2010-2012)	1982: 5-day dietary record 1992+: 3 consecutive 24-hour recalls	Energy, macronutrients, SFA, PUFA	Calculated stratum-specific mean intakes, adjusted for total energy
Li et al. 2017, Shen et al., 2017, & CHNS website, China[4–6]	China Health and Nutrition Survey (CHNS)	Prospective household-based study, multi-stage random cluster design, including low, middle, and high-income rural/urban communities.	Range 6978 to 11892 across years 1989-2015 (48.0-49.3%)	1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011, 2015 (26 years)	CHNS raw data[5]: 18+ Li et al., 2017: 20+ Shen et al., 2017: 18+	Nationally representative, men and women in 9 provinces. Although prospective study, new households added if older households cannot participate. Li et al. excluded pregnant women.	3 consecutive 24-hour recalls and food weighing	Energy and macronutrients calculated from raw data[5]. Li et al: refined grain, SSB, red meat, processed meat, whole grains, dairy, nuts, fruits, vegetables, fish Shen et al: used for types of fat (SFA, MUFA, PUFA), dairy, eggs, animal and vegetable oils	Raw data: urban/rural, community. Li et al.: age, urban/rural, province, education, and occupation Shen et al.: age, area type
Wang et al., 2016, China[7]	Survey name(s) not reported	Cross-sectional, multi-stage, random cluster sample	17524 to 27442 (48.0-49.2%)	1986-1988, 2000-2004, 2008-2011 (25 years)	18+	Representative of men and women, urban and rural, in Tianjin (~11% of total population of China)	7-day consecutive diet record, (weighting)	For food not covered by CHNS studies: cereals, potatoes, legumes, vegetables, fruits	Intakes per reference person (man 60kg, 18 yr old)

Author, year, country	Data source	Study design	Sample size (% male)	Years of collection (total length)	Population age	Population type	Method of dietary assessment	Nutrients and food groups assessed	Adjustments
National Institute of Health and Nutrition Reports, Japan[8]	National Nutrition Survey (NNS) and the National Health Nutrition Survey (NHNS)	Cross-sectional surveys, multi-stage, stratified sampling, 5000-6000 households annually	About 15000 annually (% male NR)	Every year 1946-2018 (72 years)	All ages	Nationally representative, men and women, from 1948 onwards (excluding Okinawa until 1972), women and men.	1-day semi-weighed household dietary record	Energy, macronutrients, cereals, potatoes, sugars, beans, nuts, vegetables, fruit, seaweed, fish and shellfish, meats, eggs, milk and dairy products, oils and fats, sweets, condiments and beverages	Results weighted to compensate for difference in # of households
Kim et al., 2000, South Korea[9]	National Nutrition Survey	Cross-sectional, multistage cluster sampling with probability proportional to size	543 to 2000 house-holds, all member (% male NR)	1940, 1948, 1950, 1960, 1969, every 5 years 1970-1995 (55 years)	All ages	Nationally representative, non-institutionalized, women and men	2-day dietary record, weighted all food	Energy, macronutrients, cereals, legumes, potatoes, vegetables, fruits, seaweed, oils and fats, meat and poultry, eggs, fish, milk and dairy	No
Yun et al., 2017 & Song et al., 2019, South Korea[10,11]	The Korea National Health and Nutrition Examin-ation Survey	Cross-sectional, households selected based on multi-stage, stratified area probability on geographic area, age, and sex	Range 6526 to 17394 (40.7-46.4%)	1998, 2001, 2005, 2007-2009, 2010-2012, 2013-2015 (17 years)	Yun et al. 19+ Song et al. 19+	Nationally representative, men and women, non-institutionalized civilians aged 1 year and older (19+ for this study)	24-hour recall	Yun et al. energy, macronutrients, cereals, vegetables, fruit, meat, fish/shellfish, milk and products, and alcohol Song et al. types of fats (SFA, MUFA, PUFA)	Age standardized using the 2005 Korea Census population estimates
Lim et al., 2014, South Korea[12]	Survey name not reported	Prospective cohort study	Range 7177 to 13123 (52.2-56.6%)	1998-2010 (12 years)	20+	Participants from health examination center in Seoul, excluding energy <500 or >5000 kcal/day	FFQ	Energy, macronutrients, Meat, eggs, dairy, vegetables, kimchi, rice, bread, noodles, butter, margarine, potatoes, sugar, fruits, soda, fried foods	Age, sex, BMI, exercise
Pan et al., 2011, Taiwan[13]	Nutrition and Health Survey in Taiwan (NAHSIT)	Cross-sectional, multi-stage stratified, clustered, probability sampling	1993-1996: NS 2005-2008: 4655	1993-1996, 2005-2008 (15 years)	19+	Nationally representative, men and women, non-institutionalized, sampled over all 4 seasons to account for seasonal effects	24-hour recall and FFQ (for fats and oils)	Macronutrients, rice, wheat, bread, starches, vegetable and animal fats, poultry, red meat, fish, eggs, beans, dairy, vegetables, fruit, seaweed, SSB	Used weighted analyses to account for design effects

Author, year, country	Data source	Study design	Sample size (% male)	Years of collection (total length)	Population age	Population type	Method of dietary assessment	Nutrients and food groups assessed	Adjustments
B. SOUTH ASIA (2 COUNTIES)									
Misra et al., 2011 & Government of India, 2014, India[14,15]	National Sample Survey Organization (NSSO)	Cross-sectional, urban and rural villages selected	Between 4224 and 4436 (% male NR)	1972-1973, 1983-1984, 1993-1994, 1999-2000, 2004-2005 (33 years)	All ages	Nationally representative, women and men urban and rural population, all States, excluding Nagaland, Andaman, and Nicobar. Assumed that 59% rural, 41% urban over time (15)	Diet records (length not specified)	Energy, macronutrients, cereals (jowar, bajra, maize), pulses and pulse products, meat, fish, poultry, milk	No
Krishnas-wamy et al, 1997, India[16]	National Nutrition Monitor-ing Bureau's (NNMB) data	Cross-sectional, multistage sampling of 250 urban and 750 rural households per year per State	About 300,000 each year (% male NR)	1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1990, 1992, 1995 (20 years)	All ages	Urban and rural (75% rural), women and men in Andhra Pradesh, Gujarat, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Tamil Nadu, Uttar Pradesh, West Bengal, Orissa	1-day weighing method record in 80% of sample, 24-hour recall in 20%	Coarse cereals (jowar, bajra, ragi, maize), pulses and pulse products, vegetables, fruit	No
Bharmal 2000, Pakistan[17]	Micronu-trient Survey; National Nutrition Survey	Cross-sectional, conducted by National Institute of Health	8630 house-holds, ~10000 individ-uals (% male NR)	1976-1977, 1985-1987 (11 years)	All ages	Urban and rural	Quantitative food weighing	Cereals, wheat, rice, pulses, fats/oils, eggs, fish, meat, roots, vegetables, fruits, milk, sugar	No
C. SOUTHEAST ASIA (7 COUNTIES)									
Linando et al., 2018, Statistik Reports, Indonesia[18–20]	The National Socioecon omic Survey	Cross-sectional surveys	10000 to 315672 house-holds per year (NR)	1984, every 3 years 1990-2002, every year 2002-2021 (37 years)	All ages	Nationally representative, urban and rural, women and men	Interview with head of household (1 week consumption)	Energy, macronutrients, cereals, tubers, fish, meat, eggs and milk, vegetables, legumes, fruits, oil and fat, beverages, prepared food and beverages	No
Zainuddin et al., 2019, Malaysia[21]	Malay-sian Adult Nutrition Survey	Cross-sectional, Multi-stage, stratified sampling	2003: 2964 (53.3%) 2014: 1080 (52.9%)	2003, 2014 (11 years)	18-59	Nationally representative, men and women, non-institutionalized covering 6 zones (North, South, Central, East Coast, Sabah, Sarawak)	24-hour recall	Energy and macronutrients	No

Author, year, country	Data source	Study design	Sample size (% male)	Years of collection (total length)	Population age	Population type	Method of dietary assessment	Nutrients and food groups assessed	Adjustments
Pedro et al., 2006, FNRI report, Angeles-Agdeppa et al., 2019, Philippines[22–24]	National Nutrition Survey	Cross-sectional, multi-staged stratified sampling to represent all 80 provinces	Range 2280 to 8592 house-holds; 20749	1978, 1982, 1987, 1993, 2003, 2008, 2013 (35 years)	Pedro et al. & FNRI report age not specified Angeles-Agdeppa et al.: 19+	Nationally representative, urban and rural, men and women	Average of two non-consecutive 24-hour recalls	Energy, macronutrients cereals, starchy roots and tubers, sugars, fats and oils, meats, poultry, milk, eggs, fruits, vegetables, beans	No
Health Promotion Board, 1998, 2004 2010, 2018, Singapore[25–28]	National Nutrition Survey	Cross-sectional, sampling to be representative of sex, race, and age	1000 to 2377 (46.0-49.7%)	1998, 2004, 2010, 2018 (20 years)	18-69	Nationally representative for all ethnicities and ages. Malay and Indian people over-sampled	FFQ	Energy, macronutrients, types of fat, cereals, bread, noodles, meat, seafood, eggs, milk, yogurt/cheese, desserts, nuts, tofu, fast food and soft drinks	Standardised to the 2010 Census Singapore population
Chavasit et al., 2017, Thailand[29]	The National Food and Nutrition Survey and NHES	Cross-sectional, multi-stage, stratified random sampling	Not specified	1960, 1975, 1986, 1995, 2003, 2009 (49 years)	Prior to 1995: all ages 1995 and 2003: 15+ 2009: all ages	Nationally representative, women and men, military and civilian populations, non-nationalized, all ages (prior to 1995 and 2009), including pregnant and lactating women.	Prior to 1995: weighting method Post 1995: 24-hour recall	Energy, macronutrients, animal protein	No
Hop et al., 2003, Vietnam[30]	General Nutrition Survey	Cross-sectional, multi-stage, stratified sampling[31]	Not specified	1965, 1975, 1985, 1987, 2000 (35 years)	Not specified	Nationally representative, urban and rural, mothers and children	24-hour recall[31]	Energy, macronutrients , meats, fish, eggs and milk, fat/oil, rice, ripe fruits	No
Lako. 2001 & National Food and Nutrition Centre report, Fiji[32,33]	Longitud-inal Surveys in Naduri and National Nutrition Survey (NNS)	Naduri: longitudinal survey NNS: Cross sectional, two-stage cluster sampling, using probability proportionate to size using 1999 population	1952-1994: not specified 2004: 7372 (48.3%)	1952, 1963, 1994, 2004 (52 years)	All ages	1952 and 1963 in rural village Naduri 1994 onwards: Nationally representative, from North, East, West and Central Fiji, including 3 rural and 2 urban areas, all ethnicities	1952 and 1963: weighing method 1994 and 2004: 24-hour recall	Energy, macronutrients, staple crops, cereals, and sugar	No

Author, year, country	Data source	Study design	Sample size (% male)	Years of collection (total length)	Population age	Population type	Method of dietary assessment	Nutrients and food groups assessed	Adjustments
D. MIDDLE EAST (3 COUNTRIES)									
Aghayan et al., 2020, Iran[34]	Tehran Lipid and Glucose Study	Prospective study, multi-stage cluster random sampling	2215; 1242; 1833; 1218 (46.0-48.9%)	2006-2008, 2009-2011, 2012-2014, 2015-2017 (11 years)	18+ with complete dietary data for at least two waves	Men and women, representative of urban population of district 13 in Tehran. Exclusions: those who changed diet based on disease, under-or over-reporting of energy (±3 SD)	FFQ	Energy, macronutrients, refined grains, dairy, meat, solid fats, simple sugars, snacks and desserts	Age, sex, BMI, energy intake
Nasreddine et al., 2019, Lebanon[35]	National survey	Cross-sectional, stratified cluster sampling, by governorates (strata) and districts (clusters)	1997: 1063 (41.0%) 2008-2009: 2518 (45.1%)	1997, 2008-2009 (12 years)	20+	Nationally representative, men and women proportional to according to age, sex and district distribution	24-hour recall, multiple pass 5-step approach	Energy, macronutrients, cereals, bread, starches, vegetables, nuts and seeds, milk, meat, fish, eggs, fruit, fruit juice, sweets, SSB, alcohol, fats and oils	Sex, governorates, marital status, education, employment status
Benjelloun, 2002, Morocco[36]	National survey	Household Budget and Consumption surveys	1984/85: 41526 (47.8%) 1998/99: 14028 (49.0%)	1984-1985, 1998-1999 (15 years)	20+	Nationally representative, men and women urban and rural (40.0-46.6% rural)	Not reported, but typically household budget surveys examine $ spent on food	Cereals, vegetables, legumes, fruits, fats, sugar, dairy, eggs, meat, poultry, fish	No
E. LATIN AMERICA (6 COUNTRIES)									
Ford et al., 2018, Guatemala[37]	INCAP Nutrition Supple-mentat-ion Trial Longitu-dinal Cohort	Cluster Trial Longitudinal Cohort, people born in 1962–1977, received an intervention before age 7 of skimmed milk, sugar, vegetable protein (control: water, sugar)	810 (36.9%)	2002/2004, 2015/2017 (15 years)	37-54 with complete dietary data in both study waves	Rural adults in Eastern Guatemala, men and women, excluding pregnant or lactating women Although trial, intervention was not considered to impact dietary trends as they were assessed 30+ years later.	FFQ	Carbohydrates, fat, protein	no, cohort study
Rivera et al., 2002 & Stern et al., 2014, Mexico[38,39]	National Nutrition Survey	Cross-sectional, stratified sampling by region and rural/urban area	9101; 2649 (0% male), 10343 (48%)	1988, 1999, 2012 (24 years)	18-49 2012: 20-49	Nationally representative of women, urban and rural	24-hour recall	Energy, macronutrients SSB, milk	No

Author, year, country	Data source	Study design	Sample size (% male)	Years of collection (total length)	Population age	Population type	Method of dietary assessment	Nutrients and food groups assessed	Adjustments
De Piero et al., 2015, Argentina[40]	Name of study not specified	Cross-sectional	1998/99: 169 (27.8%) 2012/13: 160 (22.5%)	1998-1999, 2012-2013 (15 years)	Mean age 22.3±2.3 in 1998-1999 23.5±2.8 in 2012-2013	University National of Tucumán students in 3rd year of study in the Faculty of Biochemistry, Chemistry and Pharmacy.	FFQ	Energy and macronutrients	No
Monteiro et al., 1995, de Carvalho et al., 2014, Brazil[41,42]	Name of study not specified	Cross-sectional, multi-stage stratified clustering sampling	1974/75: 94699 (NR), 1987/88:2 3544 (NR), 2003: 2361 (48.9%), 2008: 1662 (43.4%)	Fat: 1961-1962, 1974-1975, 1987-1988 (27 years) Meat: 2003, 2008 (5 years)	Monteiro et al.: 25-64 de Carvalho et al.: 12+	Monteiro et al.: Nationally representative, including São Paulo, Curitiba, Rio de Janeiro, Belo Horizonte, Salvador, Recife, Fortaleza de Carvalho et al.: São Paulo	Monteiro et al.: Not specified de Carvalho et al.: two 24-hour recalls	Monteiro et al.: Fat de Carvalho et al.: meat	No
Blanco-Metzler et al., 2017, Costa Rica[43]	National House-hold Income and Expend-iture Surveys	Probabilistic sampling design using 348 and 468 strata (zone and region)	2004-2005: 4231 (NR) 2012-2013: 5705 (NR)	2004-2005, 2012-2013 (9 years)	All ages	Nationally representative, urban and rural, 4231 households in 2004-2005 (37.8% rural) and 5705 in 2012-2013 (26.8% rural)	Food purchased over 7 consecutive days	Energy	No
Albala et al., 2002, Chile[44]	National House-hold Surveys on Food Expend-iture	Not reported	Not reported	1988, 1998 (10 years)	All ages	Nationally representative, urban and rural	Food purchased	Energy and macronutrients	No

Author, year, country	Data source	Study design	Sample size (% male)	Years of collection (total length)	Population age	Population type	Method of dietary assessment	Nutrients and food groups assessed	Adjustments
F. NORTH AMERICA (2 COUNTRIES)									
Statistics Canada, 2017, Tugault et al., 2019 & Jones et al., 2019, Canada[45–47]	Canadian Comm-unity Health Survey	Cross-sectional, multi-stage stratified cluster sample, representative for age, sex, geography, SES	2004: 26565 (~50.0%) 2015: 16146 (50.0%)	2004, 2015 (11 years)	19+ Tugault et al.: 18+	Nationally representative, men and women, 1+ years old, living in the ten provinces. Exclusions: Indigenous peoples living on reserves, military, institutionalized, pregnant or breastfeeding women	24-hour recall, multiple pass	Statistics Canada: energy, macronutrients Tugault et al.: vegetables, Potatoes, fruit, fruit juices, grains, dairy, meat, fish and shellfish, legumes, nuts and seeds, eggs, processed meats, sweets (servings/day)Jones et al.: SSB and alcohol	Tugault et al.: energy intake, age, ethnicity, immigration status, education, supplement use, smoking status
Bleich et al., 2009, Ford et al. 2013, Yancy et al. 2014, Zeng et al., 2019, Marriott et al., 2019 & USDA Data Tables, 2021, Ernst et al., 1997, United States[48–55]	National Health and Nutrition Examin-ation Survey	Cross-sectional, multi-stage probability sample	Prior to 1998: 9872 to 14167 (38.50-56.2%) Post 1999: 3699 to 5762 (46.3-58.5%)	1971-1974, 1976-1980, 1988-1994, 1999-2000, 2001-2002, 2003-2004, 2005-2006, 2007-2008, 2009-2010, 2011-2012, 2013-2014, 2015-2016, 2017-2018 (47 years)	20+ Ford et al., Yancy et al. & Ernst et al.: 20-74	Nationally representative, men and women, non-institutionalized civilians	24-hour recall	Energy, macronutrients, SFA, MUFA, PUFA Foods available from USDA Data Tables: 1994-2008: dairy, fats and oils, grains, vegetables, roots/tubers, fruits, meat, eggs, fish, legumes, nuts, sweeteners Zeng et al. (1999-2016): meat, processed meat Bleich et al. & Marriott et al.: SSB	Yancy et al.: age, BMI, race, physical activity, marital status, education, employment, day of week of recall, dieting Ford et al., Bleich et al. & Marriott et al.: age
G. EASTERN EUROPE (5 COUNTRIES)									
Jahns et al., 2003 & Dellava et al., 2010, Russia[56,57]	Russian Longitu-dinal Monitor-ing Survey	Cross sectional, stratified 3- stage cluster (20 regions, 10 districts using probability proportional to size)	Range 8342 to 10670 (% male NR)	1992, 1993,1994, 1995,1996, 1998, 2000, 2001, 2002, 2003, 2004, 2005 (13 years)	Jahns et al.: 19-55 Dellava et al.: 25-55	Nationally representative, women and men, random sample of working-age adults. Each year same housing units were surveyed, if original occupant moved, both current and former residents interviewed	24-hour recall	Jahns et al.: energy, macronutrients Dellava et al. fat intake	No
Franz-Zunft et al., 1999 & Dofkova et al., 2001, Czech Republic[58,59]	House-hold budget survey of Czech Statis-tical Office	Household budget survey, 420 households each year	Not reported	1980-1997 (17 years)	All ages	Nationally representative, collection occurred over the full year	Diary of all foods bought for the household or obtained from own production over 1 month	Energy, macronutrients., meat, fish, milk, eggs, fats and oils, sugar, bread, cereals, pulses, potatoes, vegetables, fruit	No

Author, year, country	Data source	Study design	Sample size (% male)	Years of collection (total length)	Population age	Population type	Method of dietary assessment	Nutrients and food groups assessed	Adjustments
Franz-Zunft et al., 1999, Waśkiewicz et al., 2015, Poland[58–60]	Waśkiewicz et al: Pol-MONICA and WAW-KARD project (2012)	Franz-Zunft et al.: household budget survey Waśkiewicz et al: Cross-sectional, part of MONICA project, selected from electoral and population register	Franz-Zunft et al.: NR Waśkiewicz et al: 614 to 2552 (49.1-53.3%)	Franz-Zunft et al.: 1980-1989, 1990-1992, 1993-1997 Waśkiewicz et al: 1984, 1988, 1993, 2001, 2012 (28 years)	Franz-Zunft et al.: all ages Waśkiewicz et al: 35-64	Franz-Zunft et al.: nationally representative Waśkiewicz et al.: Representative of Warszawa (urban), men and women	Franz-Zunft et al.: foods purchased Waśkiewicz et al: 24-hour recall	Franz-Zunft et al.: carbohydrate, protein Waśkiewicz et al: energy, fat, SFA, animal fat	Waśkiewicz et al: age, season, smoking
Babinska et al., 2002, Slovak Republic[61]	Name of study not specified	Cross-sectional, selected at random from a telephone book and clubs for elderly	1991/94: 2368 (37.4%) 1995/99: 1650 (26.6%)	1991-1994, 1995-1999 (8 years)	19-80	Not nationally representative, but aimed to recruit a diverse age, SES groups, and men and women (from farms, schools, enterprises, state institutes, companies)	24-hour recall	Energy, macronutrients	No
Ivanova et al., 2006, Bulgaria[62]	National House-hold Budget Survey	Random sampling in census district, then random household selection	3000 house-holds, # of parti-cipants NR	1985-1990, 1991-2002 (17 years)	All ages	Nationally representative	Diary of all income spent on foods, measured 2x/ month/year	Energy, macronutrients, bread, oil, butter, lard, margarine, vegetables, fruits	No
H. NORTHERN EUROPE (8 COUNTRIES)									
Heitmann et al., 2000, Groth et al., 2014, Denmark[63,64]	Heit-mann et al.: Part of Danish MONICA project Groth et al.: DANSDA	Heitmann et al.: longitudinal, from a national register Groth et al.: simple random sample from the civil registration system	Heitmann et al.: 122 to 233 (44.3-53.3%) Groth et al.: 1310 to 3043 (46.2-48.8%)	Heitmann et al.: 1987-1988, 1993-1994 (7 years) Groth et al.: 1995, 2000-2002, 2003-2004, 2005-2008 (13 years)	Heitmann et al.: 30-60 Groth et al.: 20-75	Heitmann et al.: Semi-nationally representative of men and women aged 30, 40, 50, and 60 years old drawn Groth et al.: Nationally representative, non-institutionalized Danish citizens	Heitmann et al.: Diet history interview Groth et al.: 7-day pre-coded food diary	Heitmann et al.: energy, macronutrients Groth et al.: SFA	Heitmann et al.: age Groth et al.: energy
Pietinen et al., 1996, Finland[65]	Part of MON-ICA project	Cross-sectional, random sample from population register	866 to 962 (45.7-48.5%)	1982, 1987, 1992 (10 years)	25-64	North Karelia, Kuopio, Turku and 12 small rural municipalities to be representative of sex and age in each area	3-day diet records	Energy, fat, SFA, MUFA, PUFA	No

Author, year, country	Data source	Study design	Sample size (% male)	Years of collection (total length)	Population age	Population type	Method of dietary assessment	Nutrients and food groups assessed	Adjustments
Männistö et al., 2010, Finland[66]	FIN-DIET survey	Cross-sectional, random sample from population register	2039 to 2862 (NR)	1997, 2002, 2007 (10 years)	1997-2002: 25-64 2007: 25-74	Nationally representative, men and women	2- or 3-day diet records	Energy, fat, SFA, MUFA, PUFA; from household budget survey (reported in Figure 3): bread, sweets, fruits, fruit juice, potatoes, sugars, soft drinks	No
Irish Universities Nutrition Alliance reports, Ireland[67,68]	NSIFCS (1997-1999) and NANS (2008-2010)	Cross-sectional, random two-stage sampling within district electoral divisions	1997-1999: 1379 (48.0%) 2008-2010: 1274 (49.8%)	1997-1999, 2008-2010 (13 years)	18-64	NSIFCS: nationally representative for the Republic of Ireland and Northern Ireland, men and women; NANS: nationally representative for the Republic of Ireland, men and women	4- and 7-day semi-weighted food record	Energy, macronutrients, meat, eggs, fish, dairy, fruit, vegetables, roots, legumes, nuts, oils, grains, sweets	No
Ramazauskiene et al., 2011, Lithuania[69]	No specific name	Cross-sectional, stratified random sample, by sex & age, primary health care centres	1467 to 2061 (42.5-47.4%)	1987, 1993, 1999, 2007 (20 years)	25-64	Men and women from 5 rural municipalities: Kaišiadorys, Kretinga, Kupiškis, Joniškis, and Varėna	24-hour recall	Energy, macronutrients, SFA, MUFA, PUFA	Age standardized to 2007 population
Johansson et al. 1999 & Totland et al., 2000, Norway[70–72]	National Food Consumption Survey	Cross-sectional, sample drawn from National Register (Folkeregisteret)	1787 to 3144 (48.2-48.6%)	1993-1994, 1997, 2010-2011 (18 years)	Prior to 1997: 16-79 2010-2011: 18-70	Nationally representative, men and women, conducted over the phone	24-hour recall and/or FFQ	Energy, macronutrients, SFA, MUFA, PUFA, cereals, bread, sweets, potatoes, vegetables fruits, meat, fish, eggs, dairy, oils, soda, alcohol	No
Krachler et al., 2005 & Johansson et al., 2012, Sweden[73,74]	MONICA Project; Västerbotten Intervention Program (VIP)	MONICA: Cross-sectional, from population registry VIP: Cross-sectional, recruited from primary health care centres	MONICA: 1353 to 1608 (47.7-50.9%) VIP: NR for each year	MONICA: 1986, 1994, 1999 (13 years) VIP: every 2 years 1986-2010 (24 years)	25-65	MONICA: Men and women from Vasterbotten and Norrbotten VIP + MONICA: men and women from Västerbotten, recruited when they turn 30, 40, 50 or 60 years	FFQ	MONICA: energy MONICA + VIP: macronutrients	Age and BMI for macronutrient intakes

Author, year, country	Data source	Study design	Sample size (% male)	Years of collection (total length)	Population age	Population type	Method of dietary assessment	Nutrients and food groups assessed	Adjustments
Pryer et al., 2001, Marriot et al., 2003. Whitton et al., 2011, Govern-ment of UK 2019, Johnson et al., 1991, United Kingdom[75–79]	National Food Survey, National Diet and Nutrition Survey	Cross-sectional, multi-stage random probability by region and electoral wards of different SES	965 to 2197 (38.7-49.5%)	1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1986-1987, 2000-2001, 2008-2010, 2010-2012, 2012-2014, 2014-2016, 2016-2019 (59 years)	19-64	Nationally representative (Scotland, Wales, London), living in private households	7-day diet record, weighted	Energy, macronutrients, SFA, MUFA, PUFA	No
Pot et al, 2015, United Kingdom[80]	National Survey of Health & Develop-ment	Longitudinal birth cohort study	989 (44.3%)	1982, 1989, 1999, 2006-2011 (29 years)	36-64 (at baseline aged 36)	Born in March 1946 in England, Scotland, Wales	5-day diet diary (unweighted)	Energy, macronutrients, cereals, dairy, fats, meats, fish, vegetables, fruit, nuts, pulses, alcohol, soft drinks	No
Abina et al., 2003, Volozh et al., 2002, Estonia[81,82]	No specific name	Abina et al.: independent random sample of population Volozh et al.: independent random sample of male population	Abina: 534 to 989 (55.5-87.2%) Volozh: 752 to 1890 (100%)	1984/1986, 1992-1994, 1999/2001	Abina et al.: 20-54 Volozh et al.: 30-54	Abina et al.: independent samples from Tallinn, Estonia Volozh et al.: male population of Tallinn, Estonia	Abina et al.: 24-hour recall Volozh et al.: 24-hour recall	Abina et al.: energy, macronutrients Volozh et al.: SFA, MUFA, PUFA	Standardized to age and sex distribution of Estonia
I. WESTERN/SOUTHERN EUROPE AND AUSTRALASIA (AUSTRALIA AND NEW ZEALAND) (9 COUNTRIES)									
Winkler et al., 1997, Germany[83]	Part of MONICA project	Independent random sample	537 (52.3%) and 605 (58.3%)	1987-1988, 1991-1992 (5 years)	25-64	Men and women in Erfurt (East Germany)	3-day weighted records	Grains, vegetables, potatoes, fruit, juice, nuts, sugar, sweets, meat, fish, eggs, dairy, fats/oils, soft drinks	Age standardized to 1988 population
Gose et al., 2016, Germany[84]	German National Nutrition Monitor-ing Study	Longitudinal study	1840 (42.3%)	2005-2007, 2008-2009, 2009-2010, 2010-2011, 2012-2013 (8 years)	14-80 at baseline (mean age men: 50.1, women: 48.6)	Drawn from the nationally representative German National Nutrition Survey, men and women	24-hour recall	Energy, macronutrients, SFA, MUFA, PUFA, bread, cereals, pastries, vegetables, fruits, fruit juice, fats, dairy, eggs, meats, fish, soft drinks, confectionary, alcohol	Tested age*time interaction and was not significant

Author, year, country	Data source	Study design	Sample size (% male)	Years of collection (total length)	Population age	Population type	Method of dietary assessment	Nutrients and food groups assessed	Adjustments
Hulshof et al., 2003 & National Reports Netherlands[85–87]	Dutch National Food Consumption Survey	Cross-sectional, stratified probability sample selected from consumer panel	2078 to 4466 (46.1-50.9%)	1987-1999, 1992, 1997-1998, 2007-2010, 2012-2016 (29 years)	19+	Nationally representative based on age, sex, region, urbanization, education, excluding institutionalized, households with a house-keeper aged 75+, pregnant or lactating women	2-day diet record	Energy, macronutrients, SFA, MUFA, PUFA, bread, cereals, potatoes, vegetables, fruit, milk, cheese, meat, fats, sugar, cakes, soft drinks, alcohol	No
Marques-Vidal et al., 2015, Switzerland[88]	Bus Santé Geneva study	Cross-sectional, random sample in age and sex-specific strata to be proportional to population	4307 to 6922 (47.1-49.6%)	1993-1999, 2000-2005, 2006-2012 (19 years)	35-74	Representative sample of non-institutionalized men and women in Geneva. Exclusions: energy <850 or >4000 kcal, protein >500 g, fiber >100 g	Semi-quantitative FFQ	Energy, macronutrients, SFA, MUFA, PUFA	Age, smoking, country of birth, marital status
Nicolosi et al., 1988, Turrini et al, 1999, Carnovale et al., 2000, Turrini et al, 2001, Leclercq et al., 2009, Sette et al., 2011, Italy[89–94]	ISTAT National Surveys; INN Food Consumption Surveys; INRAN-SCAI	ISTAT: stratified random sample of municipalities INN and INRAN-SCAI: stratified random sample of households in main areas of Italy	Prior to 1994: NR 1994-1996: 1844 (46.4%) 2005: 2312 (46.2%)	1951, 1961, 1971, 1980-1984, 1983, 1985, 1994-1996, 2005-2006 (55 years)	Prior to 1994: 35-74 1994-1996: 18-60 2005-2006: 18-64.9	Nationally representative, men and women	Interviews, food inventory, 7-day dietary diary, 3-day diet record	Energy, macronutrients, animal fat, vegetable fat Turrini et al. 2001 & Leclercq et al: grains, pastries, vegetables, fruits, oils, dairy, eggs, nuts, meats, fish, sweets, alcohol	No
Volatier et al., 1999, Perrin et al., 2002, Dubuisson et al., 2010 & ANSES, 2017, France[95–98]	MONICA Project; ASPCC; INCA surveys	Cross-sectional, MONICA: multi-stage sampling by age & town size; INCA: stratified sample by region & urban area, probability proportional to size	802 to 3157 (41.8-51.1%)	1985-1987, 1993-1994, 1995-1997, 1998-1999, 2006-2007, 2014-2015 (30 years)	MONICA: 35-64 ASPCC: 19-64 INCA: 18-79	MONICA: in Bas-Rhin, Eastern France, men and women ASPCC and INCA: Nationally representative, men and women based on region, age, sex, occupation, urbanization, excluding under-reported based on energy intake	MONICA: 3-day diet record, FFQ ASPCC and INCA1-2: 7-day diet record INCA3: 24-hour recall and FFQ	Energy, macronutrients, SFA, MUFA, PUFA, cereals, pizza, pulses, potatoes, pastries, sweets, dairy, fats and oils, eggs, meats, fish/shellfish, fruits, vegetables, alcohol	MONICA: age

Author, year, country	Data source	Study design	Sample size (% male)	Years of collection (total length)	Population age	Population type	Method of dietary assessment	Nutrients and food groups assessed	Adjustments
Serra-Majem et al., 1995, Moreno et al., 2002, Varela-Moreiras et al., 2010, Rodríguez, et al., 2016, Spain[99–102]	House-hold budget & expen-diture surveys, National Institute of Statistics	Two-stage stratified sampling (towns and households)	1964-91: 20800-28000 house-holds 2000-14: 12000 house-holds	1964-1965, 1980-1981, 1990-1991, 2000,2005, 2010, 2014 (50 years)	All ages	Nationally representative, 50 provinces into 17 regions, 20800 households in 1964-1965, 24000 in 1980-1981, 28000 in 1990-1991	Surveys collected $ spent on food, trained interviewer visited household daily or every other day for 1 week	Energy, macronutrients, SFA, bread, pasta, rice, potatoes, vegetables, pulses, fruits, meat, fish, eggs, dairy, sugar, fats/oil	No
Trichopoulou et al., 2003, Greece[103]	DAta Food NEtwor-king (DAF-NE)	Household budget survey	NR	1987-1988, 1993-1994, 1998-1999 (12 years)	All ages	Not reported, but likely to be nationally representative	Examined purchased quantity	Vegetables (excludes potatoes and legumes), fruits	No
Ridoutt et al., 2016 & Grech et al., 2018, Australia[104,105]	NSDA; NNS; NNPAS	NSDA: multi-staged sampling NNS & NNPAS: stratified multi-staged samples	5548 to 7618 (48.0-48.4%)	1983, 1995, 2011-2012 (29 years)	25-64 For foods: age 19+	NSDA: six Australian state capital cities within a 16 km radius of the National Heart Foundation centers NNS & NNPAS: nationally representative, both sexes	24-hour recall	Energy, macronutrients, alcohol, fruits, vegetables, starchy roots, meat, seafood, dairy, eggs, grains, legumes, nuts and seeds, sugar, vegetable oil, butter	Food: based on 2011 age class distribution, and adjusted for under-reporting
Flood et al., 2010 Australia[106]	Blue Mount-ains Eye Study	Population-based cohort study	971 to 2878 (42.3-47.9%)	1992-1994, 1997-1999, 2002-2004, (12 years)	49+ (mean 65 at baseline)	Non-institutionalized permanent residents living in 2 postcodes of the Blue Mountains area. Exclusions: energy intake <598 or >4302 kcal/day	FFQ	Energy, macronutrients, SFA, MUFA, PUFA	No
Russell et al., 1999, Miller et al., 2016 & Parnell et al., 2011, New Zealand[107–109]	LINZ89; NNS97; ANS08/09	Cross-sectional, multi-stage, stratified, probability-proportional-to-size of private dwellings	LINZ89: 1618 (49.2%) NNS97 & ANS 08/09: 4636 to 4721 (NR)	1989, 1997, 2008-2009 (20 years)	15+	Nationally representative, women and men, non-institutionalized, urban and rural living in private dwellings, oversampling of Māori & Pacific Peoples	24-hour recall and FFQ	Energy, macronutrients, SFA, MUFA, PUFA, grains, potatoes, fats, milk, cakes, sweets, meats, fruits, vegetables, seafood, eggs, nuts and seeds	No

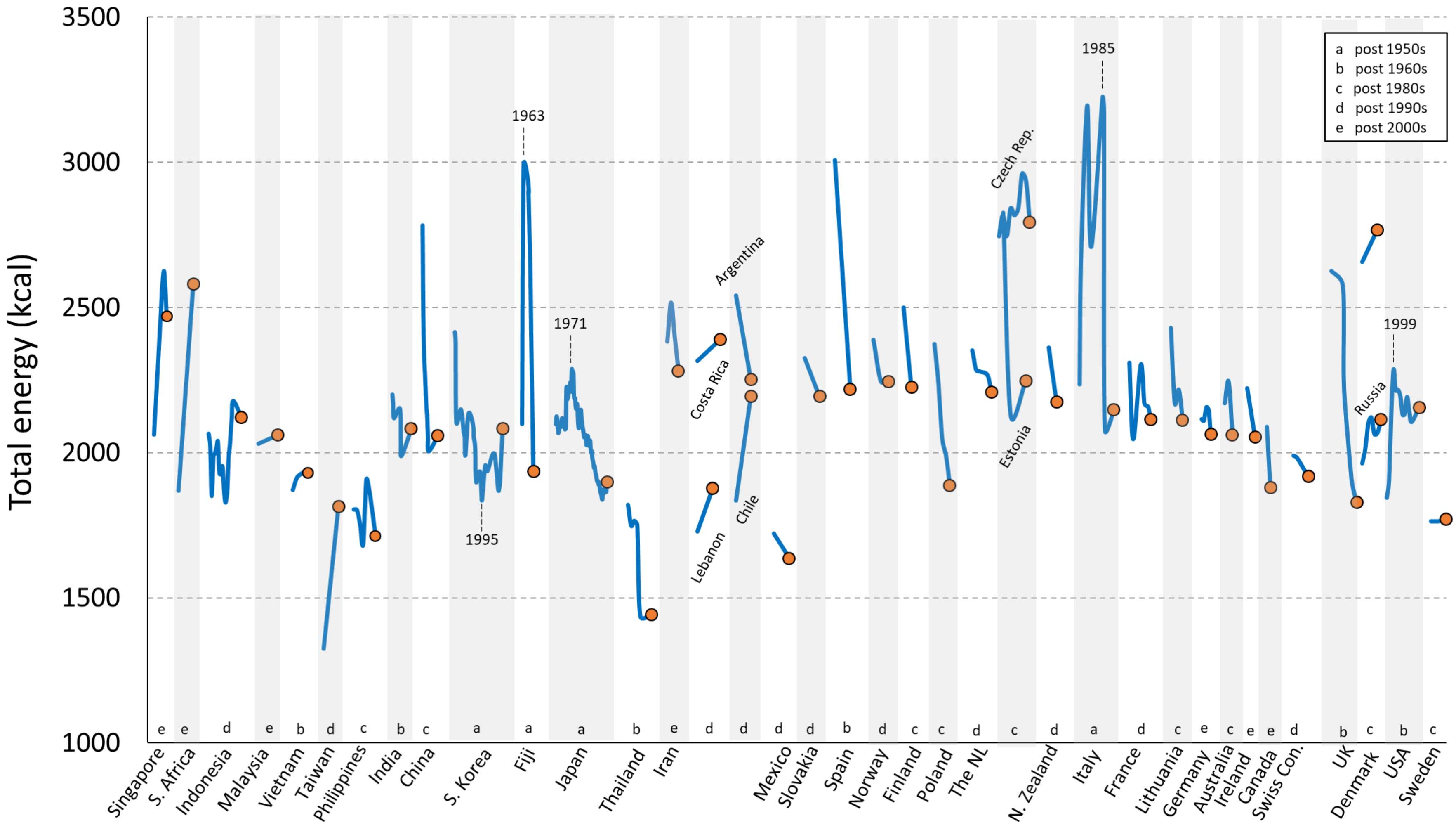
Abbreviations: NR = not reported; PURE-NWP-SA Study = Prospective Urban and Rural Epidemiology in the North West Province of South Africa; FFQ = food frequency questionnaire; TB = tuberculosis; BRISK = Black Risk Factor Study; CRIBSA = Cardiovascular Risk in Black South Africans Study; SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; FNRI = Food and Nutrition Research Institute; NHES = National Health Examination Survey; SSB = sugar-sweetened beverages; SES = socioeconomic status; NSIFCS = North South Ireland Food Consumption Survey; NANS = National Adult Nutrition Survey; MONICA = Monitoring of Trends and Determinants in Cardiovascular Disease; ASPCC = National Food Consumption Survey; INCA = Individual national food consumption; ENIB = Nutritional Survey of The Balearic Islands; OBEX = Obesity and Oxidative Stress Survey; ENCAT = Evaluation of Nutritional Status in Catalonia NSDA = National Dietary Survey of Adults; NNS = National Nutrition Survey; NNPAS = National Nutrition and Physical Activity Survey; LINZ89 = 1989 Life in New Zealand Survey; NNS97 = 1997 National Nutrition survey; ANS08/09 = 2008-09 New Zealand Adult Nutrition Survey

Supplementary Table S8. Mean daily intake of nutrients and foods, Global Dietary Database, 1990 and 2018

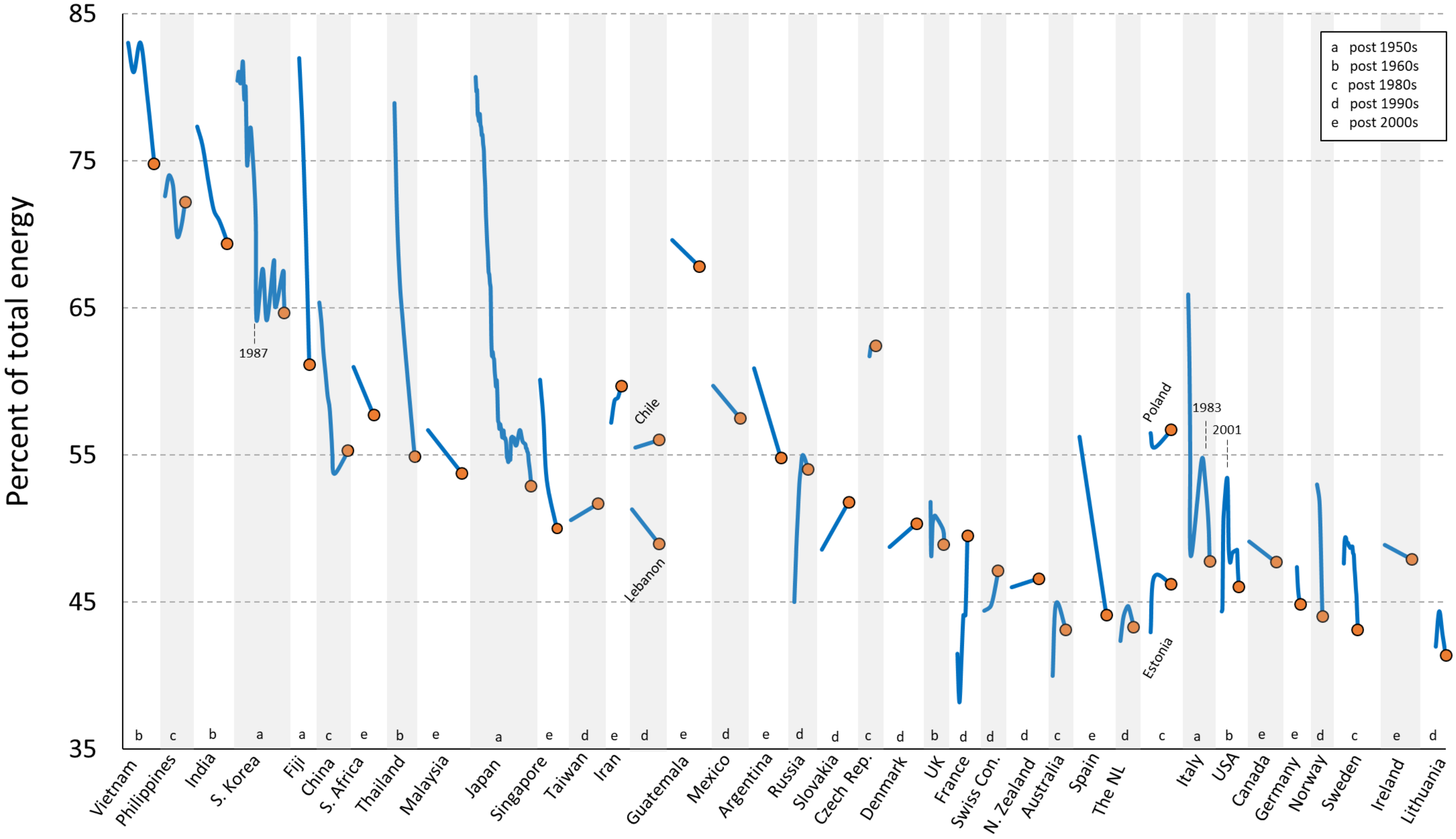
Nutrient or food item (consumption per day)	East & Southeast Asia		Former Soviet Union		High-income countries		Latin America & Caribbean		Middle East & North Africa		South Asia	
	1990	2018	1990	2018	1990	2018	1990	2018	1990	2018	1990	2018
Carbohydrates (%e)	59.9	59.5	48.8	49.2	48.9	48.5	56.2	55.3	56.3	55.4	67.0	65.8
Protein (g)	45.6	71.2	66.5	76.2	83.0	79.6	60.0	75.3	61.1	74.2	42.6	45.5
SFA (% e)	9.5	11.3	13.2	11.9	12.9	12.8	8.6	9.7	9.4	10.1	5.3	6.1
MUFA (%e)	8.4	9.1	16.0	15.9	13.1	12.8	11.8	10.8	13.8	14.2	5.9	6.4
Unprocessed red meats (g)	29.2	87.1	136.3	114.1	52.7	45.0	48.8	68.3	39.9	36.4	7.0	7.4
Seafood (g)	23.4	44.1	24.0	30.4	21.5	25.1	18.7	21.9	13.8	22.6	9.2	11.9
Eggs (g)	12.5	34.9	31.7	34.0	17.3	18.5	13.8	24.9	19.2	29.9	3.5	6.0
Cheese (g)	1.7	1.6	29.5	34.2	28.8	31.7	10.3	12.5	15.2	17.3	0.5	0.6
Yoghurt (including fermented milk) (g)	10.0	9.6	82.4	83.6	36.3	37.1	17.6	17.5	58.6	59.7	6.8	6.9
Total Milk (g)	28.0	45.5	116.7	145.3	176.2	185.1	85.3	150.3	105.5	106.0	51.6	83.7
Total dairy (g)	39.8	56.7	228.6	263.0	241.4	253.9	113.3	180.3	179.3	183.0	59.0	91.2
Nuts and seeds (g)	1.6	8.5	3.4	14.7	3.4	8.0	1.1	6.1	6.4	11.0	2.6	3.7
Refined grains (g)	390.0	379.1	156.3	146.3	119.6	126.6	180.3	202.2	260.6	329.7	365.5	340.4
Whole grains (g)	11.6	14.1	66.2	63.6	32.0	34.9	11.2	15.7	14.9	23.3	97.0	105.8
Total grains (g)	401.6	393.2	222.6	209.8	151.6	161.5	191.5	217.9	275.6	353.0	462.5	446.2
Fruits (g)	80.3	87.9	89.0	113.7	102.5	115.0	87.4	111.1	92.4	106.1	35.4	38.5
Non-starchy vegetables (g)	77.7	257.3	136.3	186.3	117.8	135.6	86.9	121.0	129.9	153.5	156.7	162.9
Potatoes (g)	7.2	18.1	130.2	140.5	96.0	53.8	25.7	29.1	42.5	72.1	35.0	51.2
Other starchy vegetables (g)	34.8	24.7	42.3	35.8	17.2	14.9	73.6	71.3	30.4	31.4	20.1	13.6
Total roots (g)	42.0	42.8	172.6	176.3	113.2	68.6	99.4	100.4	72.9	103.5	55.1	64.7
Beans and legumes (g)	22.7	23.9	14.4	14.6	18.0	18.2	45.5	47.5	28.9	27.4	26.6	26.5
Added sugars (g)	2.9	4.5	7.9	10.4	10.5	11.1	15.6	13.2	10.9	10.2	11.0	19.9

Estimates from Global Dietary Database (https://www.globaldietarydatabase.org/). Cells in blue indicate decreased intake between 2018 and 1990, white cells indicate increased intake (statistical testing not conducted).

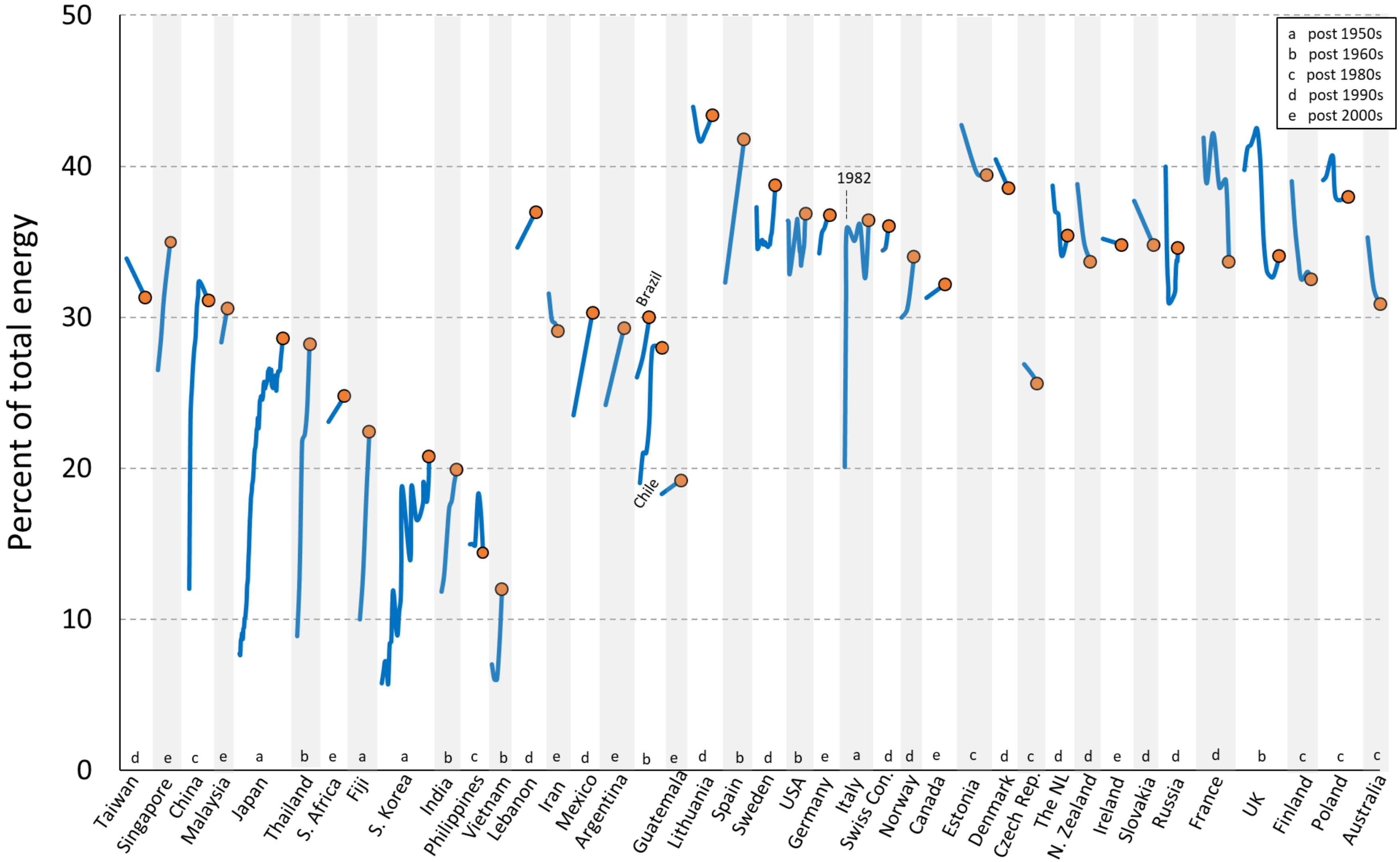
Supplementary Figure S1. Trend lines, energy intake (kcal), by country, years 1950-2019 (n = 42 countries)



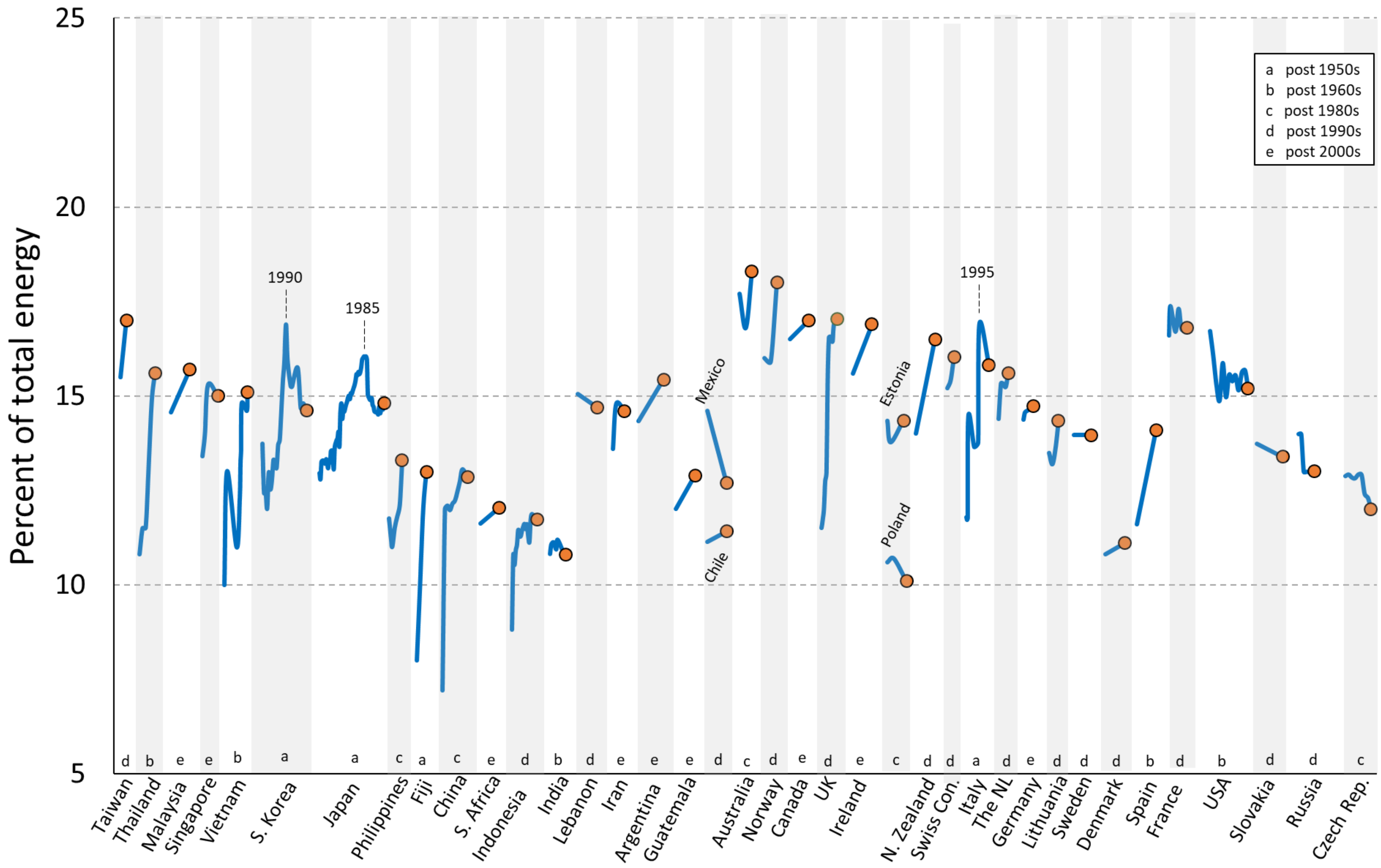
Supplementary Figure S2. Trend lines, carbohydrate intake (% of total energy), by country, years 1950-2019) (n = 40 countries)



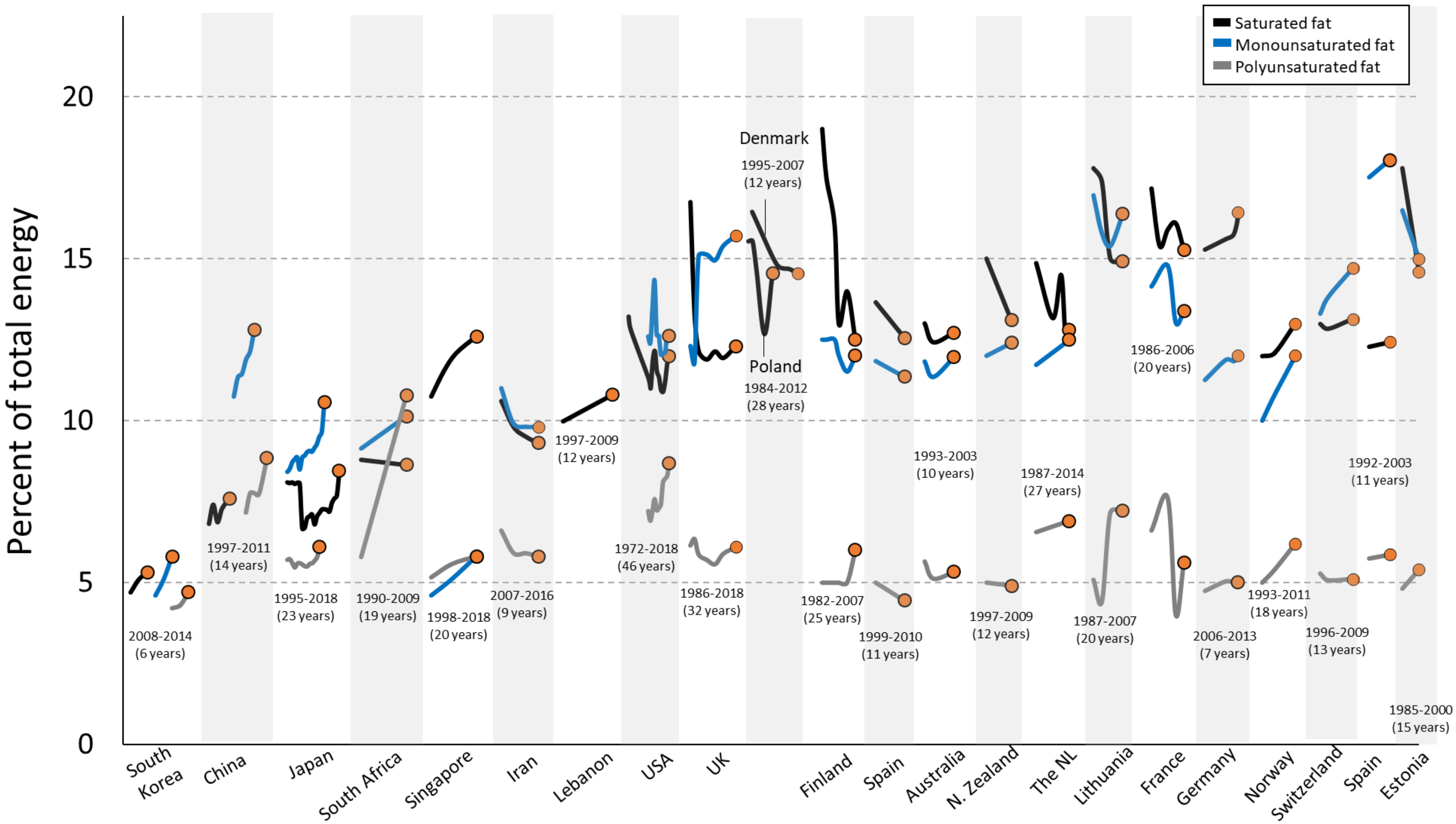
Supplementary Figure S3. Trend lines, fat intake (% of total energy), by country, years 1950-2019 (n = 42 countries)



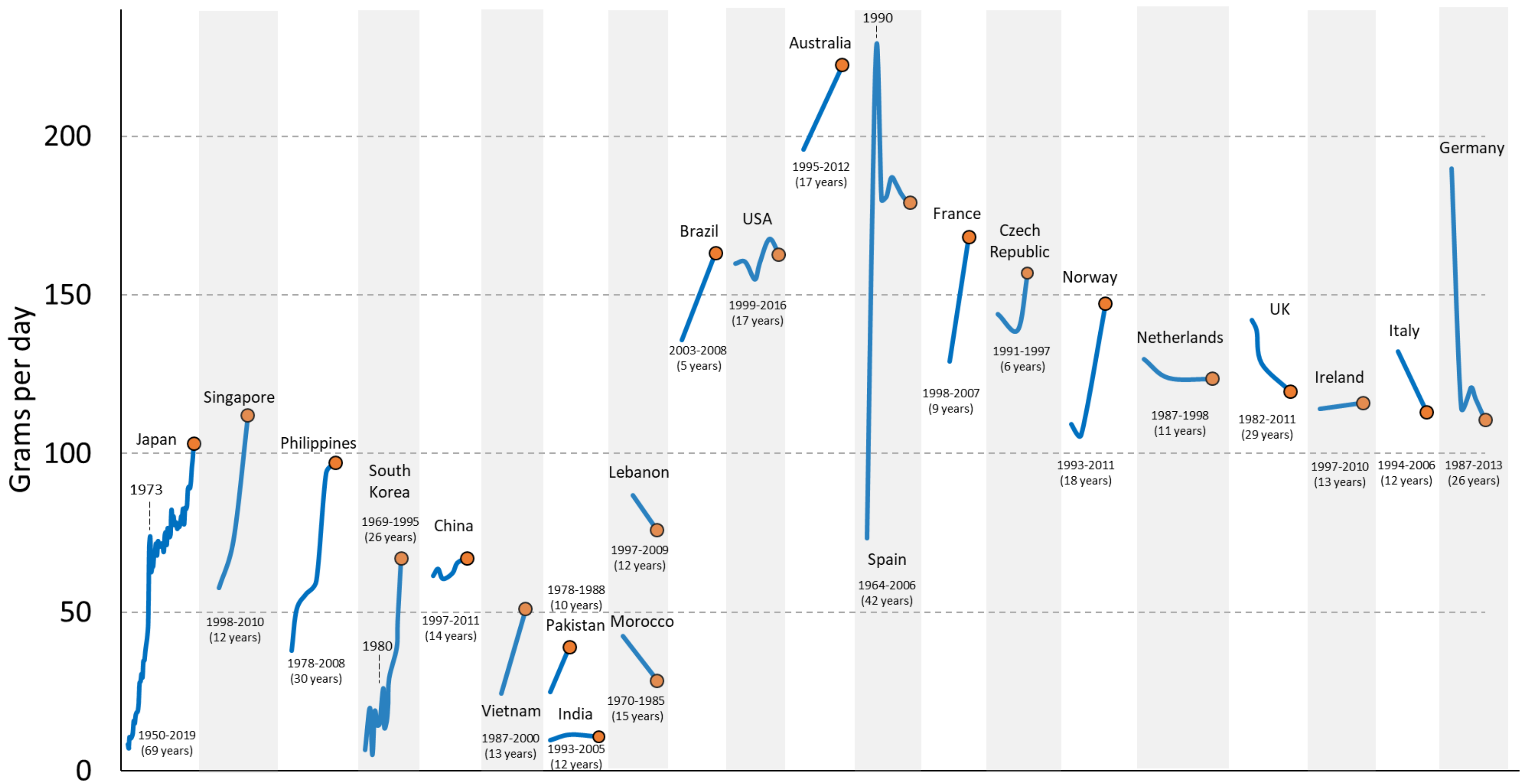
Supplementary Figure S4. Trend lines, protein intake (% of total energy), by country, years 1950-2019 (n = 38 countries)



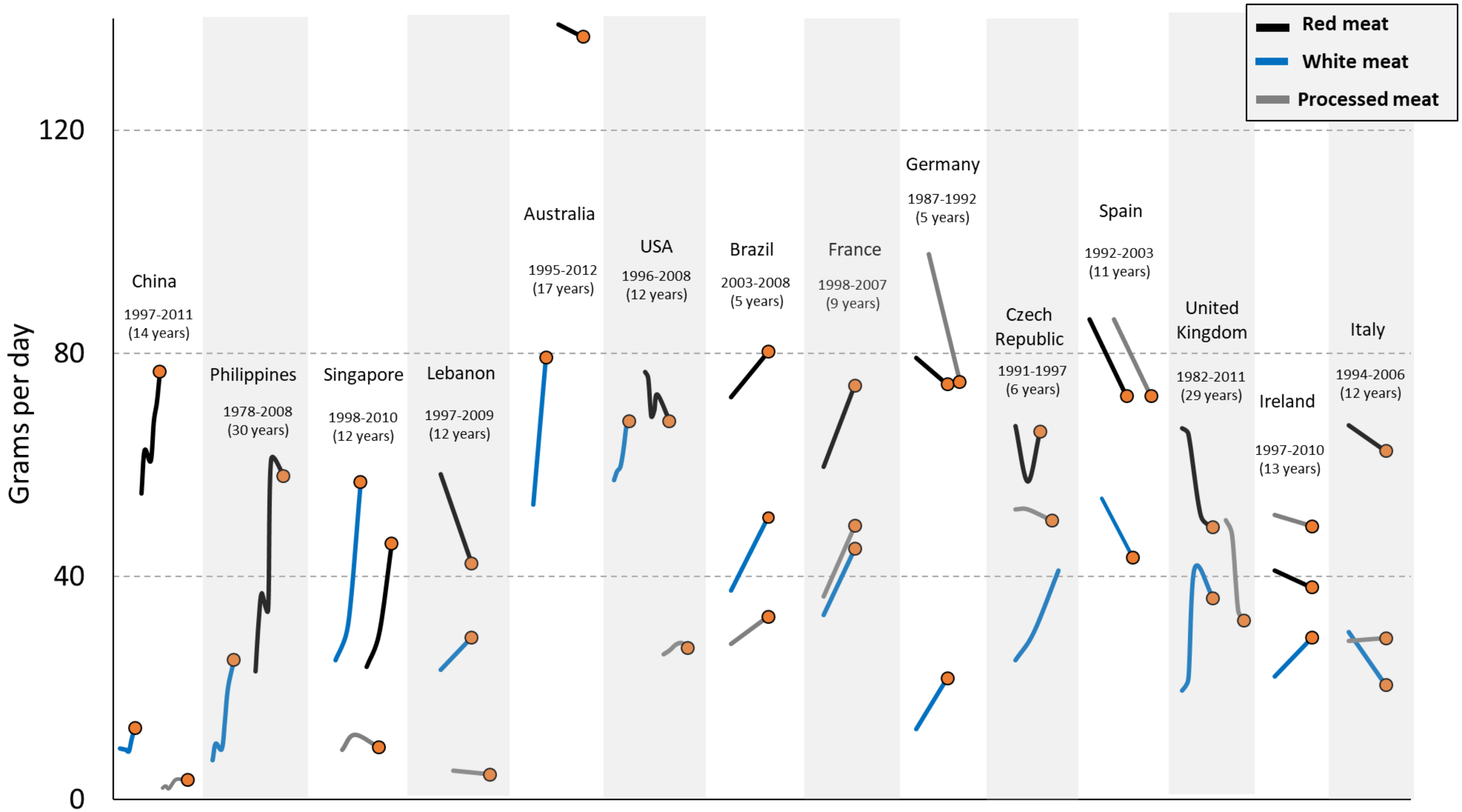
Supplementary Figure S5. Trend lines, dietary <u>saturated, monounsaturated, and polyunsaturated fat</u> (% of total energy), by country, years 1970-2019 (n = 23 countries)



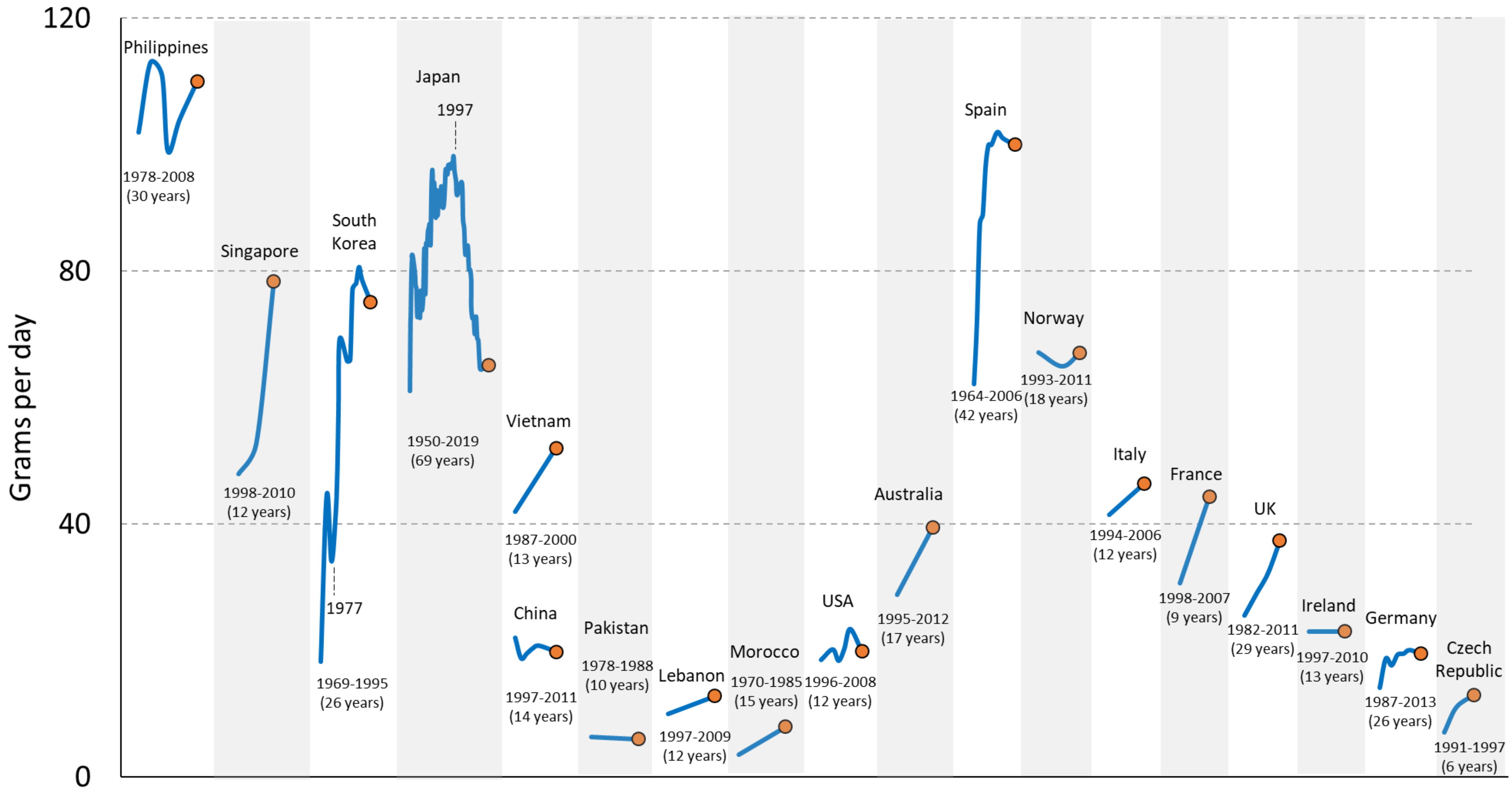
Supplementary Figure S6. Trend lines, meat intake (% of total energy), by country, years 1950-2019 (n = 22 countries)



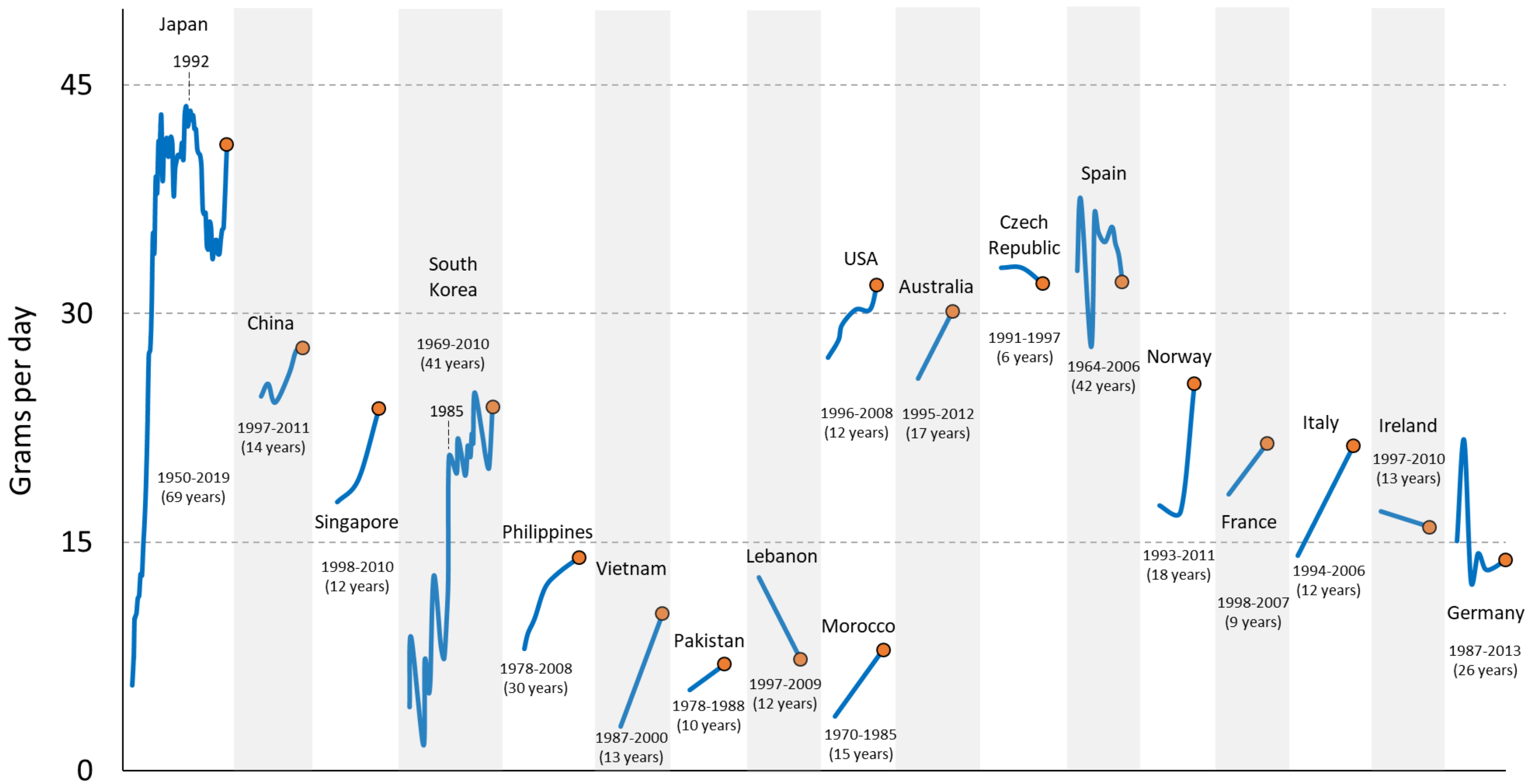
Supplementary Figure S7. Trend lines, <u>meat (red unprocessed vs. white vs. processed meat)</u> intake (% of total energy), by country, years 1970-2019 (n = 14 countries)



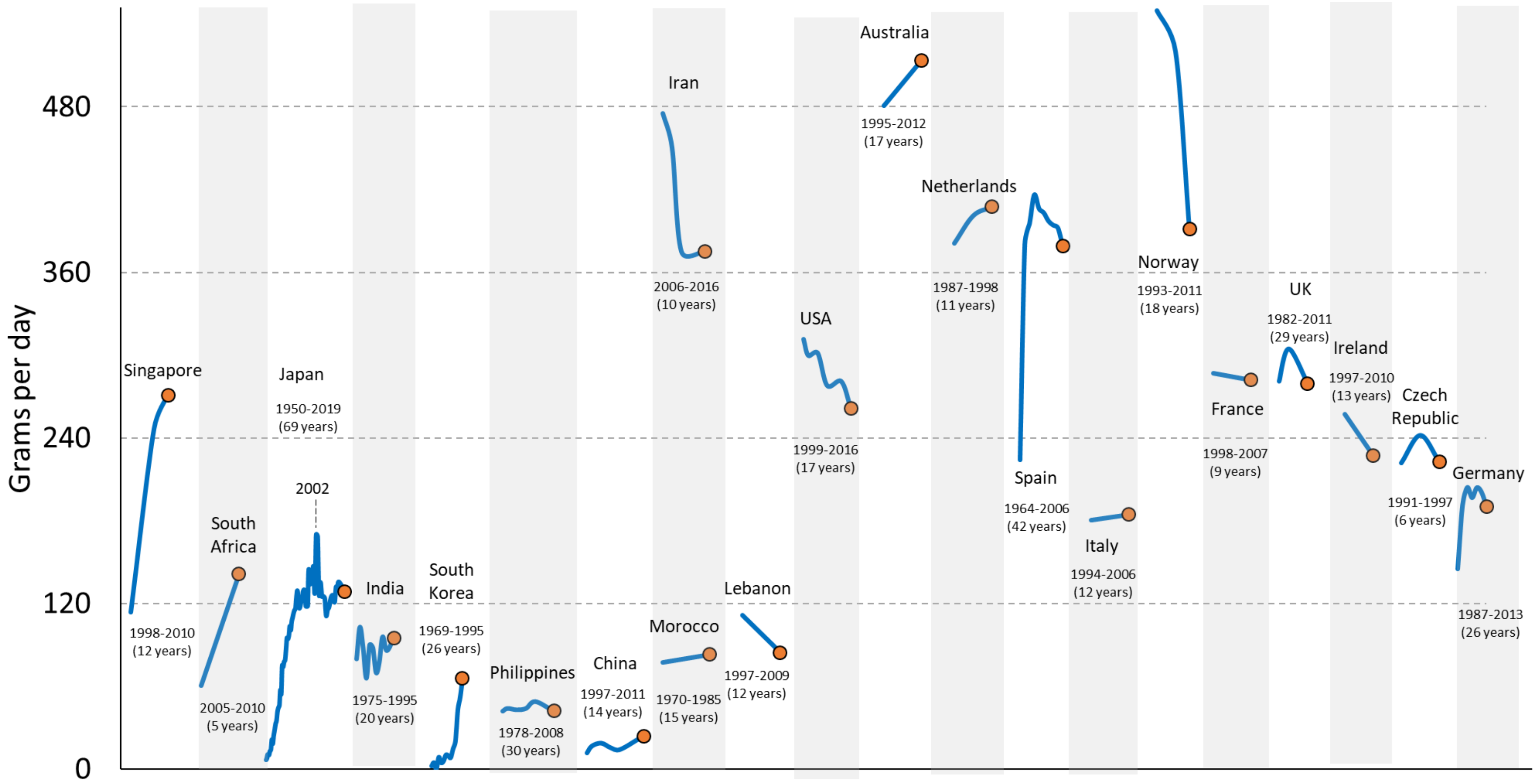
Supplementary Figure S8. Trend lines, fish intake (% of total energy), by country, years 1950-2019 (n = 19 countries)



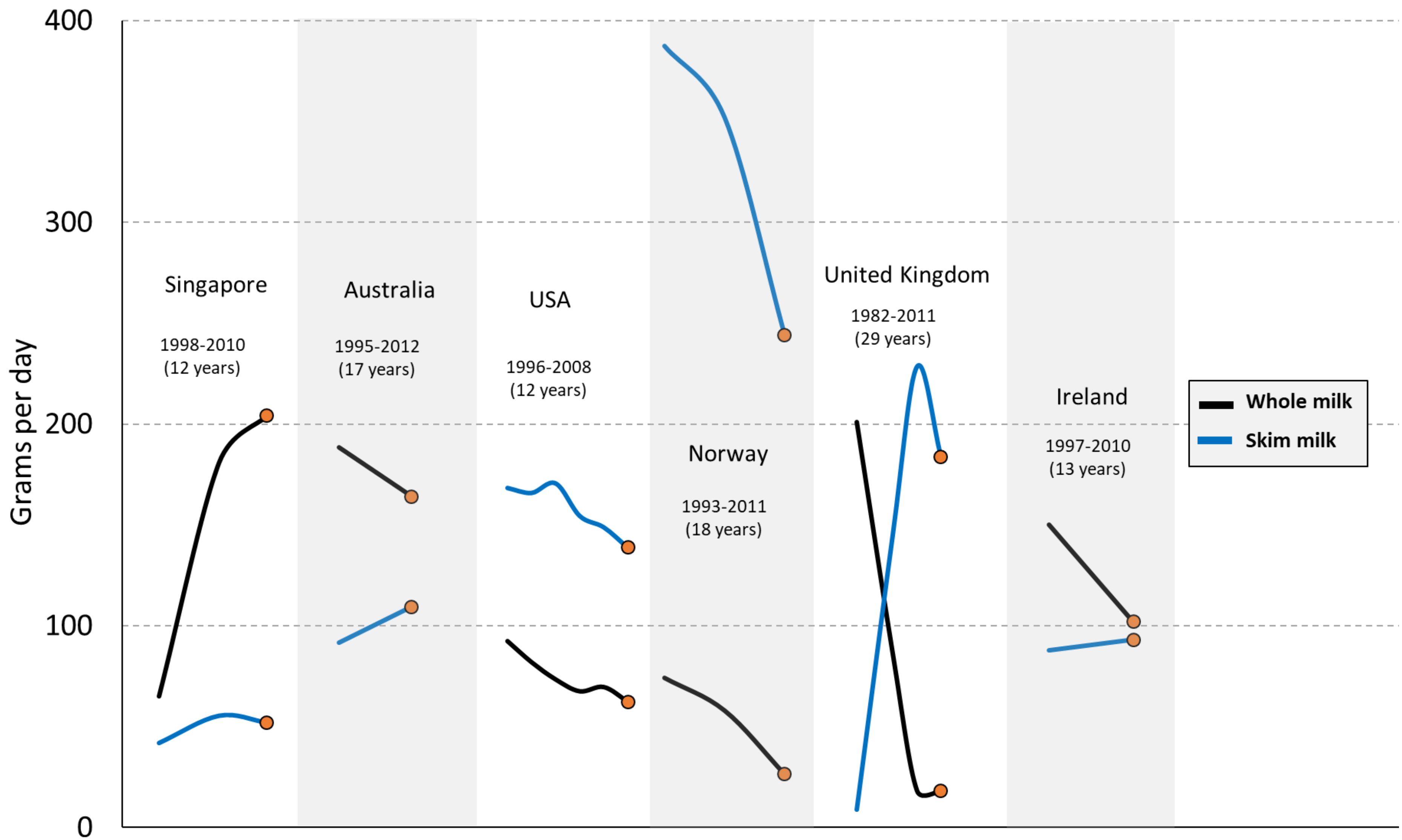
Supplementary Figure S9. Trend lines, egg intake (% of total energy), by country, years 1950-2019 (n = 18 countries)



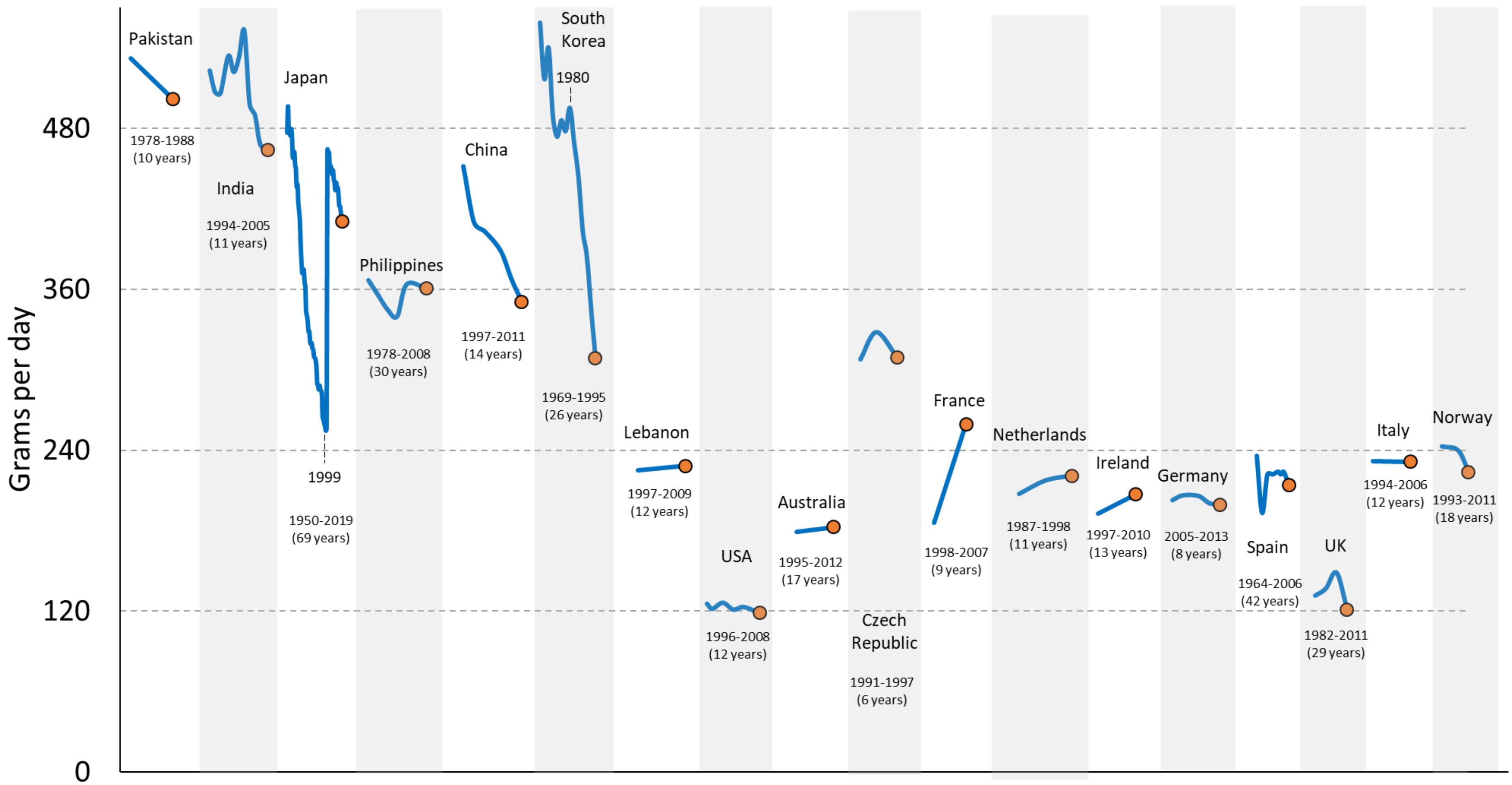
Supplementary Figure S10. Trend lines, dairy (exluding ice cream) intake (% of total energy), by country, years 1950-2019 (n = 21 countries)



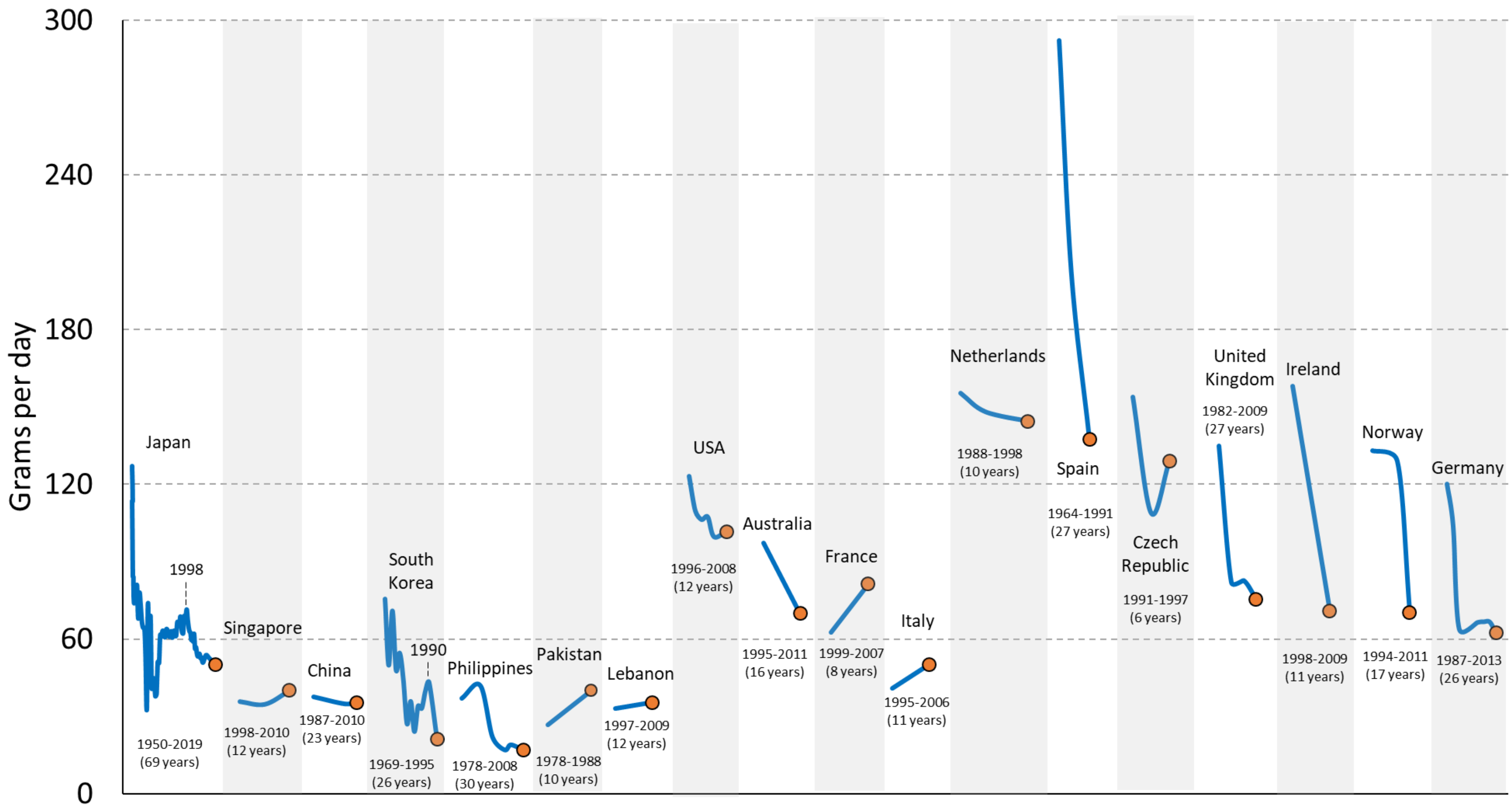
Supplementary Figure S11. Trend lines, whole milk vs. skim milk intake (% of total energy), by country, years 1980-2019 (n = 6 countries)



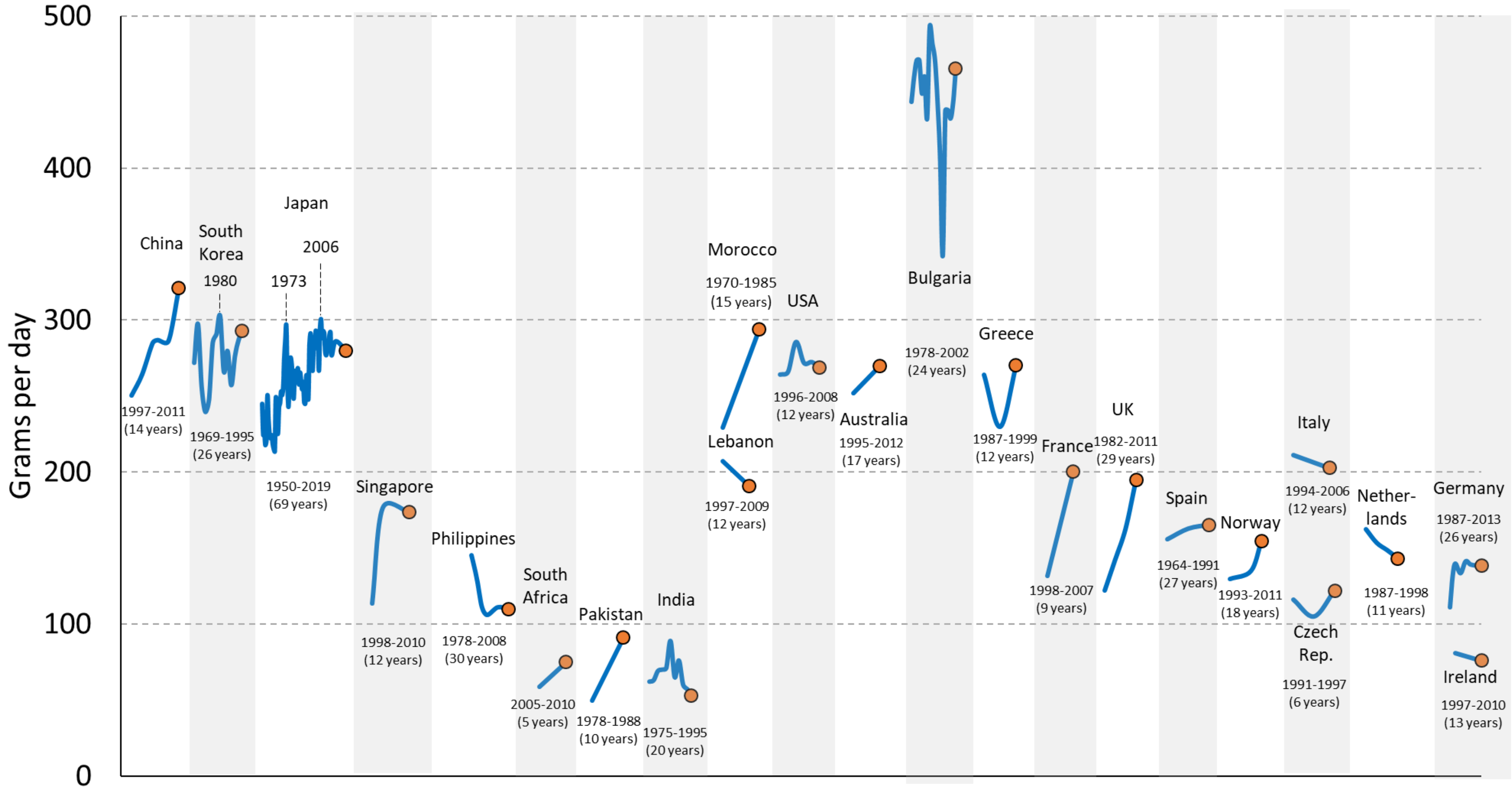
Supplementary Figure S12. Trend lines, <u>grain and cereal</u> intake (% of total energy), by country, years 1950-2019 (n = 18 countries)



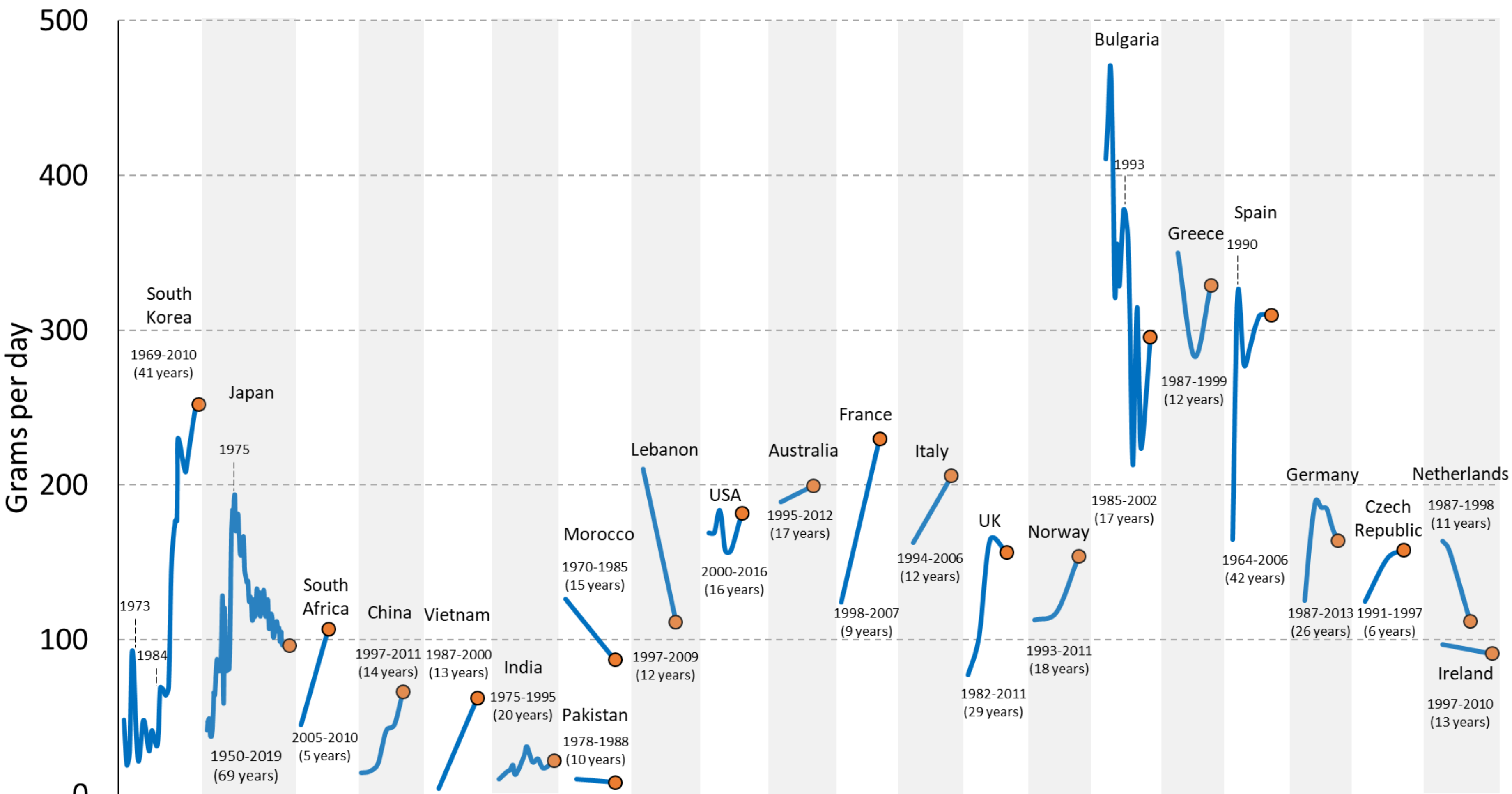
Supplementary Figure S13. Trend lines, roots and tubers intake (% of total energy), by country, years 1950-2019 (n = 18 countries)



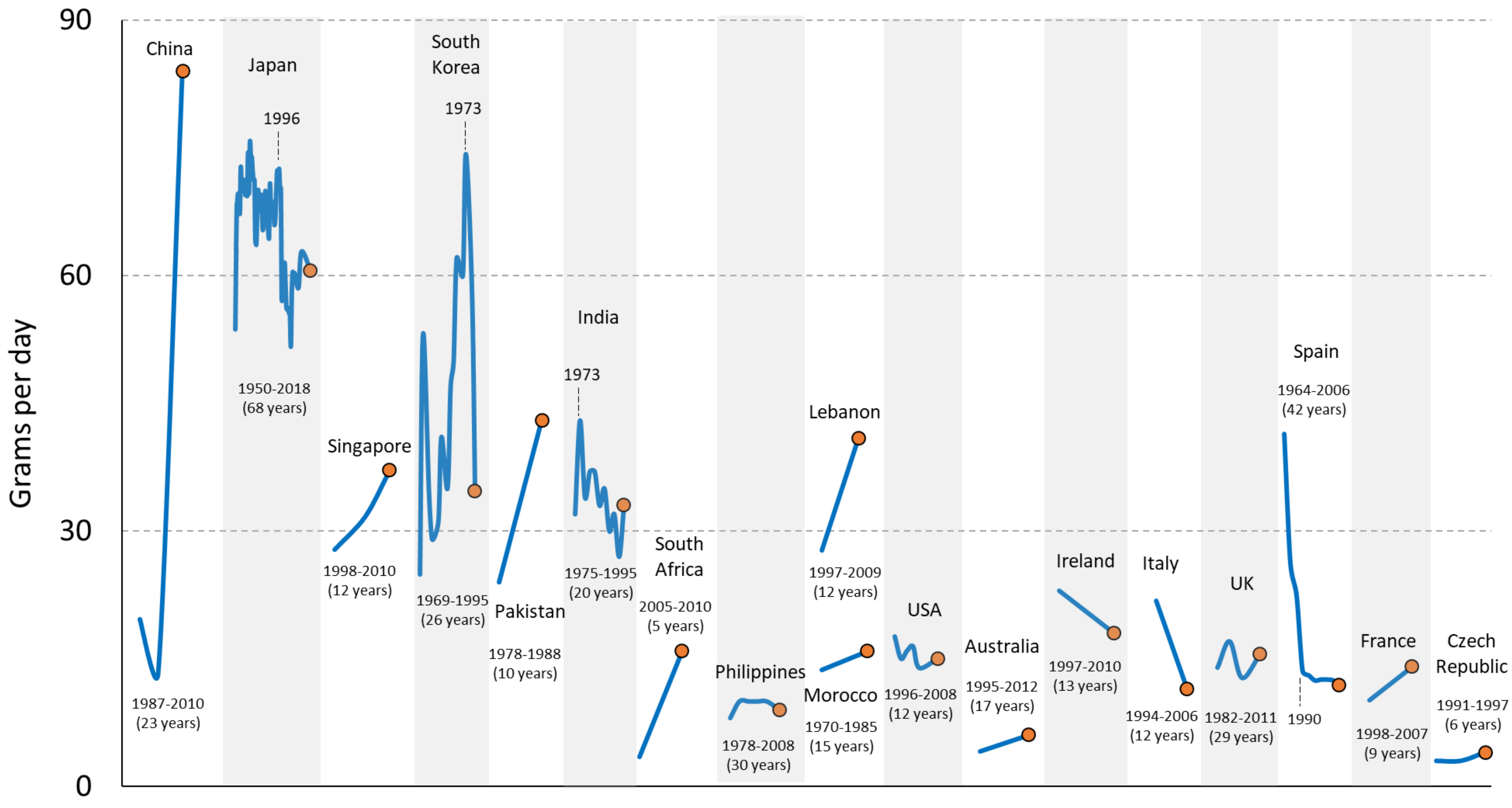
Supplementary Figure S14. Trend lines, vegetable (excluding potatoes) intake (% of total energy), by country, years 1950-2019 (n = 23 countries)



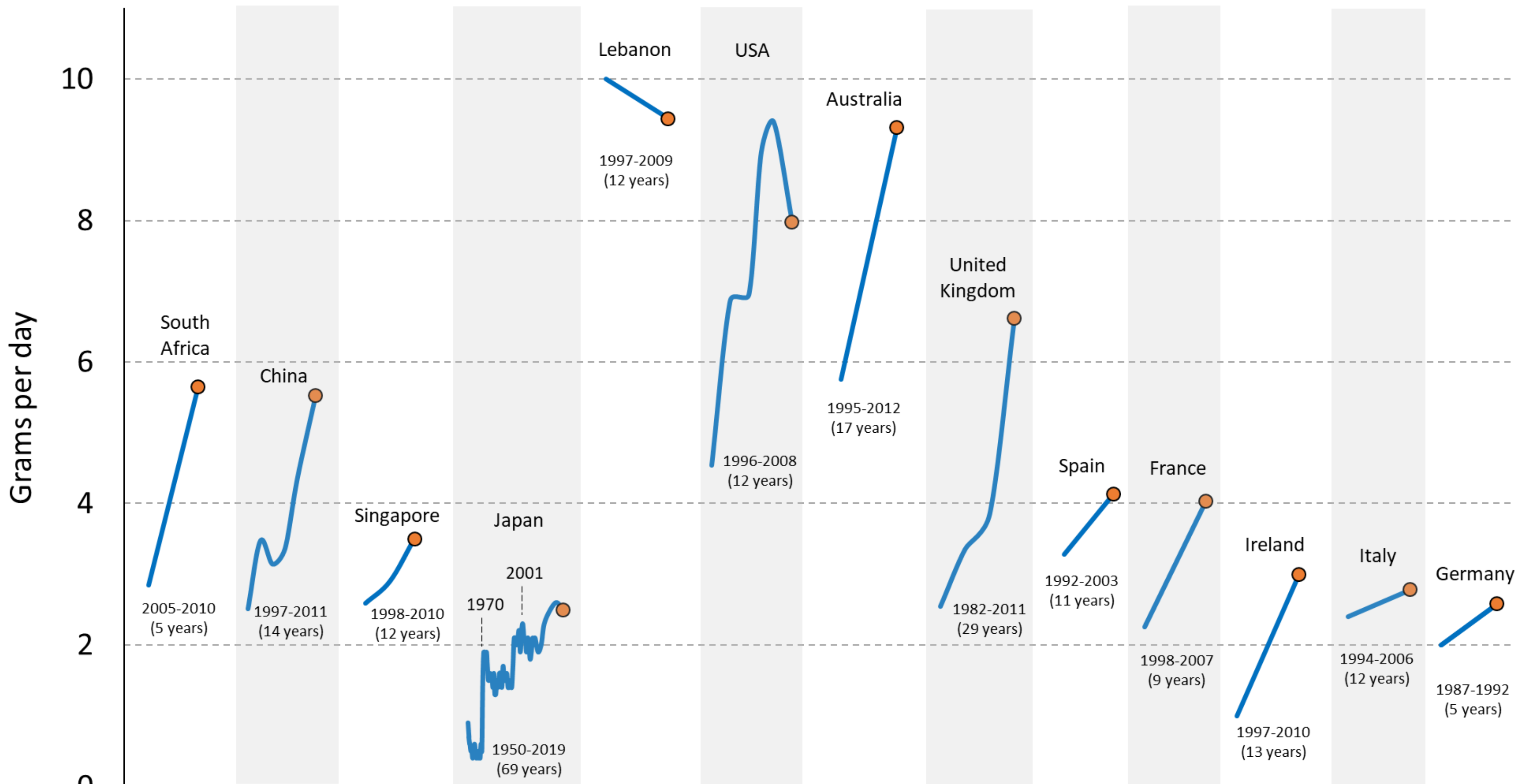
Supplementary Figure S15. Trend lines, fruit (excluding juice) intake (% of total energy), by country, years 1950-2019 (n = 22 countries)



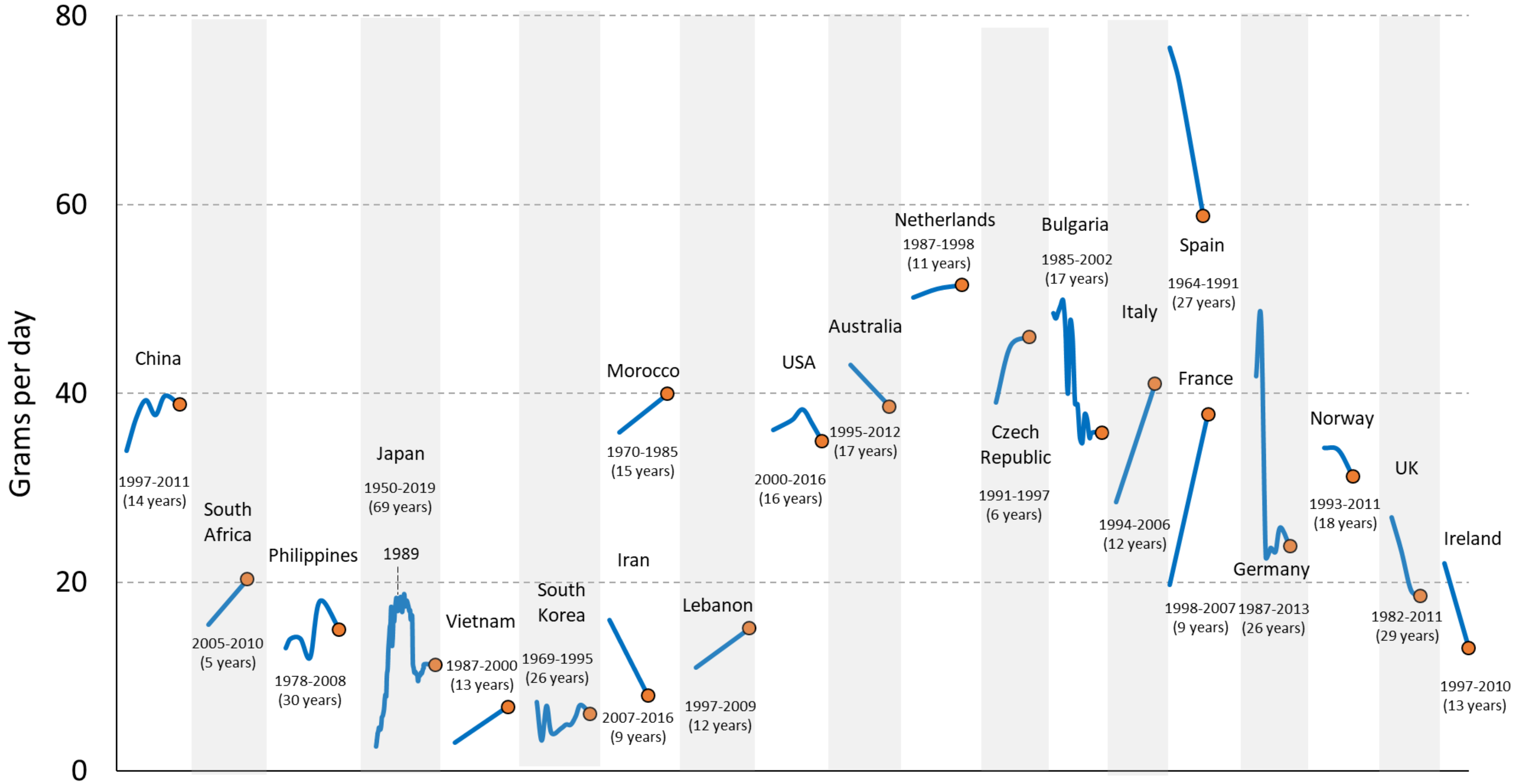
Supplementary Figure S16. Trend lines, legumes and pulses intake (% of total energy), by country, years 1950-2019 (n = 18 countries)



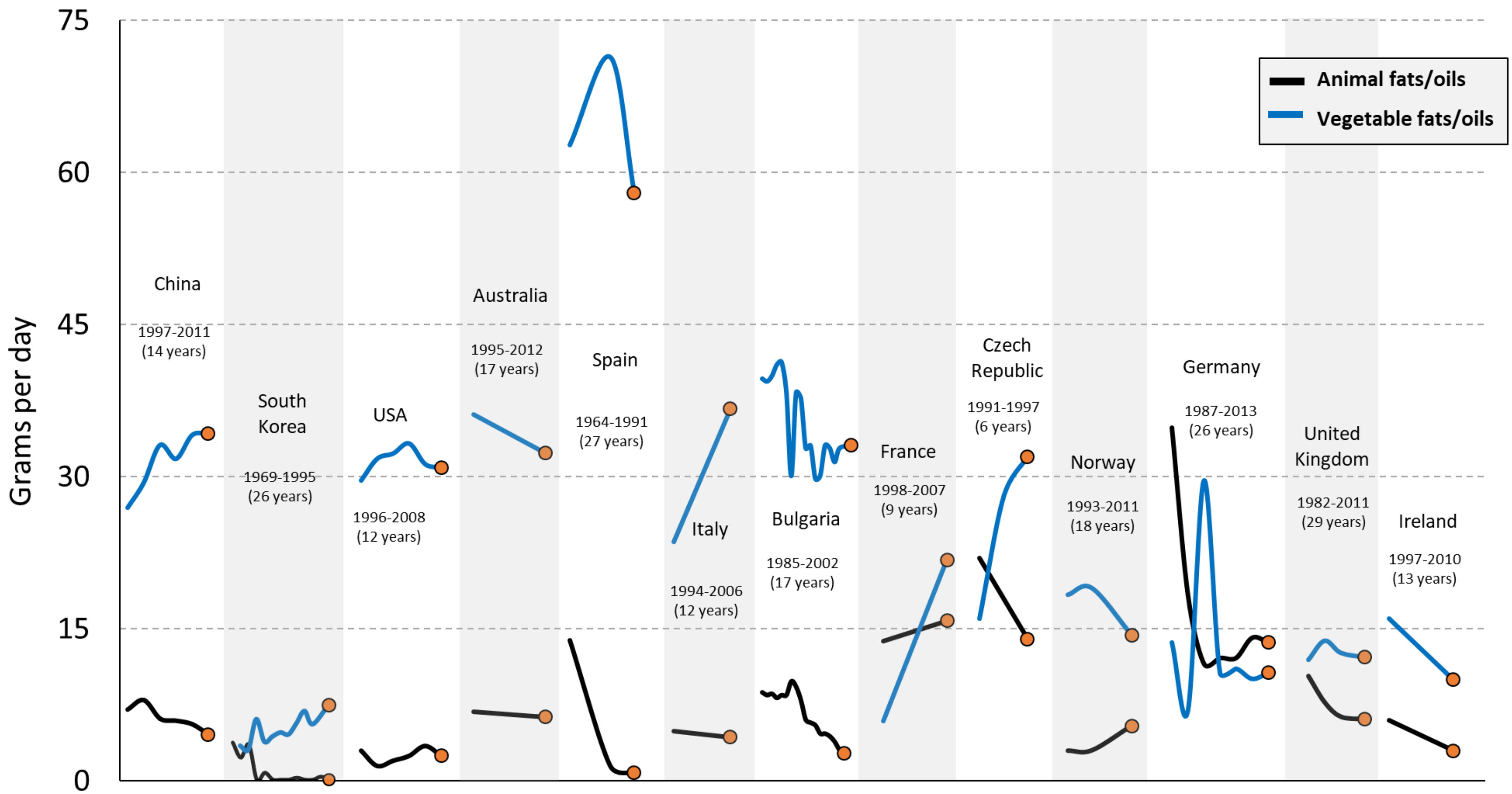
Supplementary Figure S17. Trend lines, nuts and seeds intake (% of total energy), by country, years 1950-2019 (n = 16 countries)



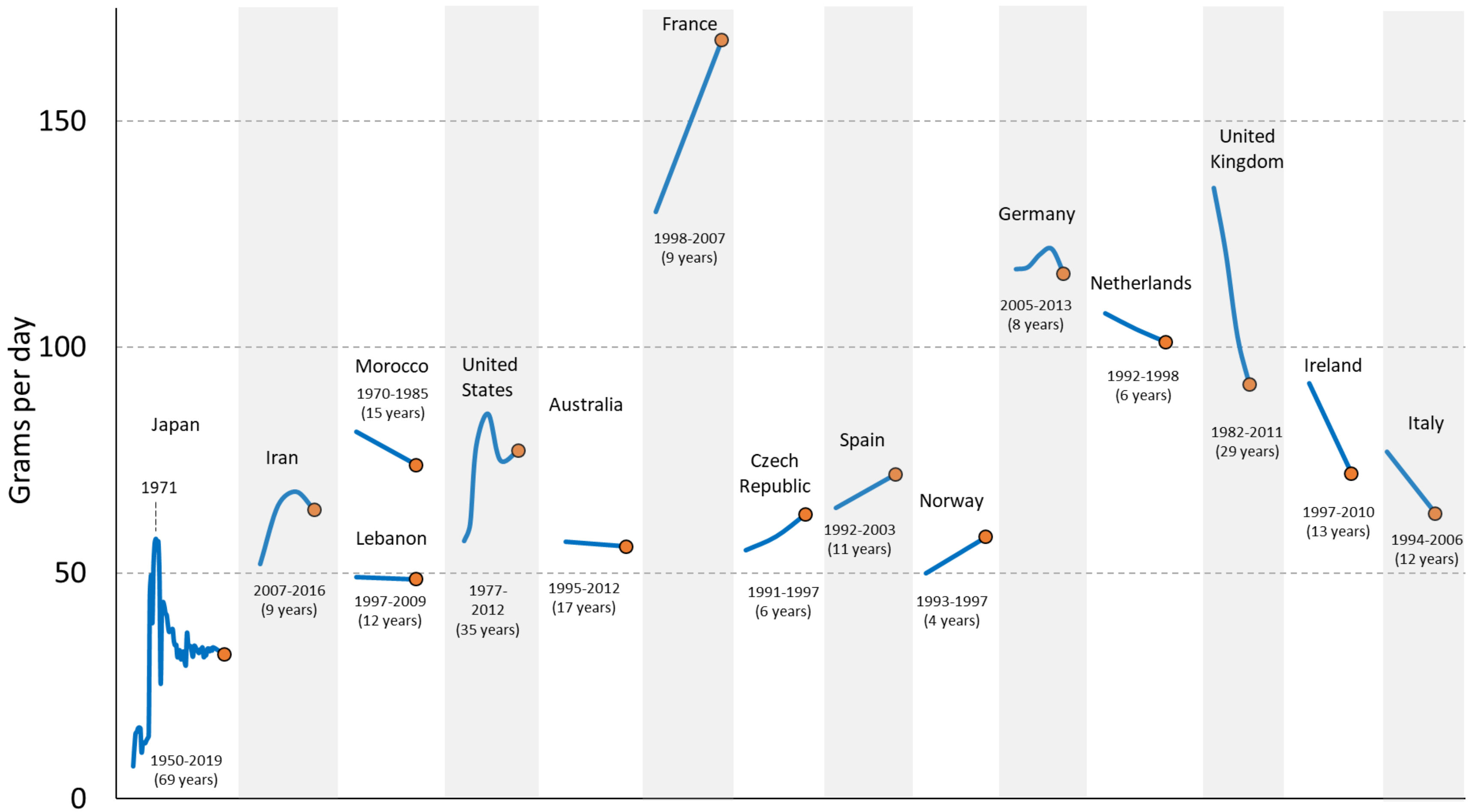
Supplementary Figure S18. Trend lines, <u>added fats and oils (butter, margarine, lard, oils)</u> intake (% of total energy), by country, years 1950-2019 (n = 21 countries)



Supplementary Figure S19. Trend lines, <u>added animal vs. vegetable fats and oils</u> intake (% of total energy), by country, years 1960-2019 (n = 13 countries)

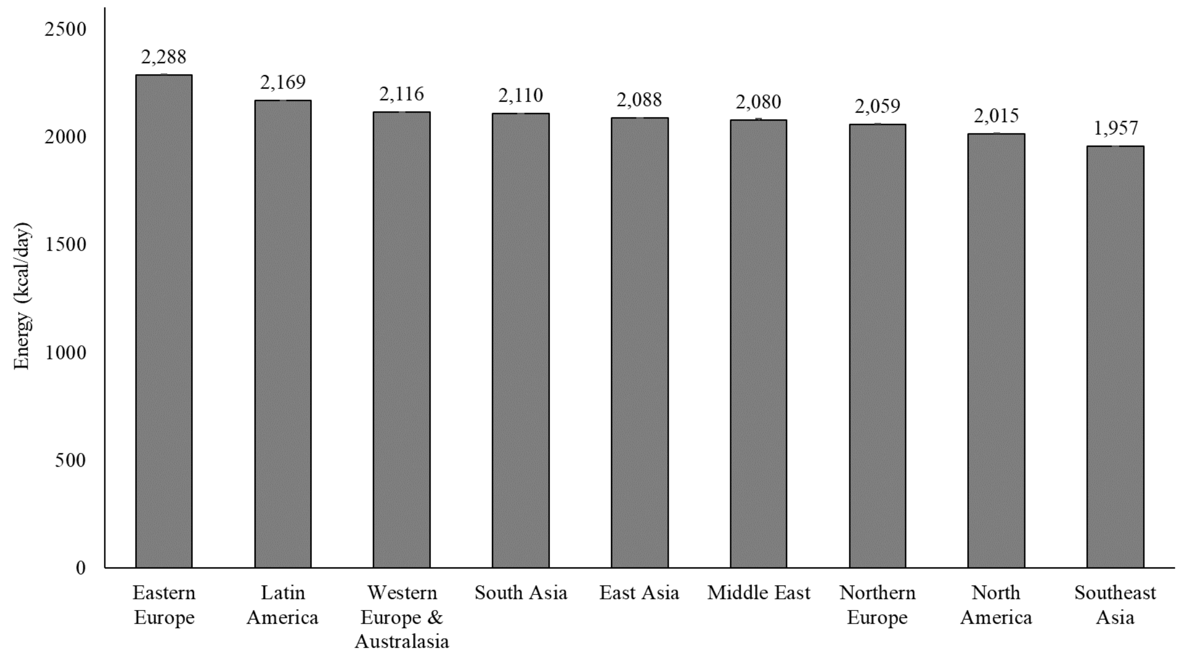


Supplementary Figure S20. Trend lines, <u>sweets (added sugars, ice cream, biscuits, confectionery)</u> intake (% of total energy), by country, years 1950-2019 (n = 15 countries)



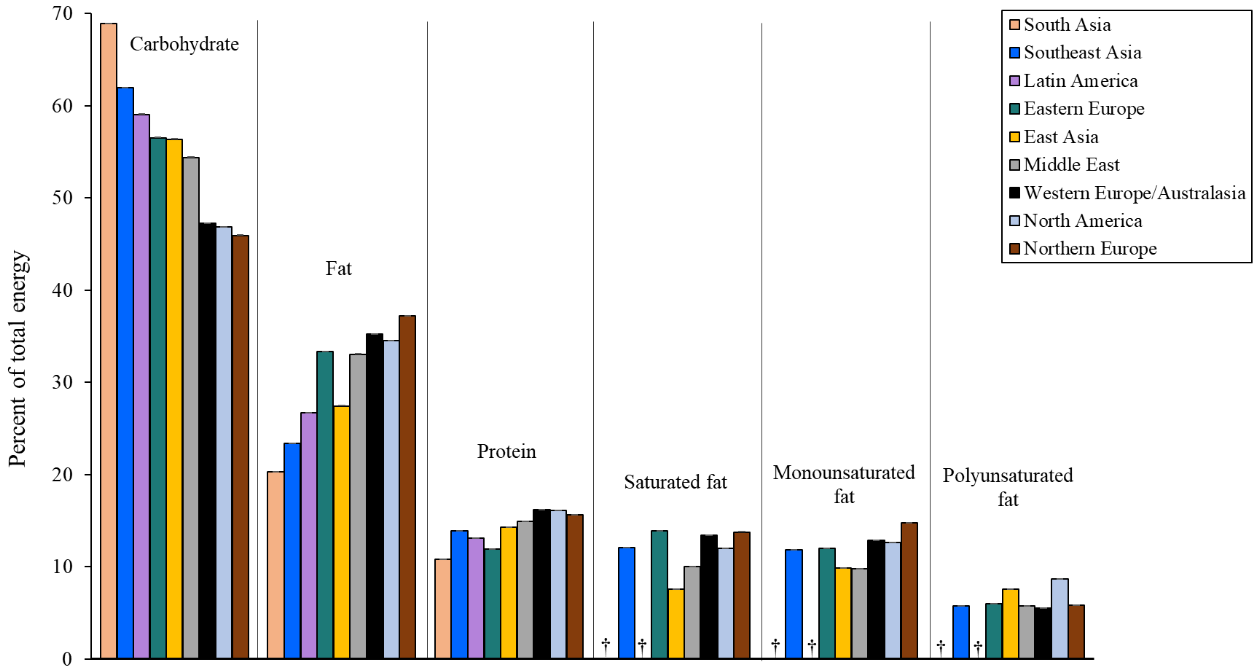
Supplementary Figure S21. Average (SE) intakes of macronutrients, fats, and foods based on most recent intakes (post year 2000)

A. Energy



Total number of particiapnts across surveys (sample size at last survey): Eastern Europe 11081, Latin America 16208, Western Europe and Australasia 35963, South Asia 4224, Middle East 3736, Northern Europe 9381, East Asia 42021, North America 20888, and Southeast Asia 346055.

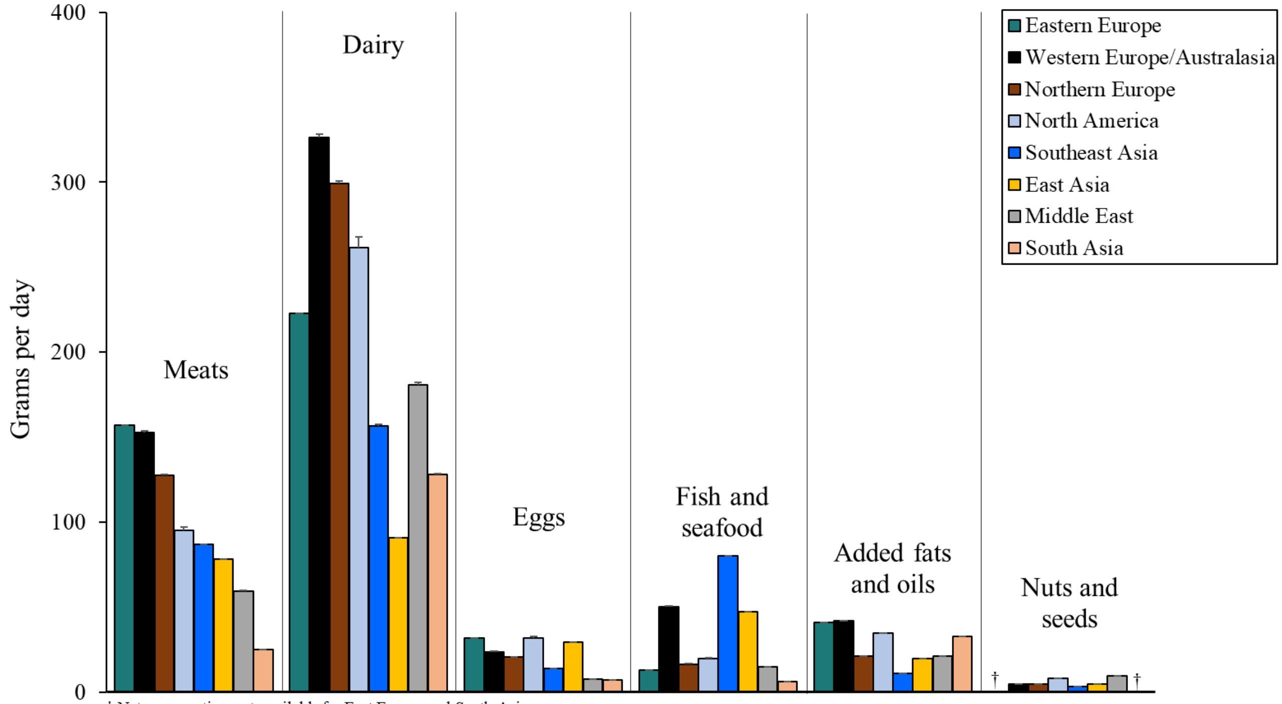
B. Macronutrients and types of fats (% of energy)



† Saturated, monounsaturated, and polyunsaturated fat estimates unavailable for South Asia and Latin America.

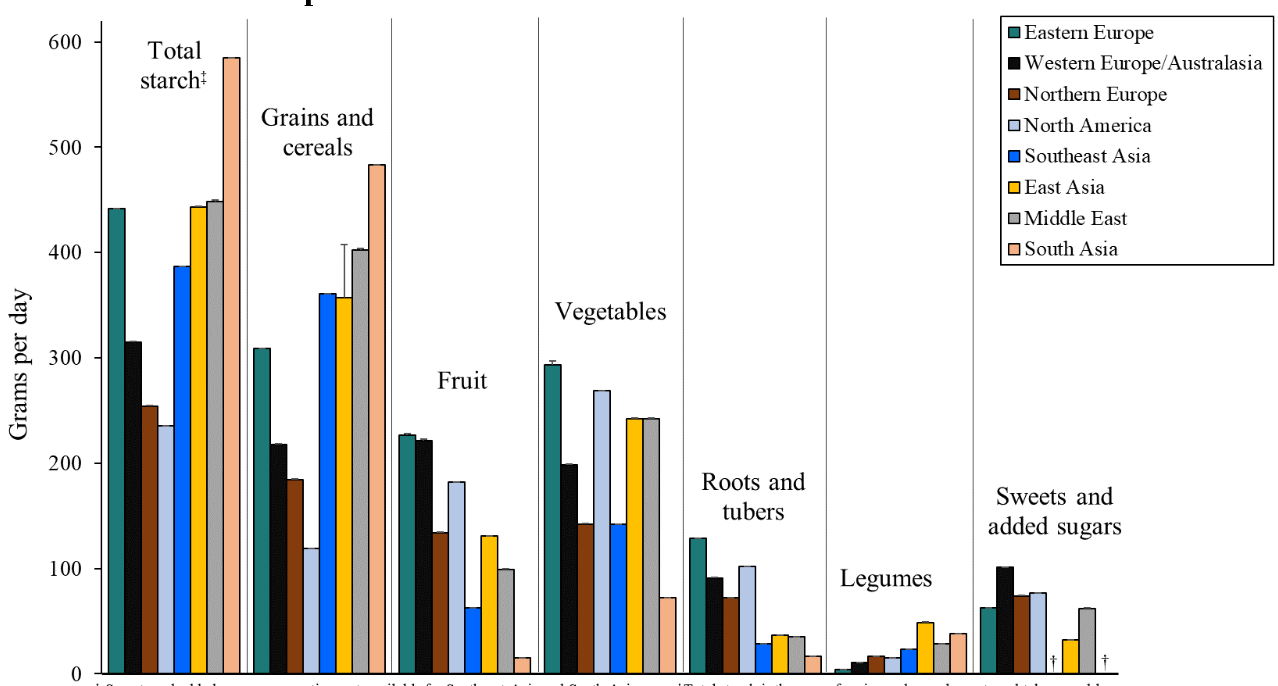
Total number of participants across surveys (sample size at last survey): South Asia 4224, Southeast Asia 346055 (1182 for types of fat), Latin America 16208, Eastern Europe 11081 (614 for types of fat), East Asia 42021 (37356 for types of fat), Middle East 3736 (3736 for types of fat), Western Europe/Australasia 35963 (33651 for types of fat), North America 20888 (4742 for types of fat), and Northern Europe 9381 (7985 for types of fat).

C. Animal proteins and other fats and oils



† Nut consumption not available for East Europe and South Asia.
Total number of participants across surveys: Eastern Europe 3787, Western Europe/Australasia 25700, Northern Europe 4050, North America 4742, Southeast Asia 21931, East Asia 28464, Middle East 17764, and South Asia 10000.

D. Starches and other plant foods

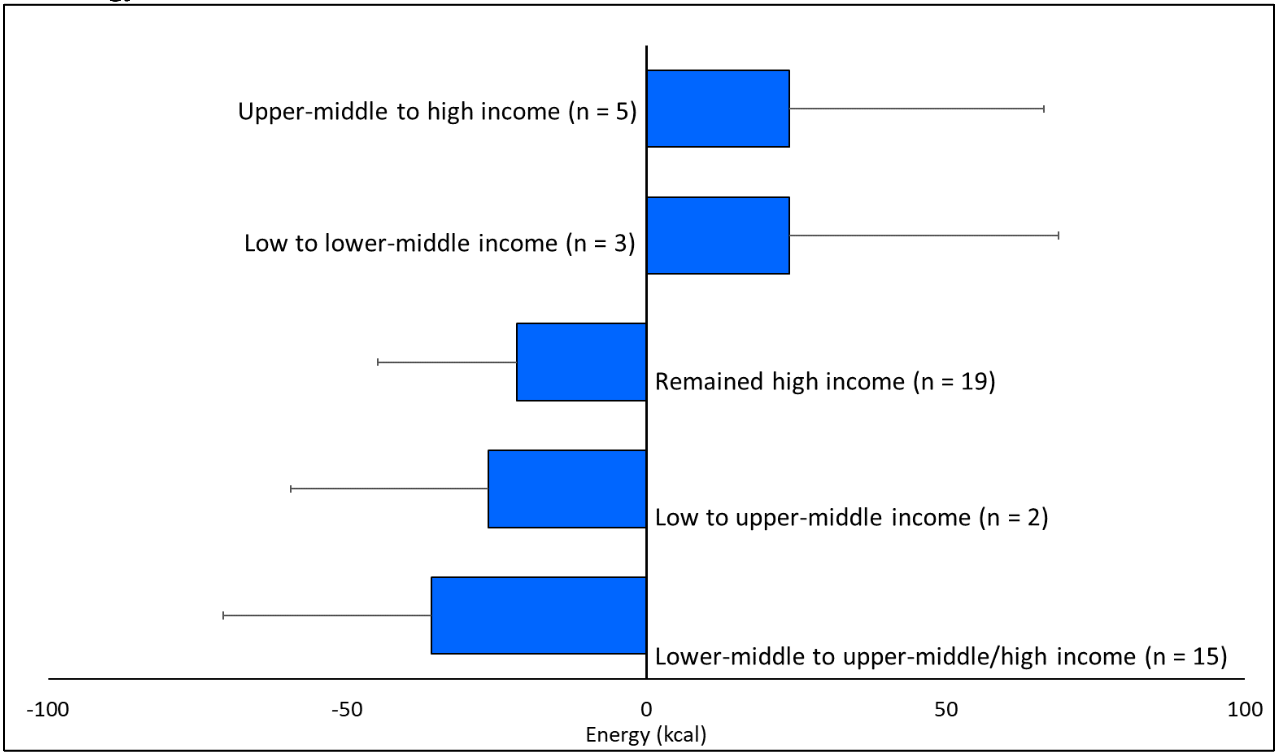


† Sweets and added sugar consumption not available for Southeast Asia and South Asia. ‡Total starch is the sum of grains and cereals, roots and tubers, and legumes.
Total number of participants across surveys: Eastern Europe 3787, Western Europe/Australasia 25700, Northern Europe 4050, North America 4742, Southeast Asia 21931, East Asia 28464, Middle East 17764, and South Asia 10000.

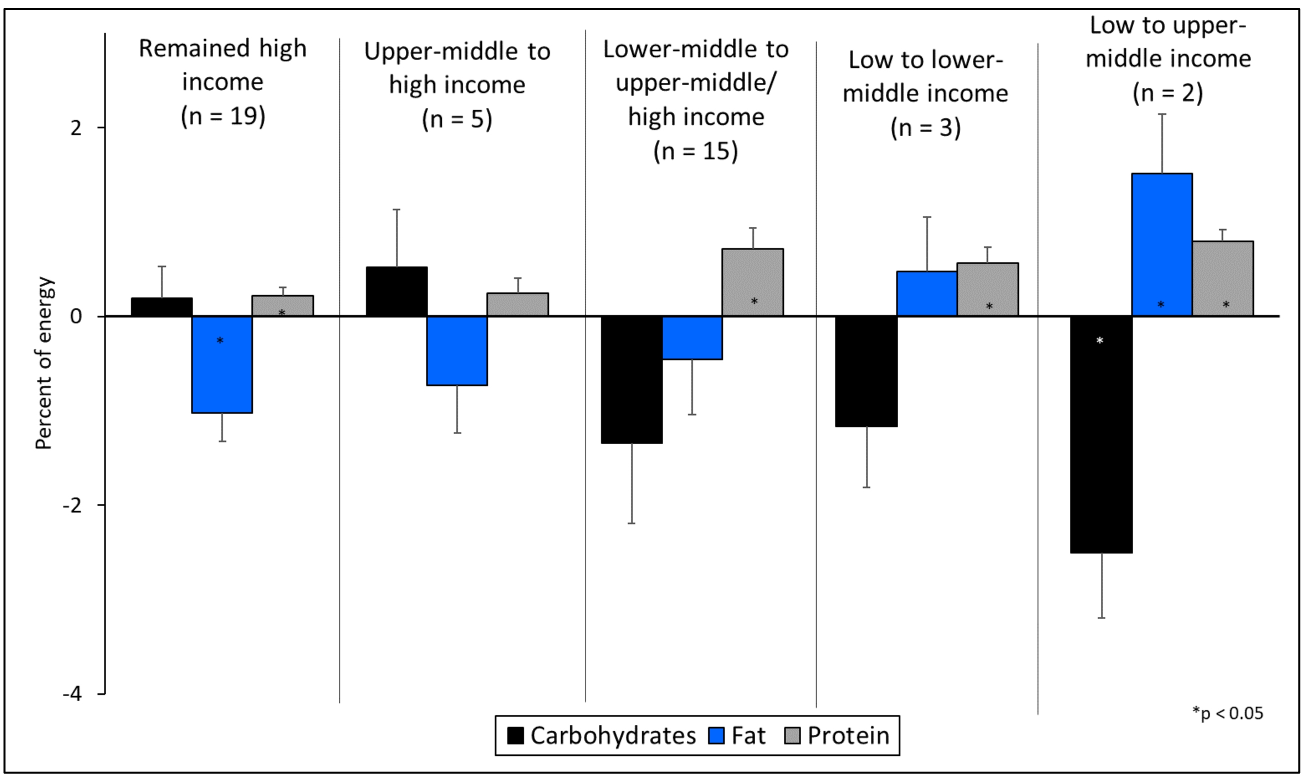
Foods not available for Latin America.

Supplementary Figure S22. Change in energy and macronutrient intakes, per decade (SE), by GDP transition from 1987-2019, adjusted for median age over time and method of dietary assessment

A. Energy



B. Macronutrients



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Chapter 3

Dietary changes over a 15-year period in 16 countries: findings from the PURE prospective cohort study

Prepared for submission.

Abstract

Background: Prospective cohort studies that assess dietary trends using repeat diet assessments in multiple world regions are few but are required to better understand changes in patterns of food consumption.

Methods: We examined changes in food and beverage consumption among adults during follow-up using the Prospective Urban Rural Epidemiology cohort study of individuals from 16 low-, middle, and high-income countries. Food and beverage intakes were measured repeatedly using a diet questionnaire every three years between 2007-2022. Changes were estimated using mixed-effects models, with a random intercept for participant nested within center, adjusted for age at baseline and sex.

Results: 121,029 participants had ≥1 dietary assessment over a median period of 12.1 years (IQR: 10.0-13.3). Overall, dietary change was modest, with some variations by region. Milk increased in middle-income countries (MICs) by 0.02 servings/day (95% CI: +0.01, +0.03), China by 0.14 s/day (+0.09, +0.20), and in low-income countries (LICs) by 0.05 s/day (+0.03, +0.06), while decreased in high-income countries (HICs) by -0.11 s/day (-0.14, -0.08). Eggs increased in HICs, MICs, and China up to 0.11 eggs/day (+0.10, +0.12), and remained unchanged in LICs. All regions increased chicken consumption, up to 0.09 s/day (+0.08, +0.10) in MICs. HICs increased cooked fish consumption by 0.04 s/day (+0.01, +0.07), with little change in other regions. Fruit consumption decreased in HICs (-0.12 s/day, -0.14, -0.10) and MICs (-0.01 s/day, -0.02, -0.003), while increased in China (+0.12 s/day, +0.10, +0.13) and LICs (+0.03 s/day, +0.02, +0.04). Fresh and cooked vegetable consumption decreased in HICs [-0.06 s/day (-0.07, -0.05) and -0.03 s/day (-0.05, -0.01), respectively] and in MICs [-0.03 s/day (-0.03, -0.02) and -0.08 s/day (-0.09, -0.07), respectively]. China decreased cooked vegetable (-0.04 s/day, -0.05, -0.03), with no change to fresh vegetable consumption. LICs increased fresh vegetable (+0.01 s/day, +0.004, +0.02), and did not change cooked vegetable intake. The probability of consuming >1.5s/day of rice decreased in HICs (0.04 to 0.02), MICs (0.23 to 0.18), China (0.42 to 0.27), and LICs (0.42 to 0.36) over follow-up.

Conclusions: In LICs, there were some improvements in components of higher diet quality, including increased milk, chicken, fruit, and fresh vegetables. Despite increases in fruit in China and LICs, consumption of fruits and vegetables did not improve in most regions between 2007-2022. This work aids in identifying targets for nutritional policies in different world regions.

Introduction

Diet is a potentially modifiable risk factor for cardiovascular and metabolic diseases, and for overnutrition (e.g., obesity) and undernutrition (e.g., stunting, wasting) which co-exist in different segments of the same populations (1-4). Efforts to increase the availability, accessibility, and affordability of healthy foods around the world are ongoing (1,3). However, the effectiveness of these efforts may vary between populations due to variability in cultural preferences for foods, socioeconomic development, national food supply chains, technological advancement, and public health policies (1-2).

Systematic assessments of dietary changes around the world are required. Many prior investigations of global dietary trends (5-9) rely on food supply estimates or household purchasing surveys, which may not reflect individual consumption as they do not account for food spoilage during production and transportation or food waste after purchase (9-10). At the individual level, the examination of dietary trends primarily relies on repeat cross-sectional assessments (e.g., Canadian Community Health Survey, China Health and Nutrition Survey) (11). With appropriate sampling techniques and the use of study weights, repeat cross-sectional surveys are a useful method to measure dietary trends in large nationally representative samples of participants. However, many countries, especially lower-income countries, do not have adequate cross-sectional dietary assessments of trends (8).

In addition to repeat cross-sectional studies, to study changes in diet, prospective long-term cohort studies with several standardized repeat diet assessments are valuable. Previous cohort studies of dietary trends typically focus on a single country (e.g., The

Canadian Longitudinal Study on Aging, Blue Mountains Eye Study, Cebu Longitudinal Health and Nutrition Survey). The present analysis from The Prospective Urban Rural Epidemiology (PURE) Study is the first to assess secular trends in diet in a large global prospective cohort study of individuals sampled from the general community, involving multiple low-, middle-, and high-income countries from several continents. The specific objective of this study was to assess trends in intakes of food and beverage groups over fifteen years of follow-up in the PURE Study overall, and in countries grouped by geographic regions and income levels.

Methods

Study design and participants

The design of the PURE study (NCT03225586) has been described previously (12-13). Briefly, the study is a large prospective cohort study of free-living men and women aged 35 to 70 years. For the current analysis, we included countries from the first phase of enrollment with >2 cycles of follow-up, including participants from 626 urban and rural communities in 16 countries (Argentina, Brazil, Canada, Chile, China, Colombia, India, Iran, Malaysia, Pakistan, Poland, South Africa, Sweden, Türkiye, United Arab Emirates, and Zimbabwe). The PURE sampling, recruitment, and data collection approach are described in prior publications (12-13). Countries were categorized into seven geographic regions, including North America/Europe (Canada, Poland, Sweden, Türkiye), South America (Brazil, Chile, Argentina, Colombia), the Middle East (United Arab Emirates, Iran), South Asia (India, Pakistan), China, Malaysia, and Africa (South Africa, Zimbabwe) (Suppl. Table S1). Countries were also grouped into four income groups, including high-income (Canada, Sweden, United Arab Emirates), middle-income (South Africa, Poland, Türkiye, Brazil, Chile, Argentina, Malaysia, Iran, Colombia), China as its own region (due to rapid changes in income relative to other countries), and low-income (India, Pakistan, Zimbabwe) (12-13). Recruitment occurred between January 2003 and March 2013. Standardized questionnaires were used to collect information about sociodemographic factors, health behaviors, health history, and medication use by research assistants trained with comprehensive operation manuals, videos, and workshops. Standard case-report forms were employed to record data on cardiovascular disease events, cancers, hypertension, and diabetes during follow-up, which were adjudicated centrally in each country by trained researchers using common definitions (12-13). During the follow-up, each participant was contacted at least every three years either by telephone or by a face-to-face visit. The study was approved by Hamilton Health Sciences Research Ethics Boards and by research ethics committees at each center.

Procedures

A 17-22 item FFQ (sFFQ) was consistently administered every three years at follow-up cycles (e.g., 3, 6, 9, 12-year) in each country. For this analysis, only follow-up dietary data were used as the baseline FFQ is a different longer dietary instrument of up to 220 different food items and may not be compatible with the sFFQ. Food and beverage items were grouped into nine common groups to allow for comparison across the follow-up cycles: milk, eggs, chicken, unprocessed red meat, cooked fish, rice, fruits, fresh/raw vegetables, and cooked vegetables (Suppl. Table S2). Egg, cooked vegetable, and fish intake were measured consistently across follow-up visit two to follow-up visit four. On the sFFQ, participants were asked, “During the past year, on average, how often have you consumed the following foods or drinks?”. Reported frequencies of consumption varied from never to >4 times/day, and country-specific portion sizes were applied when frequencies were converted to intakes. For comparison, standard serving sizes, where one serving of milk (244.0 grams), eggs (50.0 g), chicken (50.0 g), red meat (50.0 g), fish (87.5 g), rice (150.0 g), fruits (125.0 g), and vegetables (125.0 g) were assigned to each food item. At each follow-up, participants were asked “Have you changed your diet during the last three years?” and “if yes, was it due to health conditions?”.

Statistical analysis

Participants without repeated dietary measurements (n = 19,010) were excluded (Suppl. Table S3). The primary analysis was a longitudinal analysis using linear mixed-effect models with dietary variables measured at each time point in servings/day (s/day) as the response variable, visit number as a fixed effect, and a random participant-specific intercept, nested within center (also adjusts for region and country). Outliers were removed (>99th percentile). As the distribution of reported rice intake was not continuous, mixed-effect multinomial logistic regression with a random participant-specific intercept, nested within center was applied. For rice intake, participants were grouped into four intake groups: <0.5 s/day, 0.5-1.0 s/day, 1.0-1.5 s/day, and >1.5 s/day. We estimated changes in food intake over the full follow-up for all items (2007-2022), except for eggs, cooked fish, and cooked vegetables which were assessed consistently from follow-up visit two onwards. The dietary changes were assessed overall and by groups of countries by region and income category, adjusting for age at baseline (as not all participants had a follow-up visit one) and sex.

Although the cohort is aging over time, we do not expect most participants to change their diet due to aging, as the cohort includes mostly middle-aged adults (82.3% of the population was <65 years old at the first follow-up visit). Typically, dietary change occurs in older adults (e.g., >70 years old) as their need for calories decreases, and only 5.2% of the PURE cohort was >70 years old at the first follow-up visit (14-16). Nevertheless, to test if dietary change over time differed from dietary change related to aging, we examined if the dietary change estimates in the overall population (aging over time) were similar to change among two subsets that were the same age at different time points. The two subsets included a subset of the population that was aged 55-60 years old at follow-up visit two and a subset that was aged 55-60 years old at follow-up visit four. We performed a sensitivity analysis to examine if trends differed among older adults (≥65 years old at baseline) compared to middle-aged adults (<65 years old at baseline). The older adult ≥65 age group captures dietary change in participants who are an average age of 70.7 (SD 2.5) years old at repeat visit one to an average age of 79.1 (SD 3.5) years old by visit four. To examine if there was a difference between older and middle-aged adults, we tested if the interaction between this age grouping and time in the study was significant. We also performed sensitivity analyses comparing trends a) among participants who reported changing their diet at any follow-up visit relative to those who did not report changing their diet and b) among participants who reported having an event during the follow-up (reported until September 15, 2022) compared to the remaining population. Data were analyzed using R version 4.2.2.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or manuscript writing.

Results

A total of 121,029 participants were included in this analysis, of which 29,602 provided one measure, 39,698 two repeat measures, 35,311 three repeat measures, and 16,418 four repeat measures (Suppl. Table S3). As a participant could contribute multiple repeat diet measures over follow-up, there were 79,187 participants at follow-up visit one, 60,825 participants at follow-up visit two, 76,055 participants at follow-up visit three, and 65,356 participants at follow-up visit four (Table 1). Participant characteristics were similar across the four follow-up cycles (Table 1). Median follow-up time was 12.1 years (IQR: 10.0–13.3) (Suppl. Table S1). About a sixth of participants reported changing their diet since their last follow-up visit, of which 68.0–73.4% changed their diet due to health conditions (Table 1). In the overall population, consumption of milk (+0.07 s/day, 95% CI: +0.06, +0.08, $p < 0.0001$), eggs (+0.06 s/day, +0.05, +0.06, $p < 0.0001$), chicken (+0.07 s/day, +0.06, +0.09, $p < 0.0001$), unprocessed red meat (+0.06 s/week, +0.03, +0.09, $p < 0.0001$), cooked fish (+0.02 s/week, +0.01, +0.02, $p = 0.0002$), and fruit (+0.03 s/day, +0.03, +0.04, $p < 0.0001$) increased. Fresh vegetable (-0.03 s/day, -0.03, -0.03, p

<0.0001) and cooked vegetable (-0.05 s/day, -0.05, -0.04, p <0.0001) consumption decreased over follow-up.

Changes in diet over 15 years of follow-up by *geographic region*

Over the follow-up duration, milk consumption increased in China (+0.14 s/day, +0.09, +0.20), Africa (+0.09 s/day, +0.01, +0.16), South America (+0.07 s/day, +0.05, +0.09), and South Asia (+0.02 s/day, +0.01, +0.03), and decreased in Malaysia (-0.21 s/day, -0.33, -0.10) and North America/Europe (-0.06 s/day, -0.08, -0.05), and was unchanged in the Middle East (Figure 1-2). Egg intake increased in China (+0.11 eggs/day, +0.10, +0.12), South America (+0.09 eggs/day, +0.08, +0.10), Malaysia (+0.06 eggs/day, +0.04, +0.08), North America/Europe (+0.05 eggs/day, +0.04, +0.06), and was unchanged in the Middle East, South Asia, and Africa. Chicken consumption increased in Malaysia (+0.18 s/day, +0.14, +0.23), South America (+0.13 s/day, +0.12, +0.14), the Middle East (+0.12 s/day, +0.10, +0.15), Africa (+0.12 s/day, +0.08, +0.16), China (+0.06 s/day, +0.04, +0.08), and South Asia (+0.01 s/day, +0.005, +0.02), and decreased in North America/Europe (-0.03 s/day, -0.03, -0.02). Unprocessed red meat intake increased in the Middle East (+0.13 s/day, +0.10, +0.17), North America/Europe (+0.04 s/day, +0.03, +0.06), China (+0.03 s/day, +0.02, +0.04), and South Asia (+0.002 s/day, +0.0006, +0.004), decreased in South America (-0.23 s/day, -0.32, -0.14), and intakes were unchanged in Malaysia and Africa. Cooked fish increased in North America/Europe (+0.02 s/day, +0.01, +0.04), decreased in South America (-0.01 s/day, -0.01, -0.002) and China (-0.01 s/day, -0.01, -0.002), and was unchanged in remaining regions. Fruit intake increased in China (+0.12 s/day, +0.10, +0.13), South Asia (+0.04 s/day, +0.03, +0.05), and the Middle East (+0.03 s/day, +0.02, +0.05), decreased in Africa (-0.19 s/day, -0.24, -0.13), North America/Europe (-0.11 s/day, -0.12, -0.09), Malaysia (-0.05 s/day, -0.07, -0.03), and did not change in South America. Fresh vegetable consumption increased in South Asia (+0.01 s/day, +0.004, +0.02), decreased in the Middle East (-0.06 s/day, -0.08, -0.05), North America/Europe (-0.05 s/day, -0.05, -0.04), and South America (-0.01 s/day, -0.02, -0.01), and was unchanged in China, Malaysia, Africa. Cooked vegetable consumption increased in South Asia (+0.02 s/day, +0.01, +0.04), and decreased in Africa (-0.10 s/day, -0.14, -0.05), South America (-0.09 s/day, -0.11, -0.07), Malaysia (-0.05 s/day, -0.08, -0.01), the Middle East (-0.05 s/day, -0.07, -0.03), North America/Europe (-0.04 s/day, -0.06, -0.02), and China (-0.04 s/day, -0.05, -0.03). Overall, rice intake decreased in all regions (Figure 3). For instance, the probability of consuming >1.5s/day of rice decreased over follow-up in North America/Europe [0.03 (95% CI: 0.03, 0.03) on visit 1 to 0.02 (0.02, 0.02) on visit 4], South America [0.17 (0.17, 0.17) to 0.12 (0.12, 0.12)], the Middle East [0.14 (0.14, 0.14) to 0.05 (0.05, 0.05)], South Asia [0.44 (0.44, 0.44) to 0.38 (0.38, 0.38)], China [0.42 (0.42, 0.43) to 0.27 (0.27, 0.27)], and Malaysia 0.73 (0.73, 0.73) to 0.66 (0.65, 0.66)] (all $p < 0.0001$) (Figure 3). In Africa, the probability of consuming >1.5s/day did not change over follow-up ($p = 0.18$), though the probability of consuming 1.0-1.5 s/day decreased from 0.12 (0.12, 0.12) to 0.07 (0.07, 0.07) over follow-up ($p < 0.0001$).

Dietary trends over 15 years of follow-up by *country income group*

Results for China are presented in the previous section. Over follow-up, milk intake increased in low-income countries (LICs) by 0.05 s/day (95% CI: +0.03, +0.06) and middle-income countries (MICs) by 0.02 s/day (+0.01, +0.03) (Figure 4-5). By contrast, milk intake decreased in high-income countries (HICs) by -0.11 s/day (-0.14, -0.08). Egg intake increased in HICs (+0.06 eggs/day, +0.05, +0.07), MICs (+0.05 eggs/day, +0.05, +0.06), but intakes were unchanged in LICs. In HICs, chicken and unprocessed red meat consumption increased by 0.02 s/day (+0.01, +0.03) and +0.04 s/day (+0.02, +0.05), respectively. In MICs, chicken consumption increased (+0.09 s/day, +0.08, +0.10), while unprocessed red meat decreased (-0.04 s/day, -0.05, -0.03). In LICs, there were small increases in chicken (+0.02 s/day, +0.01, +0.03) and unprocessed red meat (+0.01 s/day, +0.001, +0.02) intakes. There were increases in fish intakes over follow-up in HICs, MICs, and LICs, up to an increase of +0.04 s/day (+0.01, +0.07) in HICs. Fruit consumption decreased in HICs (-0.12 s/day, -0.14, -0.10) and MICs (-0.01 s/day, -0.02, -0.003), and increased in LICs (+0.03 s/day, +0.02, +0.04). Fresh vegetable and cooked vegetable consumption decreased in HICs [-0.06 s/day (-0.07, -0.05) and -0.03 s/day (-0.05, -0.01), respectively] and MICs [-0.03 s/day (-0.03, -0.02) and -0.08 s/day (-0.09, -0.07), respectively], while LICs increased fresh vegetable consumption (+0.01 s/day, +0.004, +0.02) and did not change cooked vegetable consumption. Rice intake decreased in all income regions (Figure 3). For example, the probability of consuming >1.5s/day of rice decreased in HICs [0.04 (0.04, 0.04) in visit 1 to 0.02 (0.02, 0.02) in visit 4], MICs [0.23 (0.23, 0.23) to 0.18 (0.18, 0.18)], and LICs [0.42 (0.42, 0.42) to 0.36 (0.35, 0.36)] (all p <0.0001) (Figure 3).

Sensitivity analyses

Dietary changes in the cross-sectional subset of participants aged 55-60 at repeat visit two and aged 55-60 years old at repeat visit four were similar to changes observed in the overall population (Suppl. Figure S1). This suggests that dietary changes observed in the overall population are likely not related to the aging of the cohort. Overall, dietary change was consistent in a) participants <65 years old compared to participants ≥65 years old, b) participants who reported changing their diets compared to those who did not report changing their diets, and c) participants with interim events compared to participants without interim events (Suppl. Figures S2-S4).

Discussion

In this large international prospective cohort study from 16 countries in five continents, we analyzed dietary trends from four cycles of follow-up collected across fifteen years. Overall, dietary change was modest over follow-up, with some variations by geographic and country income groupings. Milk decreased in high- and middle-income countries and increased in China and low-income countries. Overall, all regions increased or maintained egg, chicken, and cooked fish consumption, while all regions decreased rice consumption. Unprocessed red meat increased in all income regions, except middle-income countries decreased intakes. High- and middle-income countries decreased fruit, fresh vegetable, and cooked vegetable consumption. China increased fruit, maintained fresh vegetable intake, and decreased cooked vegetable consumption. Low-income countries increased fruit and fresh vegetable intakes and did not change cooked vegetable consumption.

Collectively, our results suggest some improvements in components of higher diet quality in China and low-income countries, including increased milk, chicken, and fruit consumption. However, there were no improvements in fruit and vegetable intakes in other regions between 2007-2022, highlighting the importance of sustaining and creating nutritional policies and interventions aimed at increasing fruit and vegetable consumption in all world regions.

Several of our findings are consistent with estimates of change from food supply data, the Global Dietary Database (GDD), the Global Burden of Disease Study (GBD) (Suppl Table S4), and previous repeat cross-sectional studies of diet over time (17-31). However, some findings are inconsistent. Coherent with the findings in North America/Europe, both the Canadian Community Health Surveys (CCHS, 2004-2015) and NHANES in the United States (1996-2008) observed decreased milk and vegetable, increased egg, and little change to total meat, fish, and rice intakes (21-23). Unlike our study, whole fruit consumption was stable in both CCHS and NHANES, though fruit juice decreased (21-23). Although we observed a decrease in fruit consumption, we used a shorter diet questionnaire that asks about overall whole fruit consumption, which may not have captured all fruit products. For example, in Canada, the United States, and Europe, frozen fruit availability has increased in the last decade, and our findings may reflect a shift from whole to frozen fruits (32-34). Our findings in South America are generally consistent with previous studies (e.g., the Health Survey of São Paulo in Brazil, 2003-2015) (24-25).

Inconsistent with our results, the GDD (2005-2018) estimated that non-starchy vegetables increased, and unprocessed red meat decreased in the Middle East (Suppl. Table S4) (18). The decrease in rice in the Middle East is consistent with the Tehran Lipid Study (2006-2017) in Iran which observed decreases in overall refined grains (26). Our findings, consistent with national trend estimates (2002-2012), found China increased milk, egg, meat and poultry, and fruit, and decreased vegetable and refined grain consumption (27-28). Both our study and the GDD study found increases in milk, poultry, fruit, and vegetable and decreases in rice intakes in South Asia (19-20). The decrease in rice in South Asia was not expected, but overall small, and the estimate may not include rice eaten in mixed dishes as we used a shorter dietary instrument. Our results are directionally consistent with the Malaysian Adult Nutrition Survey which observed decreased milk, fruit, rice, and increased chicken and egg consumption between 2003 and 2014 (29-30). Both the PURE study and the Cardiovascular Risk in Black South Africans (CRIBSA, 1990-2009) study observed stable meat consumption, however, only PURE observed increased milk, and decreased fruit and vegetable consumption, though CRIBSA was only among an urban population which may explain the differences (31). Variability in findings between previous studies and the PURE study may reflect differences in the composition of participants, the dietary assessment method, and different modeling techniques.

Dietary trends are influenced by many region-specific factors, including changes in income, food price, environmental crises (e.g., floods, droughts, wildfires, pests), supply chain disruptions, food taxes and subsidies, higher female participation in the workforce, cultural preferences, and nutrition policies (35-37). For example, both China and the United Arab Emirates had among the largest increases in GDP per capita during the 15 years of follow-up (Suppl. Figure S5), amid changes to industrialization, and modernization of food supply (29-30). This may partly explain why China increased milk, eggs, and fruit the most compared to other regions, while the Middle East increased chicken and unprocessed red meat consumption. Our findings in South America can be related to a combination of dietary guidelines advocating to replace red meats with white meats but may also reflect rising prices of red meat compared to other meats (40-41).

Fruit intake increased in the Middle East, South Asia, and China, but decreased in North America/Europe, Malaysia, and Africa. Despite increases in fruit in South Asia, intakes remain significantly lower than in other regions. The decrease in fruit in Malaysia and Africa suggests a lack of improvement and is concerning as they are among the regions with the lowest intakes (42). In 2018, the Global Burden of Disease Study estimates that globally, 4.5% of all premature deaths were attributable to diets low in fruit, up from 4.1% in 2010, with little change to the burden of mortality from diets low in vegetables (2.5% to 2.6%) (43-44). Between 2010 and 2018, the burden of mortality from diets low in fruit increased the most in Oceania (2.7% to 3.6%), Asia (5.2% to 5.6%), and Africa (2.3% to 2.9%) (43-44). Collectively, our findings suggest that the burden of disease from diets low in fruit and vegetables has not improved. Moreover, fruit and vegetables are becoming more expensive in many countries which impedes change. For instance, the price index of fruit and vegetables increased by 9.4% in India and 11.9% in Zimbabwe between 2011 and 2017 (45). Current dietary guidelines recommend five servings of fruits and vegetables per day, but even modest increases to three servings per day are associated with a lower risk of mortality (42). Efforts to increase fruit and vegetable intake are urgently needed.

Our results in low-income countries are consistent with others (20, 46), and suggest some improvements in nutrient availability as we observed a decrease in rice and an increase in milk, chicken, and fruit consumption. Malnutrition and overconsumption of carbohydrates remain a concern in many LICs, and increased consumption of fruit and animal products may be important for increasing intakes of essential micronutrients (e.g., zinc, vitamin B12) (35-36). Unprocessed red meat and vegetable consumption had little change over follow-up, which may be partly explained by the rising price of meat and vegetables, and the cultural preference toward white meat over red meat (47). On average, between 2011 and 2017, the price index of meat increased by 26.8% and 27.7% for vegetables for the LICs in this study, whereas average GDP per capita growth was 4.3% over the same period (23). Our results support prior evidence that any extra income in LICs (Suppl. Figure S5) is likely to be spent on “high-value” foods (e.g., dairy, meat, fruit) (48-50). In a previous analysis, a 10% increase in household disposable income increased meat and dairy expenditure in Sub-Saharan Africa and South Asia by over 8%, compared to only 3.5% in the United States (48).

Our findings suggest that participants sampled from the general community who are diagnosed with a new event were unlikely to change their diets. This is contrary to nutrition guidelines which suggest that populations with chronic diseases should increase consumption of vegetables, fruits, whole grains, nuts, legumes, and seafood, and reduce refined grains, processed meats, sugar-sweetened beverages, sodium, and trans fats (42). However, behavior modification is challenging, especially considering dietary patterns are rooted in traditional patterns of eating, culture, and taste preferences, as well as food availability and affordability (43-44). Also, other foods and nutrients that may be more likely to change following an event (e.g., sodium, processed meats, sugar) are not reflected in this study.

Strengths and limitations

This is the first study involving a population-based prospective cohort of several countries that have standardized repeat measures of dietary intakes over fifteen years. Study strengths include its prospective design, the inclusion of 16 countries from five continents, a large number of participants enrolled from 626 communities, and a moderate duration of follow-up. Despite some missing data during follow-up, there was a comparable representation of participant characteristics over time. Our findings were robust to sensitivity analyses investigating trend differences by age, and by participant event status. In sensitivity analyses investigating trends among participants aged 55-60 years old at two different time points, results were comparable to changes observed in the overall population, suggesting trends are not driven by population aging. Our study has several potential limitations. The short diet tool used in this study has not been validated. We reported dietary trends for a few key food items, but were unable to examine changes in energy, macronutrients, and other food items such as sugar, processed foods, and added fats/oils. For example, the intake of major foods in Africa (e.g., porridge, sadza) and China (e.g., millet, sorghum) were not measured. As a result, we may not have captured the largest changes occurring in a country/region. Due to the nature of a shorter dietary tool, we underestimated dietary intake as we have not captured all components of a food group, for instance, frozen fruits as part of fruits, or mixed dishes which can include vegetables, meats, and rice.

Conclusion

In this international prospective study, we captured differences in dietary changes over fifteen years of follow-up across different world regions. There were some encouraging trends, such as increased fruit in South Asia and China, however, fruit decreased among the lowest consumers, including Malaysia and Africa. Consumption of vegetables did not improve in most regions between 2007-2022. This work aids in identifying targets for nutritional policies and interventions and highlights the importance of sustaining and creating new initiatives aimed at increasing fruit and vegetable consumption in different world regions.

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Dietary changes over a 15-year period in 16 countries: findings from the PURE prospective cohort study

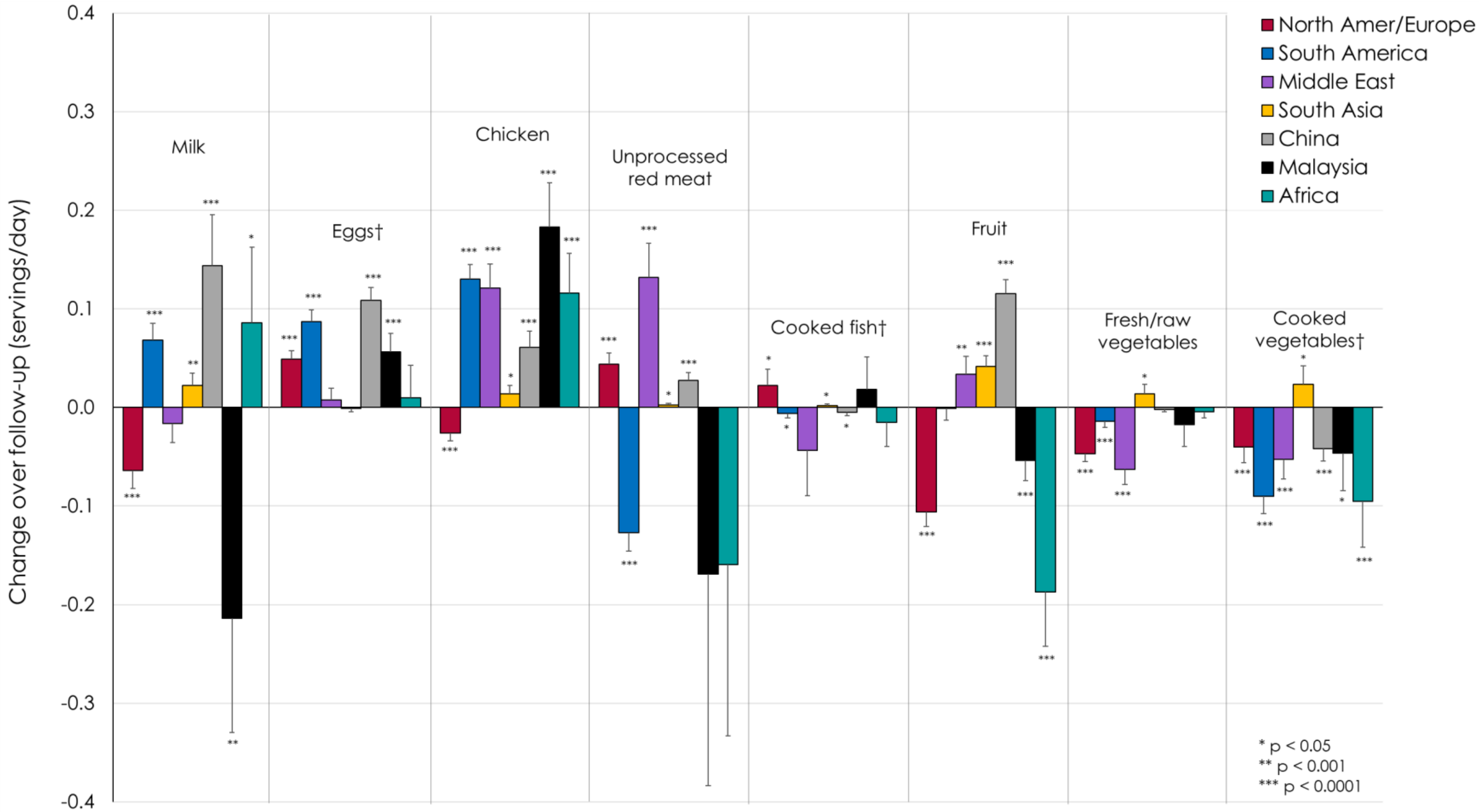
Tables and Figures

Table 1. Characteristics of the study participants providing dietary data during follow-up

Characteristic	Follow-up visit 1	Follow-up visit 2	Follow-up visit 3	Follow-up visit 4
Number of participants	79,187	60,825	76,055	65,356
Age at initial assessment (SD)	50.8 (9.8)	50.9 (9.7)	50.4 (9.7)	50.3 (9.5)
Age in years, mean (SD)	54.1 (9.8)	58.0 (9.7)	60.0 (9.7)	62.4 (9.5)
Female, n (%)	46707 (59.0)	35971 (59.1)	45266 (59.5)	38794 (59.4)
Urban location, n (%)	42816 (54.1)	34866 (57.3)	38855 (51.1)	35382 (54.1)
Geographic regions, n (%)				
North America/Europe	16441 (20.8)	16156 (26.6)	15095 (19.8)	13806 (21.1)
South America	13896 (17.5)	10693 (17.6)	14058 (18.5)	12346 (18.9)
Middle East	5948 (7.5)	3507 (5.8)	2959 (3.9)	3723 (5.7)
South Asia	14415 (18.2)	10832 (17.8)	12624 (16.6)	7801 (11.9)
China	22081 (27.9)	15322 (25.2)	23627 (31.1)	23709 (36.3)
Malaysia	5034 (6.4)	3216 (5.3)	6566 (8.6)	2840 (4.3)
Africa	1372 (1.7)	1099 (1.8)	1126 (1.5)	1131 (1.7)
Country Income groups, n (%)				
High income	12446 (15.7)	12224 (20.1)	11537 (15.2)	10191 (15.6)
Middle income	29437 (37.2)	22276 (36.6)	27447 (36.1)	23152 (35.4)
China	22081 (27.9)	15322 (25.2)	23627 (31.1)	23709 (36.3)
Low income	15223 (19.2)	11003 (18.1)	13444 (17.7)	8304 (12.7)
Reported changing diet, n (%)*	10777 (13.6)	8981 (14.9)	10720 (14.1)	5460 (13.0)
Reported changing their diet due to health conditions, n (% of total who reported changing their diet)	7670 (71.2)	6111 (68.0)	7222 (67.4)	4010 (73.4)

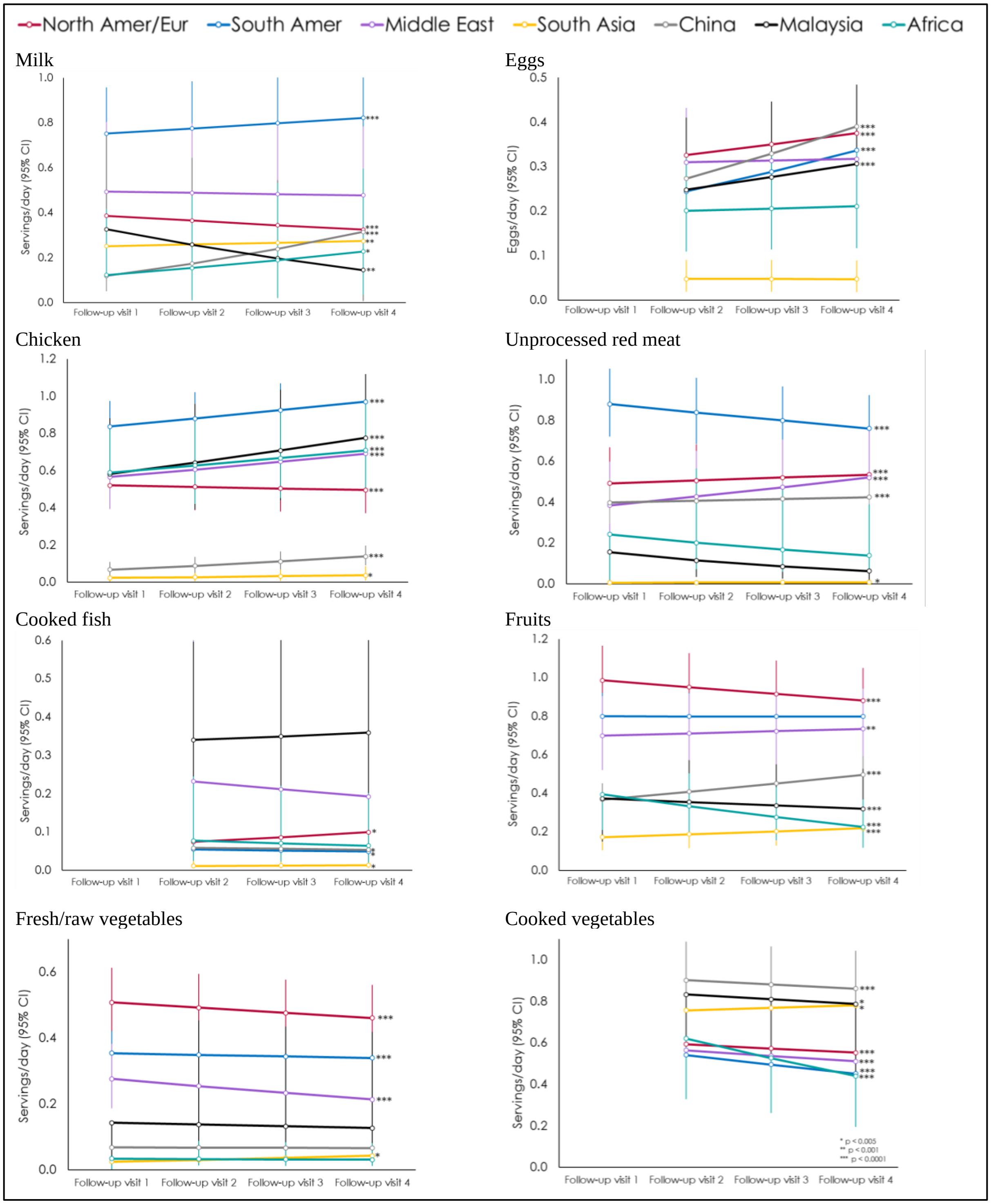
*Among participants who answered this question (n = 79,121 at follow-up visit 1, n = 60,093 at follow-up visit 2, n = 75,705 at follow-up visit 3, and n = 42,080 at follow-up visit 4). After September 2019, this question was not asked on the follow-up visit form, therefore at visit 4, 23,276 participants were not asked this question.

Figure 1. Change (servings/day, 95% CI) in foods and beverages over follow-up (2007-2022), by geographic region



†Chnage in egg, cooked fish, and cooked vegetable intake shown for vist two onwards.
Data was modeling using linear mixed-effect models with time in study as a fixed effect, and a random participant-specific intercept, nested within center. Data are adjusted for age and sex. Bars are 95% CIs. Portion size of 1 serving: milk (244.0 grams), eggs (50.0 g), chicken (50.0 g), unprocessed red meat (50.0 g), cooked fish (87.5 g), fruits (125.0 g), and vegetables (125.0 g).

Figure 2. Estimated intakes (servings/day, 95% CI) of foods and beverages over follow-up, by geographic region

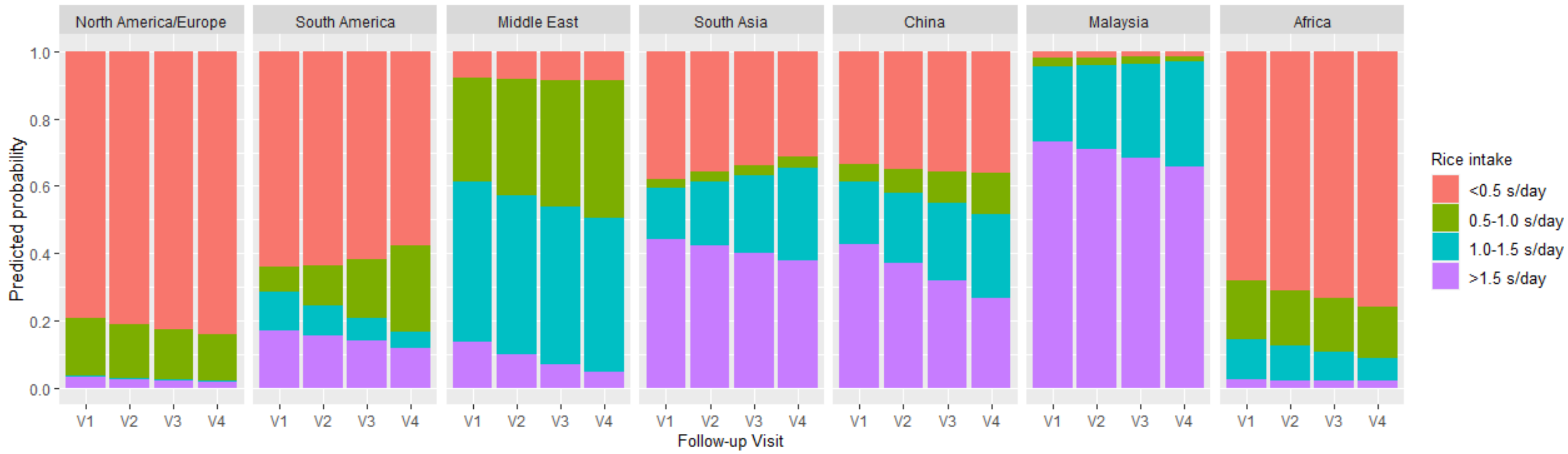


* p < 0.05 **p < 0.001 *** p <0.0001

Sample size at each follow-up visit, visit 1: n = 79,187 participants, visit 2: n = 60,825, visit 3: n = 76,055 participants, visit 4: 65,356 participants.

Figure 3. Change in the predicted probability of rice intake (servings/day) over follow-up, by geographic and country income region

A. Geographic region



B. Country income region

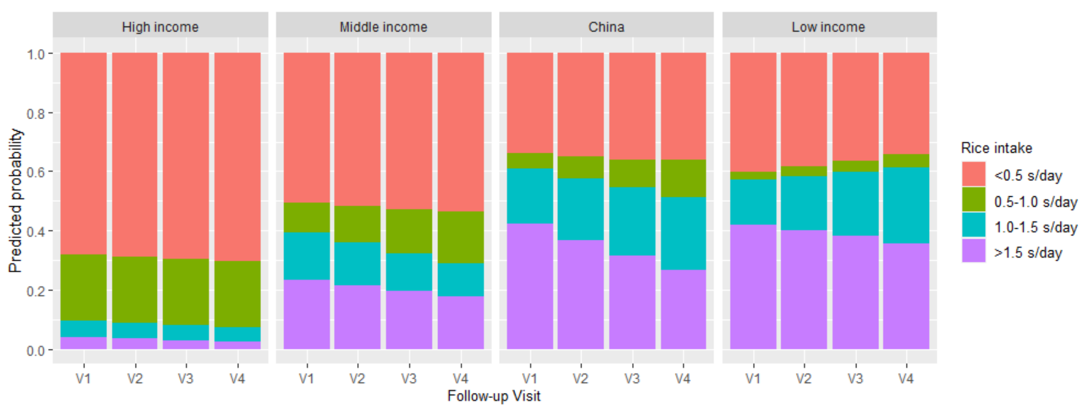
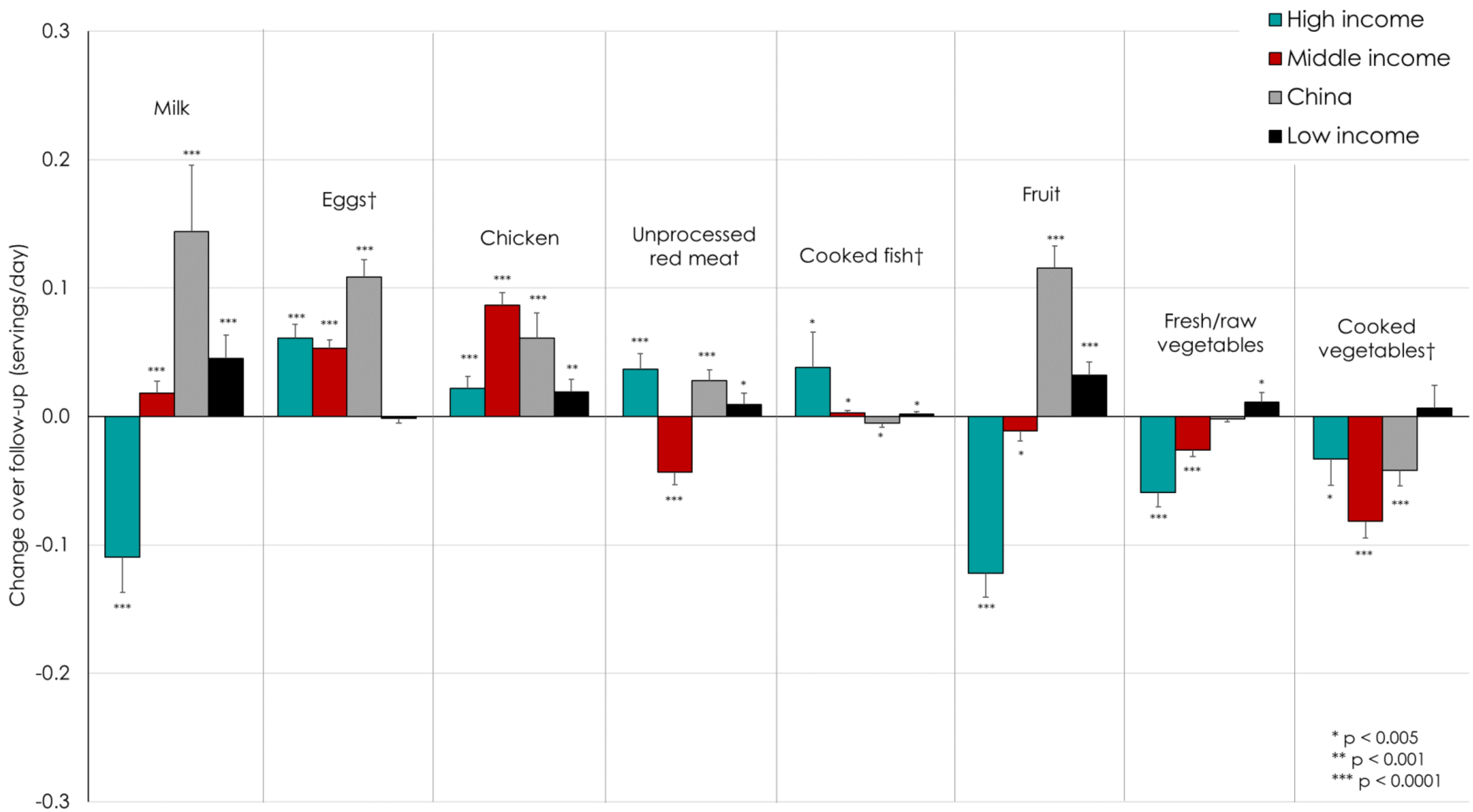
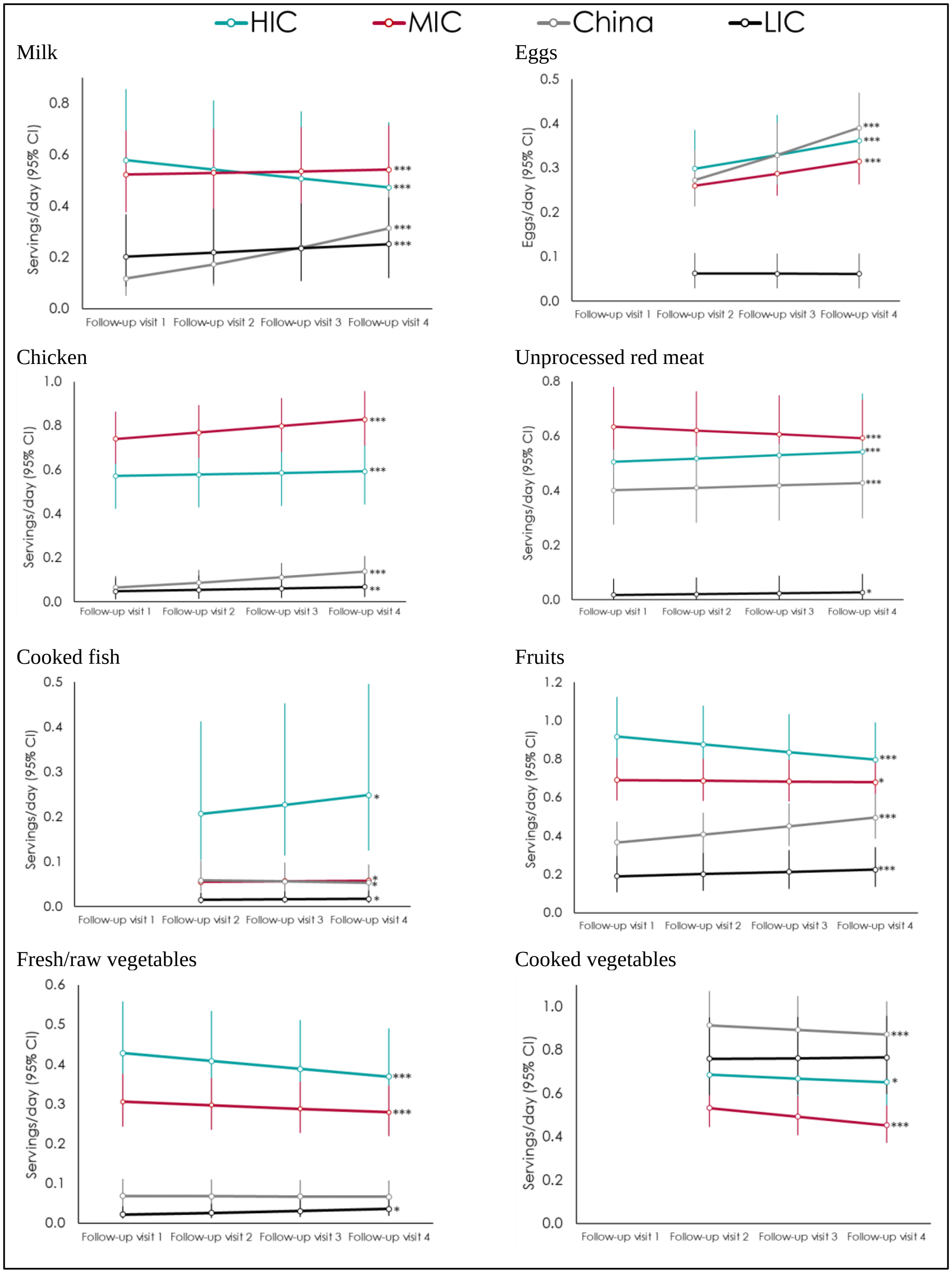


Figure 4. Change (servings/day, 95% CI) in foods and beverages over follow-up, by country income region



†Chnage in egg, cooked fish, and cooked vegetable intake shown for vist two onwards.
Data was modeling using linear mixed-effect models with time in study as a fixed effect, and a random participant-specific intercept, nested within center. Data are adjusted for age and sex.
Bars are 95% CIs. Portion size of 1 serving: milk (244.0 grams), eggs (50.0 g), chicken (50.0 g), unprocessed red meat (50.0 g), cooked fish (87.5 g), fruits (125.0 g), and vegetables (125.0 g).

Figure 5. Estimated intakes (servings/day, 95% CI) of foods and beverages over follow-up, by country income region



* p < 0.05 **p < 0.001 *** p <0.0001

Sample size at each follow-up visit, visit 1: n = 79,187 participants, visit 2: n = 60,825, visit 3: n = 76,055 participants, visit 4: 65,356 participants.

Supplementary Material

Supplement to: Dietary changes over a 15-year period in 16 countries: findings from the PURE prospective cohort study

Table of Contents

Supplemental Table S1. Countries included in the PURE Study, by geographic region, income region, and median duration of follow-up

Country (n = 16)	Geographic region (n = 7)	Income region (n = 4)*	Median duration of follow-up (IQR)
Sweden	North America/Europe	High income	12.2 (12.0–13.0)
Canada		High income	12.1 (11.6–12.8)
Poland		Middle income	13.4 (13.0–14.2)
Türkiye		Middle income	11.6 (11.5–11.9)
Colombia	South America	Middle income	12.2 (11.5–13.6)
Brazil		Middle income	12.0 (8.9–14.4)
Chile		Middle income	12.1 (11.7–14.7)
Argentina		Middle income	12.2 (9.5–13.6)
UAE	Middle East	High income	12.8 (12.4–13.6)
Iran		Middle income	9.9 (9.1–10.1)
India	South Asia	Low income	14.7 (12.1–16.9)
Pakistan		Low income	6.4 (5.5–12.1)
China	China	China	12.0 (10.5–12.7)
Malaysia	Malaysia	Middle income	9.4 (8.7–12.2)
South Africa	Africa	Middle income	10.0 (6.2–12.5)
Zimbabwe		Low income	14.6 (13.5–15.4)

*Countries grouped based on gross national income per capita from the World Bank classification for 2006 when the study was initiated.

Supplemental Table S2. Short food frequency questionnaire food definitions

Milk: does not include milk added to coffee/tea, only milk had as a beverage, or added to cereal

Eggs: includes eggs cooked, boiled, poached, scrambled, fried

Chicken: includes poultry with or without skin consumed as a main dish or as sandwich or mixed dish

Unprocessed red meat: includes beef, pork, lamb, mutton, goat, veal consumed as main dish or as sandwich or mixed dish; this does not include processed meat such as bacon

Cooked fish: includes any type of fish that is steamed, boiled, grilled, BBQ, roasted or baked

Rice: includes stick rice, rice noodle, white rice, brown rice

Fruits: includes fresh, canned, and boiled fruits; does not include fruit juice

Vegetables: potato, tapioca, cassava, and other tubers are not included in vegetable group

Supplemental Table S3. Missing data pattern, excluding participants without repeat measures (n = 121,029 participants with at least 1 repeat measures)

	Number of participants	Follow-up visit 1	Follow-up visit 2	Follow-up visit 3	Follow-up visit 4
4 repeat measures (n = 16,418)	16,418	X	X	X	X
3 repeat measures (n = 35,311)	7,877	X	X	X	.
	8,617	X	X	.	X
	14,493	X	.	X	X
	4,324	.	X	X	X
2 repeat measures (n = 39,698)	8,439	X	X	.	.
	10,692	X	.	X	.
	3,174	X	.	.	X
	3,704	.	X	X	.
	4,019	.	X	.	X
	9,670	.	.	X	X
1 repeat measure (n = 29,602)	9,477	X	.	.	.
	6,650	.	X	.	.
	8,877	.	.	X	.
	4,598	.	.	.	X

Note: Number of participants based on count of unique participants (a participant can contribute more than 1 measure per cycle of follow-up).
X = has data for that follow-up cycle
. = no data for that follow-up cycle

Supplemental Table S4. Comparison of dietary change in PURE population to FAO supply, Global Dietary Database (GDD) and Global Burden of Disease Study (GBD) estimates

A. Change in FAO food supply data (2010-2019), servings/day per capita (1)

	Milk	Eggs	Poultry	Red meat	Rice	Fruit	Vegetables
North Amer/Eur	0.09	0.11	0.20	-0.02	0.01	0.03	-0.01
South America	-0.11	0.22	0.53	0.06	0.04	-0.30	0.08
Middle East	0.02	-0.02	0.36	0.001	-0.10	-0.48	-1.61
South Asia	0.31	0.06	0.07	-0.003	-0.04	0.25	0.30
China	-0.06	0.13	0.11	0.06	0.05	0.51	1.45
Malaysia	0.001	0.28	-0.13	0.01	-0.47	0.003	0.25
Africa	-0.08	-0.02	0.04	0.01	0.01	-0.06	-0.14
	Directionally inconsistent with findings in PURE				Directionally consistent with findings in PURE		

Weighted average estimate of food supply (FAO Food Balance Sheets) change between 2010-2019 among PURE countries only and expressed in same serving sizes as PURE. Red meat is the average of bovine meat, other meat, mutton & goat meat, edible offals, and pigmeat. Fish is the average of demersal fish, freshwater fish, other marine fish, pelagic fish. Rice includes rice and products. Fruit excludes wine.

B. Change in GDD estimates (2005-2018), servings/day (2)

	Milk	Eggs	Seafood	Unprocessed red meat	Fruits	Non-starchy vegetables
North Amer/Eur	0.05	0.04	-0.02	0.03	0.08	0.02
South America	-0.05	0.28	0.02	0.22	-0.03	-0.02
Middle East	-0.26	-0.04	-0.001	-0.34	0.01	0.11
South Asia	0.07	0.01	0.003	0.0003	-0.03	-0.02
China	0.01	0.11	0.10	0.74	-0.02	1.00
Malaysia	-0.04	0.11	0.13	-0.001	-0.08	0.11
Africa				0.65		
	Directionally inconsistent			Directionally consistent with PURE findings		

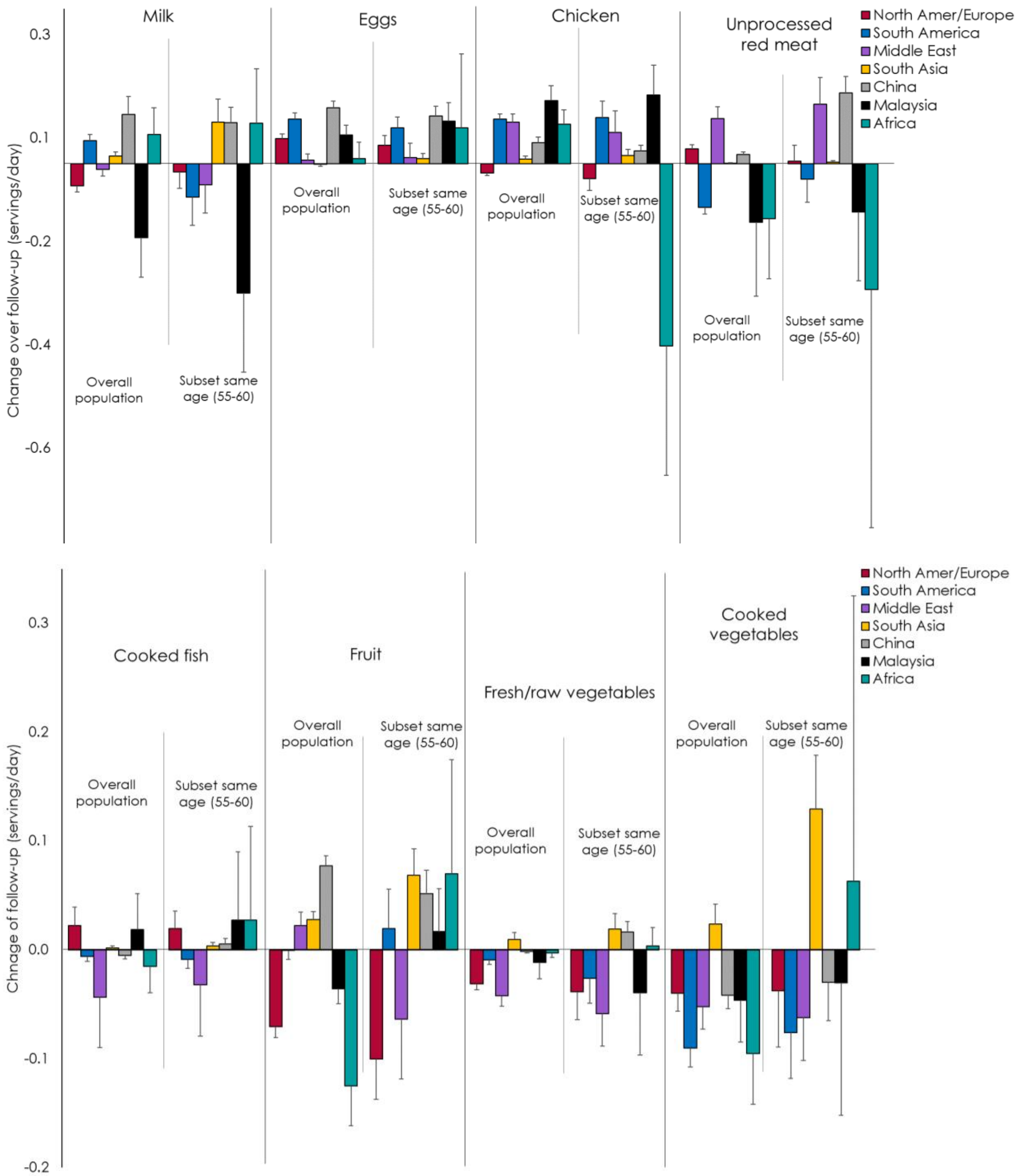
Weighted average estimate of change among PURE countries only and expressed in same serving sizes as PURE.

C. Change in GBD estimates (2000-2017), servings/day (3)

	Milk	Unprocessed red meat	Fruit	Vegetables
North Amer/Eur	0.01	0.004	0.14	-0.02
South America	-0.001	0.17	0.17	0.09
Middle East	0.01	-0.06	-0.02	0.26
South Asia	0.04	-0.005	0.25	0.53
China	0.05	0.32	0.32	0.85
Malaysia	-0.02	-0.01	0.19	0.39
Africa	0.01	0.11	0.02	0.06
	Directionally inconsistent		Directionally consistent with PURE findings	

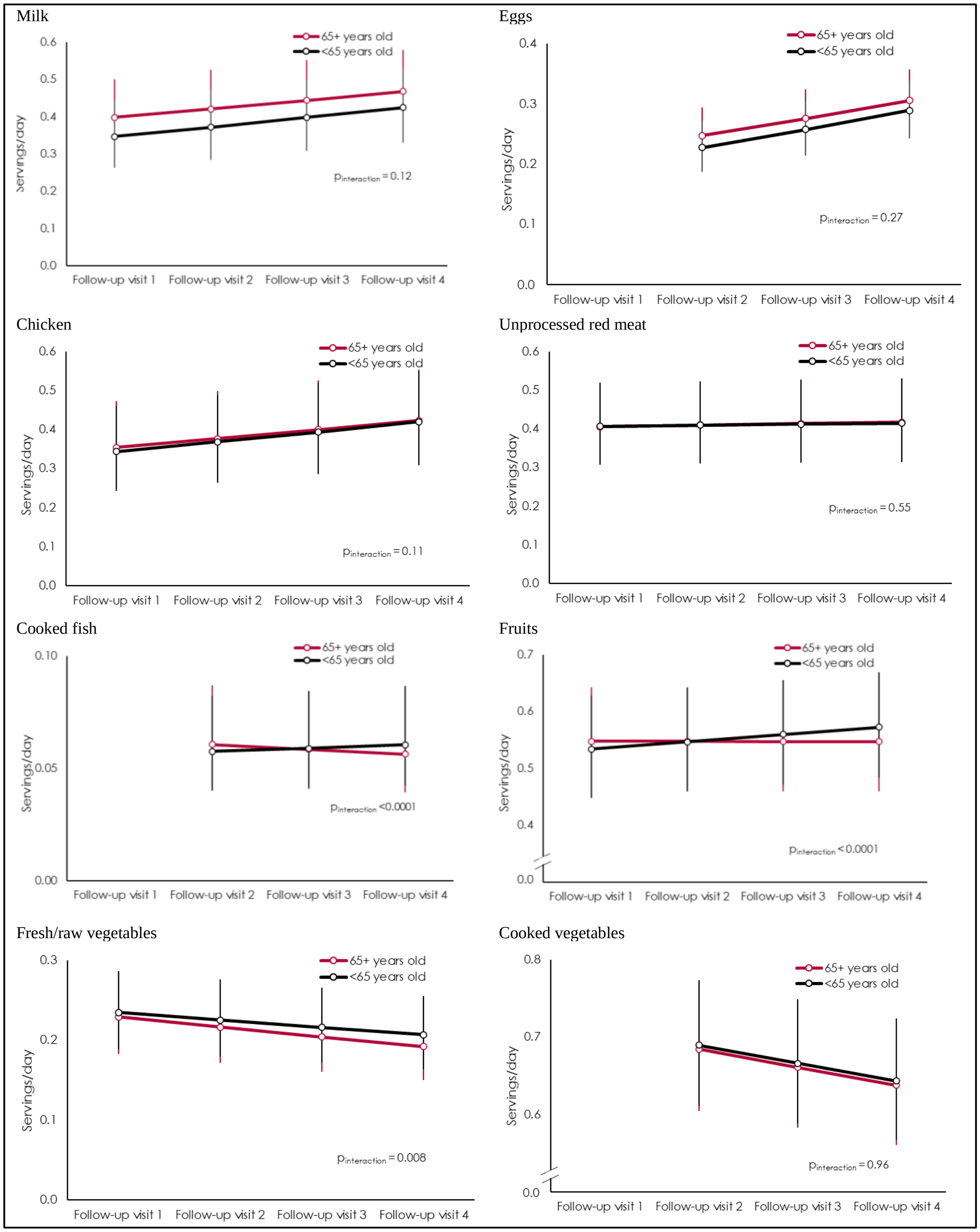
Weighted average estimate of change among PURE countries only and expressed in same serving sizes as PURE.

Supplemental Figure S1. Comparing dietary change (visit two onwards) among total PURE population (n = 121,029), compared to selected population aged 55-60 at repeat visit 2 and 55-60 at repeat visit 4 (n = 24,910)



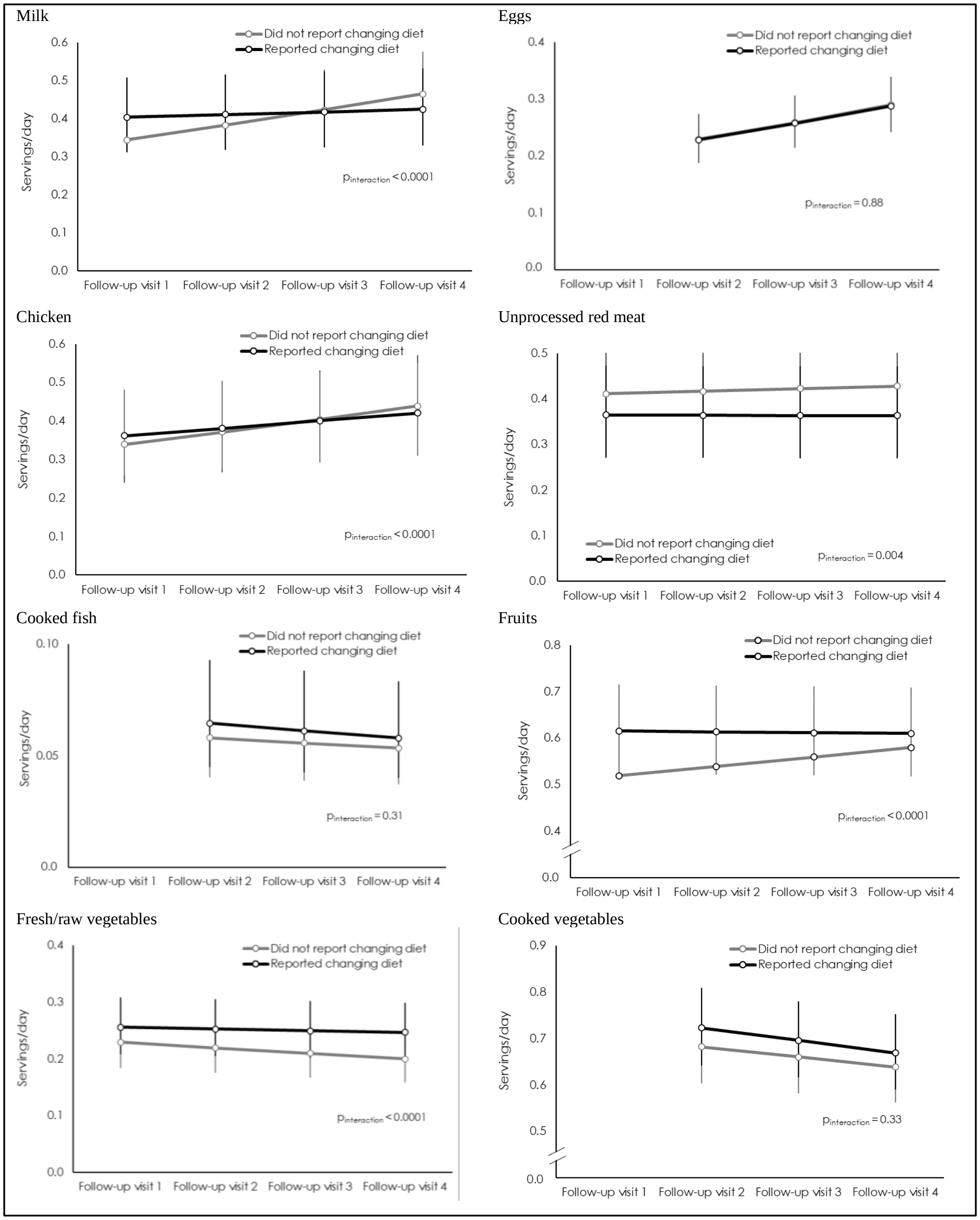
Note: Lower sample size in the subset of participants aged 55-60 years old at follow-up visit two and four, including North America/Europe (n = 6,066), South America (n = 4,692), the Middle East (n = 1,527), South Asia (n = 3,729), China (n = 7,150), Malaysia (n = 1,294), and Africa (n = 452).

Supplemental Figure S2. Estimated (servings/day, 95% CI) intakes of foods and beverages over follow-up (2007-2022) by age at baseline (<65 years old compared to ≥65 years old)



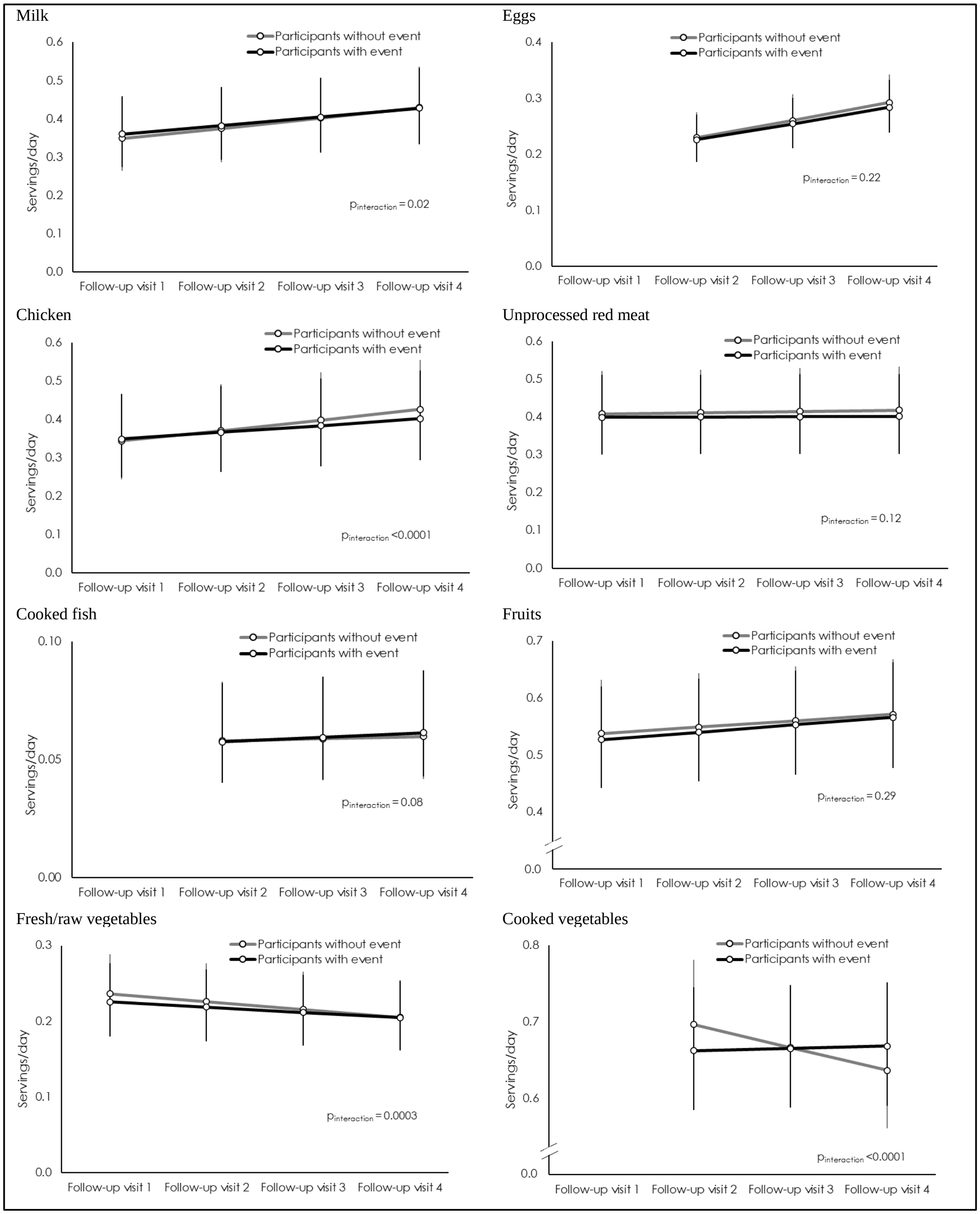
Sample size <65 years old: 70,716 at follow-up visit 1, 54,624 at follow-up visit 2, 68,822 at follow-up visit 3, and 59,855 at follow-up visit 4. Sample size ≥65 years old: 8,468 at follow-up visit 1, 6,197 at follow-up visit 2, 7,233 at follow-up visit 3, and 5,501 at follow-up visit 4.

Supplemental Figure S3. Estimated (servings/day, 95% CI) intakes of foods and beverages over follow-up (2007-2022), participants reporting changing their diet during follow-up



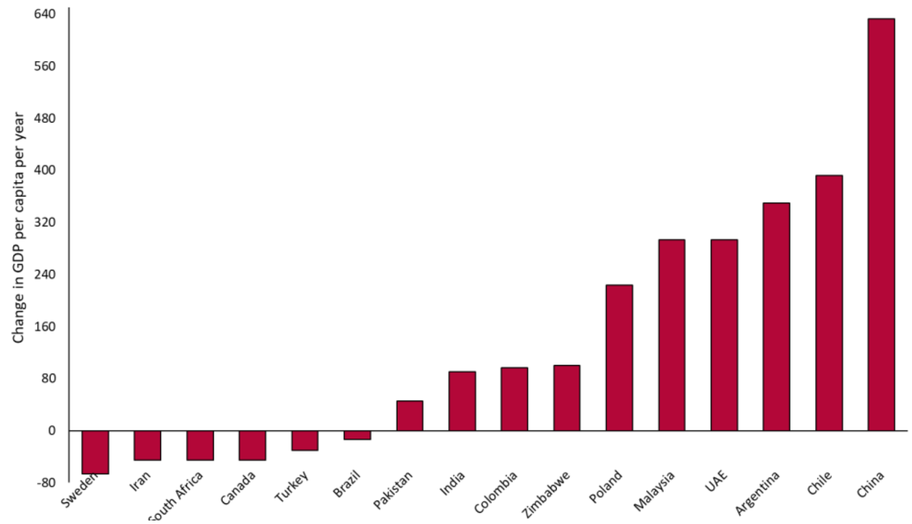
Sample size of those who did not report changing their diet: 68,344 at follow-up visit 1, 51,112 at follow-up visit 2, 64,985 at follow-up visit 3, and 36,620 at follow-up visit 4. Sample size of those who did report changing their diet: 10,777 at follow-up visit 1, 8,981 at follow-up visit 2, 10,720 at follow-up visit 3, and 5,460 at follow-up visit 4.

Supplemental Figure S4. Estimated (servings/day, 95% CI) intakes of foods and beverages over follow-up (2007-2022) by interim event status



Sample size of participants without interim event: 61,924 at follow-up visit 1, 47,879 at follow-up visit 2, 61,132 at follow-up visit 3, and 51,973 at follow-up visit 4. Sample size of participants with interim event: 17,263 at follow-up visit 1, 12,946 at follow-up visit 2, 14,923 at follow-up visit 3, and 13,383 at follow-up visit 4.

Supplemental Figure S5. Change in GDP per capita (current USD$), PURE countries, 2007-2019, by increasing change in GDP/year



Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Slope per year	% Change, 2019 vs. 2007
Sweden	53700	56153	46947	52869	60756	58038	61127	60020	51545	51965	53792	54589	51610	-66.6	-3.9%
Iran	4905	5717	5710	6600	7781	7928	6018	5586	4904	5253	5520			-45.3	12.6%
South Africa	6096	5761	5863	7329	8007	7501	6832	6433	5735	5273	6132	6374	6001	-45.1	-1.5%
Canada	44543	46594	40773	47448	52087	52678	52653	50893	43586	42322	45149	46313	46195	-44.8	3.7%
Turkey (Türkiye)	9712	10854	9039	10672	11336	11707	12519	12096	10949	10821	10514	9370	9042	-30.1	-6.9%
Brazil	7348	8831	8598	11286	13246	12370	12300	12113	8814	8710	9925	9001	8717	-13.6	18.6%
Pakistan	908	991	958	987	1165	1198	1209	1251	1357	1368	1465	1482	1285	45.7	41.5%
India	1028	999	1102	1358	1458	1444	1450	1574	1606	1733	1982	2006	2104	91.0	104.6%
Colombia	4714	5473	5193	6337	7335	8050	8218	8114	6176	5871	6378	6719	6432	96.9	36.5%
Zimbabwe	432	357	772	948	1094	1305	1430	1435	1445	1465	1548	1684	1464	100.6	239.0%
Poland	11255	14001	11528	12600	13894	13146	13781	14348	12572	12432	13861	15461	15595	223.8	38.6%
Malaysia	7243	8475	7292	9041	10399	10817	10970	11319	9955	9818	10254	11373	11415	292.9	57.6%
UAE	41810	44499	32024	33893	39195	40976	42413	43752	38663	38142	40645	43839	43103	293.4	3.1%
Argentina	7245	9021	8225	10386	12849	13083	13080	12335	13789	12790	14592	11684	10006	350.0	38.1%
Chile	10502	10751	10209	12808	14637	15352	15843	14671	13574	13754	14999	15925	14896	392.4	41.8%
China	2694	3468	3832	4550	5618	6317	7051	7679	8067	8148	8879	9977	10262	632.9	280.9%

Estimates obtained from World Bank. GDP only available until 2019.

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Chapter 4

Comparison of individual-level and supply-level estimates of dietary intake over a 50-year period (1961-2011) in 18 countries in Asia, North America, and Europe

Prepared for submission.

Abstract

Background: Reliable information on dietary trends is essential for monitoring changes in consumption and when examining associations between diet and chronic disease. Our aim was to compare individual-level dietary estimates for total energy, carbohydrate, fat, and protein intake over time to national supply data.

Methods: We compared previously published individual-level dietary survey data to supply-level data from the Global Expanded Nutrient Supply Model. We identified 186 paired estimates across the years 1961 to 2011 in 18 countries in Asia, Europe, and the United States. Individual- and supply-level estimates were compared using Spearman correlation coefficients. Linear mixed-effect models were used to estimate the difference between individual- and supply-level estimates by geographic and economic region, adjusting for time with a random intercept for country.

Results: Overall, the correlations between individual- and supply-level measures were moderate for energy (r_s = 0.34) and carbohydrate (r_s = 0.39), strong for fat (r_s = 0.85), and protein (r_s = 0.69). Compared to individual-level data, supply-level data overestimated total energy by up to 46.5% (95% CI: 44.6, 48.3), with the largest differences found in the United States and Sweden, and the smallest differences in India and China (<10%). Trends in total energy measured by individual-level surveys and total energy supply were positively correlated in 38.9% (n = 7) of countries, while trends in macronutrients align between individual-level and supply estimates in most countries. In models adjusted for time, in the United States, supply-level data exceeded individual-level estimates by 26.3-29.9% for energy, carbohydrate, and fat, while protein estimates were similar between measures. In Europe, supply-level estimates overestimated individual-level intake by 19.9% for energy, 17.0% for carbohydrate, 13.7% for fat, and 7.7% for protein, while estimates for energy and macronutrients were similar in Asia.

Conclusion: Our findings showed moderate to strong correlations between individual-level and supply-level measures of macronutrient intakes adjusted for energy. Supply-level dietary data overestimated individual-level intakes, especially in higher-income countries in the United States and Europe. In Asia and lower-income countries, our findings generally support the use of supply data in the absence of individual-level data, however, collection of individual-level data should be prioritized as supply data may not be as accurate in these regions.

Introduction

Diet is a modifiable risk factor for malnutrition and chronic diseases globally (1-4). The global monitoring of dietary trends is essential for the creation and evaluation of public health and agricultural evidence-based nutrition policies, guidelines, and interventions. Accurate data on dietary trends are also critical for examining associations between dietary changes and chronic disease rates. Individual-level dietary surveys and national supply-level food balance sheets are commonly used for estimating trends in food and nutrient intakes (5-7).

Individual-level dietary surveys involve directly asking individuals to report on their food consumption over a defined period of time and are considered the optimal method for evaluating diet-disease associations in observational studies (5). National supply-level food balance sheets (FBS) are a comprehensive and standardized estimate of food availability computed as the total quantity of foods produced and imported for human consumption, adjusted for any change in stocks that occurred since the beginning of the reference period and removing foods exported and for other uses (e.g., industrial, military, farm) (8-9). The Food and Agriculture Organization (FAO) compiles FBS in 184 countries between 1961 to 2020 for 121 food items (8-10). Considering FBS are consistently collected using comparable methods across countries and years, they have been used to compare national dietary patterns and examine diet-disease relationships in ecological studies (11-19).

Dietary monitoring using nationally representative individual-level dietary surveys is the gold standard method, but many countries, especially lower-income countries lack individual-level dietary assessments. As a result, evaluations of dietary trends largely focus on trends in FBS, which have been shown to overestimate individual-level food intakes (20-25). The differences in individual-level and supply-level estimates of macronutrients (carbohydrate, total fat, protein) have not been quantified, including the potential heterogeneity by macronutrient and world region. To address this gap, we aimed to compare estimates of energy, carbohydrate, fat, and protein consumption between individual-level and supply-level data, during the period 1961 and 2011, by geographic and economic region.

Methods

Trends in individual-level energy and macronutrient consumption were obtained from a systematic review (26). Countries with trend data from >4 different time points between 1961 and 2011 were included to ensure an adequate number of data points for comparison to supply-level data (26). Supply-level estimates were obtained from 1961 to 2011 from the Global Expanded Nutrient Supply (GENuS) Model (27). The GENuS estimated energy and macronutrient supply using FAO FBS, further accounting for the proportion of inedible food and beverage commodity weight (i.e., bones, shells, and peels) and using regional food composition tables (27). For example, seafood was estimated by the FAO as the weight of fresh or landed catches, while GENuS estimated the weight of fish gutted or filleted (27).

Statistical analysis

Individual-level and supply-level datasets were merged and matched by country, year, and nutrient. Countries were grouped into economic regions using the World Bank 2010 Gross Domestic Product (GDP) estimates, as this is the last year most countries had data across both individual- and supply-level data (28). South Korea, Japan, Poland, the Czech Republic, the United Kingdom, Sweden, the United States, Germany, the Netherlands, Italy, Spain, and France were classified as high-income countries (HIC); upper-middle income countries (UMIC) included China, Russian Federation, and Thailand, and lower-middle income countries (LMIC) included India, the Philippines, and Indonesia. Countries were also grouped into three geographic regions including Asia, Europe, and the United States. Asia included Thailand, South Korea, Indonesia, the Philippines, Japan, India, and China, and Europe included Sweden, Poland, Germany, France, the Netherlands, the United Kingdom, Russian Federation, Italy, Spain, and the Czech Republic.

Trend lines for energy, carbohydrate, fat, and protein were plotted by country comparing individual- and supply-level estimates. Spearman correlation coefficients (r_s) comparing individual-level and supply-level energy and macronutrient estimates over time were computed overall and for each country. To examine the difference between individual- and supply-level estimates by geographic and economic regions, linear mixed-effect models were computed. In these models, the difference between individual- and supply-level estimates, expressed as both absolute and percent differences, were the response variables and region was the independent variable, adjusting for the period of data collection and with a random intercept for country. The period of data collection was grouped per decade (1961-1970, 1971-1980, 1981-1990, 1991-2000, 2001-2011) to ensure sufficient data points within each time period. Linear mixed-effect models, with a random intercept for country, were also used to test if the difference between individual- and supply-level data was associated with time (per decade), and if this relationship was different across geographic and economic regions by including an interaction term for time and region (with a random intercept for country).

Results

Overall, 18 countries were included in this analysis from Europe (55.6% of the total), Asia (38.9%), and the United States (5.6%). High income countries represented 66.7% of included countries (n = 12 countries), 16.7% were upper-middle income (n = 3 countries), and 16.7% low-middle income (n = 3 countries). Individual-level dietary data was measured using 24-hour recalls (44.4% of countries), diet records (50.0%), and food frequency questionnaires (5.6%). Individual-level measures were derived mostly from nationally representative (94.4% of countries) populations in repeat cross-sectional surveys (94.4%) (Supplementary Table S1). Overall, there were 186 paired estimates between individual-level and supply-level dietary data across the years 1961 to 2011. Bland–Altman plot of agreement between individual-level and supply-level dietary data are presented in Supplementary Figure S1.

Correlation between individual- and supply-level dietary data over time

The Spearman correlations between individual-level and supply-level measures were 0.34 (95% CI: 0.21, 0.46) for energy, 0.39 (0.25, 0.52) for carbohydrate, 0.85 (0.80, 0.89) for fat, and 0.69 (0.60, 0.76) for protein (Figure 1). There was variation in correlations when examining trends by country (Figure 2). For total energy, individual- and supply-level estimates were positively correlated in the United States. In Europe, individual-level energy measures and energy supply were positively correlated in the Czech Republic, Germany, Poland, and Sweden. However, energy intake decreased in individual-level surveys in France, Italy, the Netherlands, Spain, and the United Kingdom while supply increased, with the opposite pattern in Russia. For most countries in Asia, total energy intake measured using individual-level surveys decreased, while supply estimated increased, except in the Philippines and Indonesia where trends aligned between individual- and supply-level data.

As a proportion of total energy, trends in individual-level carbohydrate intake and carbohydrate supply were positively correlated in all countries, except in the Netherlands and Sweden (Figure 2). Trends in individual-level fat intake and fat supply were well aligned in all countries, except in the United States and France where individual-level consumption decreased and fat supply increased. Overall, estimates of protein from individual-level measures were higher than protein supply. For most countries, protein intake estimated from individual-level measures and protein supply were positively correlated (Figure 2). However, in Thailand, India, the Czech Republic, and France individual-level protein consumption increased, while protein supply decreased. Supplementary Figure S2 presents trends in macronutrients as calories per day.

Difference between individual- and supply-level dietary data by *geographic region*

Overall, consumption of energy estimated from supply-level data was higher than estimated consumption from individual-level survey intakes, ranging from 46.5% to 7.8% higher, with the greatest differences found in the United States, Sweden, and Poland, and the smallest in India and China (Figure 3). On average, across all time points, energy supply exceeded individual-level estimates of energy consumption by 45.3% (95% CI: 44.7, 46.0) in the United States, 31.2% (28.3, 34.0) in Europe, and 19.4% (17.4, 21.5) in Asia. By economic region, supply-level energy was 26.3% (24.1, 28.5) higher in HIC, 20.7% (13.6, 27.9) in UMIC, and 20.6% (17.5, 23.7) in LMIC.

In linear mixed-effect models adjusting for time, supply-level estimates for the United States exceeded individual-level estimates by 1231 kcal/day (95% CI: 624, 1838, $p = 0.001$) for energy, 504 kcal/day (133, 875, $p = 0.02$) for carbohydrate, 600 kcal/day (228, 971, $p = 0.007$) for fat, and was similar for protein ($p = 0.28$) (Figure 4). As a percent difference, in the United States, supply-level data exceeded individual-level estimates by 28.5% (10.8, 46.3, $p = 0.007$) for energy, 26.3% (5.9, 46.8, $p = 0.02$) for carbohydrate, while not significantly for fat (29.9%, -3.4, 63.2, $p = 0.11$) and protein (8.9%, -10.7, 28.4, $p = 0.39$) (Figure 4). In Europe, supply-level data exceeded individual-level estimates by 781 kcal/day (578, 984, $p <0.0001$) for energy, 299 kcal/day (172, 427, $p = 0.0002$) for carbohydrate, 252 kcal/day (129, 375 $p = 0.0008$) for fat, and 36 kcal/day (10, 62, $p = 0.01$) for protein (Figure 4). As a percent difference, the European supply-level estimates were 19.9% (13.9, 25.9, p <0.0001) higher for energy, 17.0% (9.9, 24.0, p = 0.0001) for carbohydrate, 13.7% (2.7, 24.7, p = 0.03) for fat, and 7.7% (1.0, 14.5, p = 0.04) for protein (Figure 4). In Asia, supply-level data was not significantly different from individual-level estimates for energy and protein, but supply-level estimates were 177 kcal/day (30, 325, p = 0.03) higher for carbohydrate and 177 kcal/day (-322, -32, p = 0.03) lower for fat (Figure 4).

Difference between individual- and supply-level dietary data by *economic region*

In HIC, supply-level data overestimated individual-level estimates by 765 kcal/day (95% CI: 552, 978, p <0.0001) for energy, 292 kcal/day (172, 412, p = 0.0001) for carbohydrate, 274 kcal/day (168, 380, p <0.0001) for fat, and 34 kcal/day (10, 57, p = 0.01) for protein (Figure 4). As a percent difference, relative to individual-level estimates, supply estimates in HIC were 19.7% (13.9, 25.4, p <0.0001) higher for energy, 16.2% (9.6, 22.8, p = 0.0001) for carbohydrate, 17.7% (10.6, 24.7, p <0.0001) for fat, and 6.9% (0.9, 12.9, p = 0.04) for protein (Figure 4). In UMIC, carbohydrate supply was 293 kcal/day higher (65, 521, p = 0.02; as a percent difference: 15.0%, 2.5, 27.5) compared to individual-level estimates, while fat supply was 259 kcal/day lower (-463, -54, p = 0.03; as a percent difference: -20.4%, -33.7, -7.2) than individual-level data (Figure 4). In LMIC, supply-level data underestimated individual-level estimates by 239 kcal/day (-447, -30, p =0.04) for fat (Figure 4). Energy and protein supply data in UMIC, and energy, carbohydrate, and protein supply estimates in LMIC were not significantly different from individual-level data (Figure 4).

Difference between individual-level and supply-level dietary data over time

For total energy, the difference between individual- and supply-level data increased by 169 kcal/day per decade (95% CI: 146, 192, p <0.0001), with no significant difference by geographic (p-interaction = 0.10) or economic (p-interaction = 0.42) region. Per decade, the difference between individual- and supply-level for carbohydrate increased by 81 kcal/day (95% CI: 65, 97), which was similar by geographic region (p-interaction = 0.57). The difference between the two measures for carbohydrates increased by 71 kcal/day per decade (95% CI: 56, 87) in HIC, 240 kcal/day per decade (95% CI: 172, 307) in UMIC, and by 101 kcal/day per decade (95% CI: 34, 168) in LMIC (p-interaction = 0.01). By both geographic and economic regions, individual- and supply-level estimates for fat significantly differed over time, by geographic and income regions. The difference between measures for fat increased by 156 kcal/day per decade (95% CI: 134, 179) in Europe, 95 kcal/day per decade (95% CI: 51, 139) in the United States, 73 kcal/day per decade (95% CI: 61, 86) in Asia (p-interaction <0.0001), and by 101 kcal/day per decade (95% CI: 88, 113) in HIC, 65 kcal/day per decade (95% CI: 12, 118) in UMIC, and 21.0 kcal/day per decade (95% CI: -31, 74) in LMIC (p-interaction = 0.002). For total protein, the difference between individual- and supply-level data increased by 12 kcal/day per decade (95% CI: 9, 15), and was similar by geographic and economic (p-interaction = 0.53 and 0.57, respectively) regions.

Discussion

We compared 50 years of nationally representative individual-level dietary data to supply data on energy, carbohydrate, fat, and protein in 18 countries in Asia, Europe, and the United States. Overall, the correlations were moderate to strong for energy ($r_s = 0.34$) and macronutrients (range $r_s = 0.39$ to $r_s = 0.85$). Trends in total energy supply and energy measured by individual-level surveys were positively correlated in less than half of all countries, suggesting caution if supply data is applied to examine trends in energy intakes. The gap between energy estimated from individual-level and supply data increased over time by 169 kcal/day per decade. For most countries, trends in macronutrients are consistent when measured using individual- and supply-level estimates. On average, across all time points, relative to individual-level data, supply data overestimated energy by 45% in the United States, 31% in Europe, and 19% in Asia. The overestimation of supply-level data was primarily driven by carbohydrate and fat. In models adjusted for time, individual-level and supply estimates of energy and macronutrients were similar in Asia and LMICs, generally supporting the use of supply-level data in the absence of individual-level surveys. However, this finding could be related to the smaller sample size and given that supply data may not be as accurate in these regions collecting individual-level data should be prioritized.

Consistent with prior findings which compared differences in energy, macronutrients, and certain foods between individual and supply measures, we found that supply overestimated individual-level data, with heterogeneity by geographic and economic region (7, 11, 20-25). In models adjusted for time, total energy overestimation by supply data was significant in HIC, but not in UMIC and LMIC. This region-specific difference in energy overestimation may partially reflect food waste. In a global systematic review, 44% of food waste was in developing countries and 56% in developed countries, with most food waste occurring at the production, handling, and storage stages in developing countries, and at the consumption stage in developed countries (29). Supply FBS remove food loss during storage and transportation which disproportionately impact developing countries and may explain why energy was similar between supply and individual-level measures in UMIC and LMIC.

Several other factors may contribute to regional differences between individual and supply measures. For example, oil waste from restaurants and certain individual cooking practices (e.g., trimming the fat from meats) may be more prevalent in HIC (5, 21, 30). Supply data may be underestimated in UMIC and LMIC as populations are more likely to personally fish or grow food at home and may underreport informal trade across national borders (5, 11, 30). The underlying national statistics that inform FBS (e.g., production, import, export, and agricultural) may be less accurate in lower-income countries and slow to incorporate new products (e.g., low-fat dairy) (5, 11, 30). Moreover, a previous study comparing supply and individual-level measures found that beans and legumes, a staple in the diet of many of the UMIC and LMIC reflected in this study, are underestimated by supply data (7).

Given the consistency in measures of energy and macronutrients between individual and supply-level in LMIC in models adjusted for time, it may be appropriate to use supply data in LMIC that lack high-quality and timely nationally representative individual-level surveys. However, this consistency could be related to smaller sample size in this region and also suggests low accuracy given that the national data that inform food supply is challenging to appropriately capture in lower-income countries and may not reflect all food in the supply (5, 11, 30). Moreover, while individual and supply energy and macronutrient measures were comparable in our study, this may not apply for all foods (e.g., beans and legumes, nuts/seeds) which may be underestimated by supply data (7). The similarity between individual and supply measures in LMIC could also reflect a larger risk of an unstable food supply, which can further exacerbate food insecurity. For instance, while overall global rates of food insecurity have decreased, India continues to struggle with high rates of food insecurity, where almost 15% of the population is undernourished (31-33).

Supply-level dietary data is often used in ecological studies to examine dietary trends within and between countries and in association studies between dietary factors and health outcomes (11, 34). For example, Green et al. examined the relationship between energy and food supply trends and changes in the prevalence of stunting in children under five and adult ischaemic heart disease mortality in 124 countries over the period 1980-2009 (15). In such studies, the underlying assumption is that supply-level data is a proxy for individual-level intakes and that trends using both measures align (11). In our study, total energy trends aligned between individual and supply measures in less than half of the countries. As a result, if supply-level energy or macronutrient (as kcal or g/day) data is directly applied and presumed to be a proxy for individual-level, this could lead to spurious results in secular trend or association studies as supply trends may not accurately reflect dietary pattern changes occurring in the corresponding country or region.

Strengths and limitations

This study has several strengths. Within a country, individual-level intakes were estimated from large national studies with similar methodologies across survey cycles. We extracted data from countries with >4 measures to ensure an adequate number of data points for comparison to supply-level data. Supply-level data is specifically compiled and validated to be comparable across countries and time. By examining dietary trends across several countries and regions, we addressed an important limitation of previous work, which typically focused on trends in a few countries (20-24).

Our study had some potential limitations. Individual-level measures are subject to measurement errors, and the representativeness of the survey population and response rates can vary across survey years. The quality of food composition tables and nutrient databases differ between countries and may not accurately reflect total food consumption, especially in lower-income countries with outdated databases (11). When examining the results of this study by region, generalizability may be reduced as countries where dietary trend data were not available are not reflected in estimates. For example, countries in Latin America and the Caribbean, the Middle East, and Africa were not included in our analysis due to the absence of individual-level data. Additional comparisons in other countries and regions not reflected in this study are warranted. Although import and export data are generally accurate, trade across national boundaries, data on personal food production, and new products (e.g., low-fat dairy) may be underestimated in some countries resulting in inaccurate supply-level estimates (26). National food supply estimates do not consider differences in energy or nutrient requirements between males and females, different age groups, socioeconomic groups, or by stature/body size which may also explain differences between measures (11). We only examined data on energy and macronutrients, but other studies have examined the relationship between supply and individual measures for various foods (7, 25).

Conclusion

In conclusion, we examined the relationships between individual- and supply-level dietary data for energy and macronutrients across 18 countries. For many countries, trends in energy from supply data did not reflect trends in total energy measured through individual-level measures. While supply data overestimated individual-level intakes, our findings support the use of supply data to measure trends in macronutrients. Overall, our findings support the use of supply measures of energy and macronutrients in lower-income countries when individual-level data cannot be collected, but not in higher-income countries. However, the consistency of measures in lower-income countries also suggests that supply data may not be appropriately capturing all food in the supply.

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Comparison of individual-level and supply-level estimates of dietary intake over a 50-year period (1961-2011) in 18 countries in Asia, North America, and Europe

Figures

Figure 1. Correlations between supply-level and individual-level dietary data for energy and macronutrients (n = 18 countries, 186 paired datapoints)

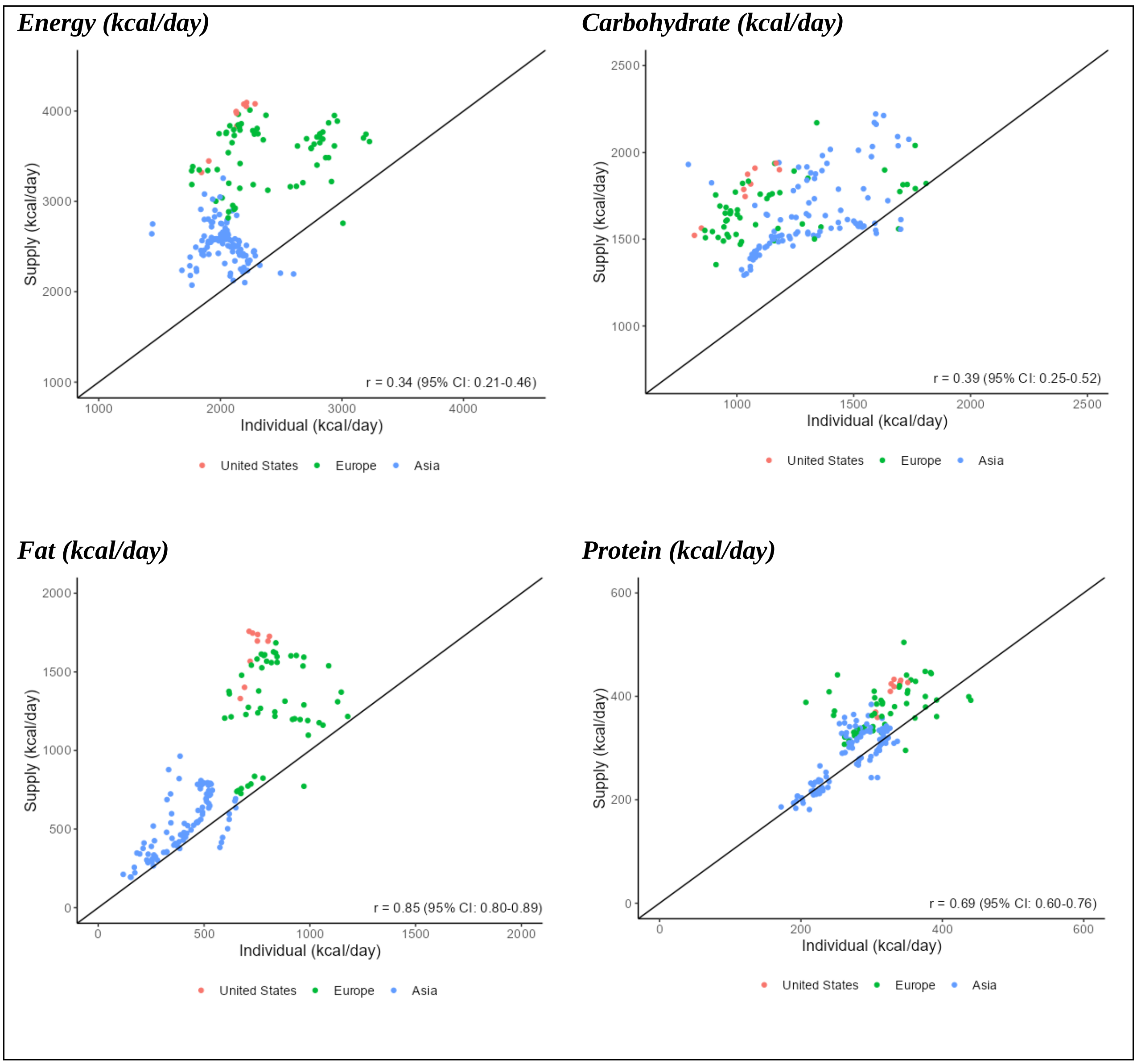
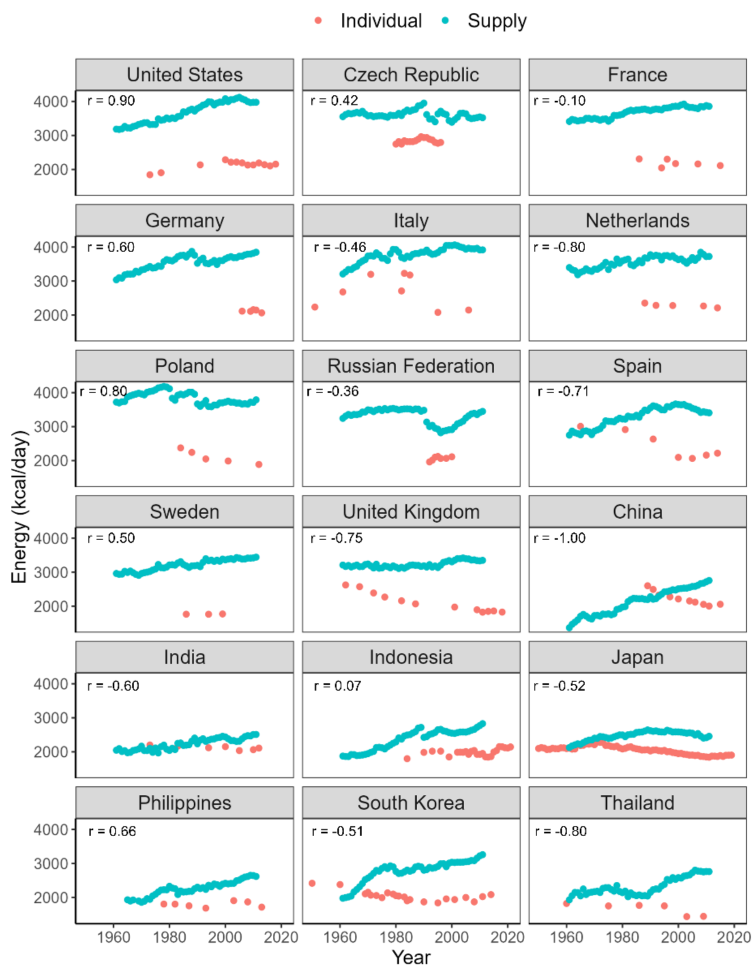
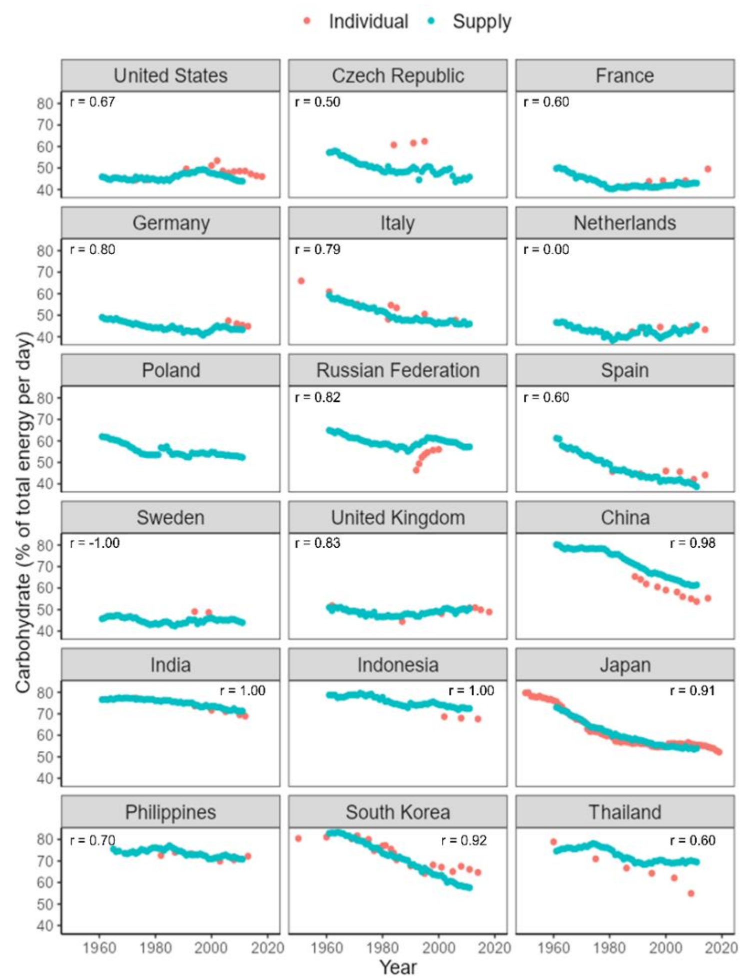


Figure 2. Comparison of supply-level and individual-level dietary data for energy and macronutrients over time, by country

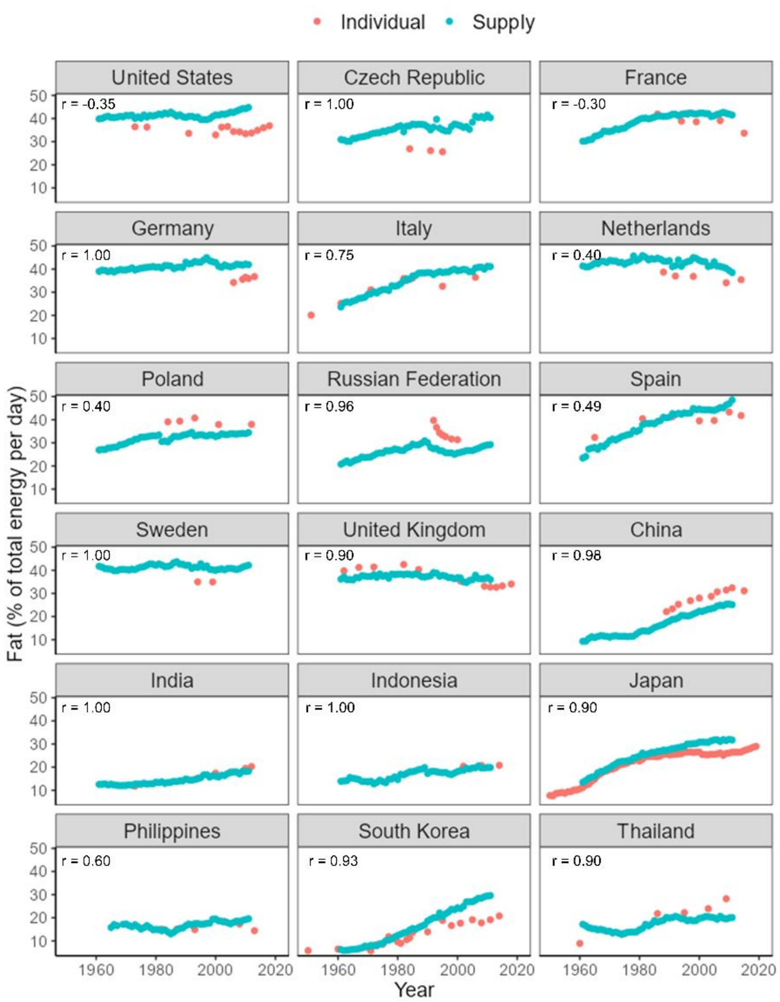
A. Energy (kcal/day)



B. Carbohydrate (% of total energy/day)



C. Fat (% of total energy/day)



D. Protein (% of total energy/day)

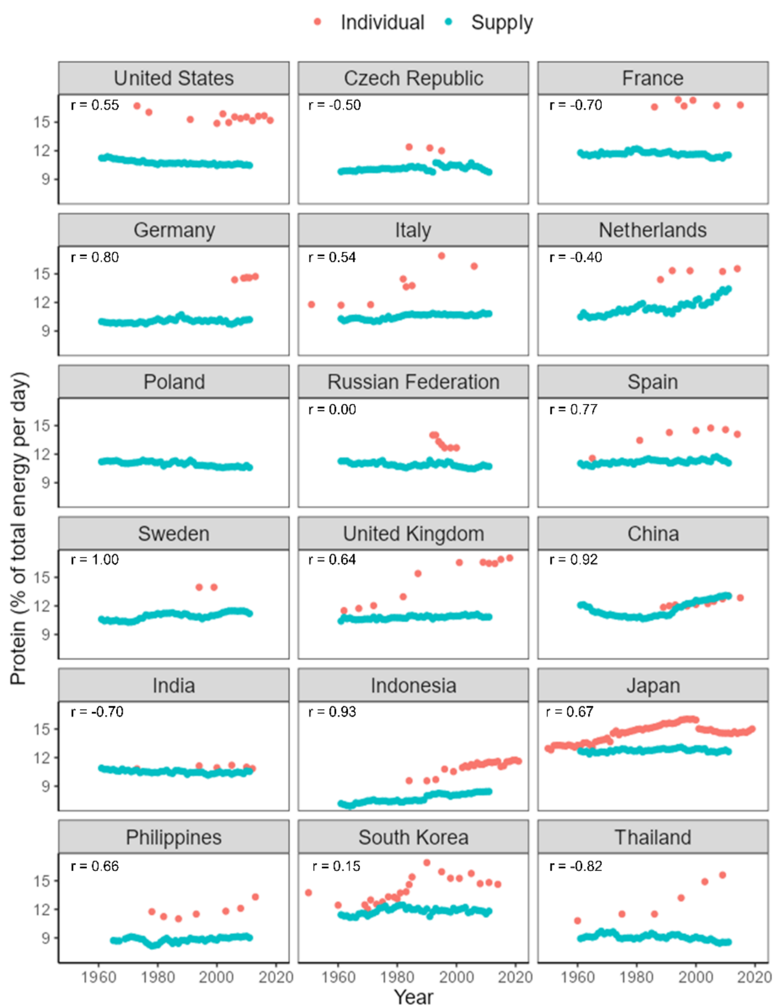


Figure 3. Average percent difference (95% CI) between supply- and individual-level for total energy, over all time points, by geographic and income region

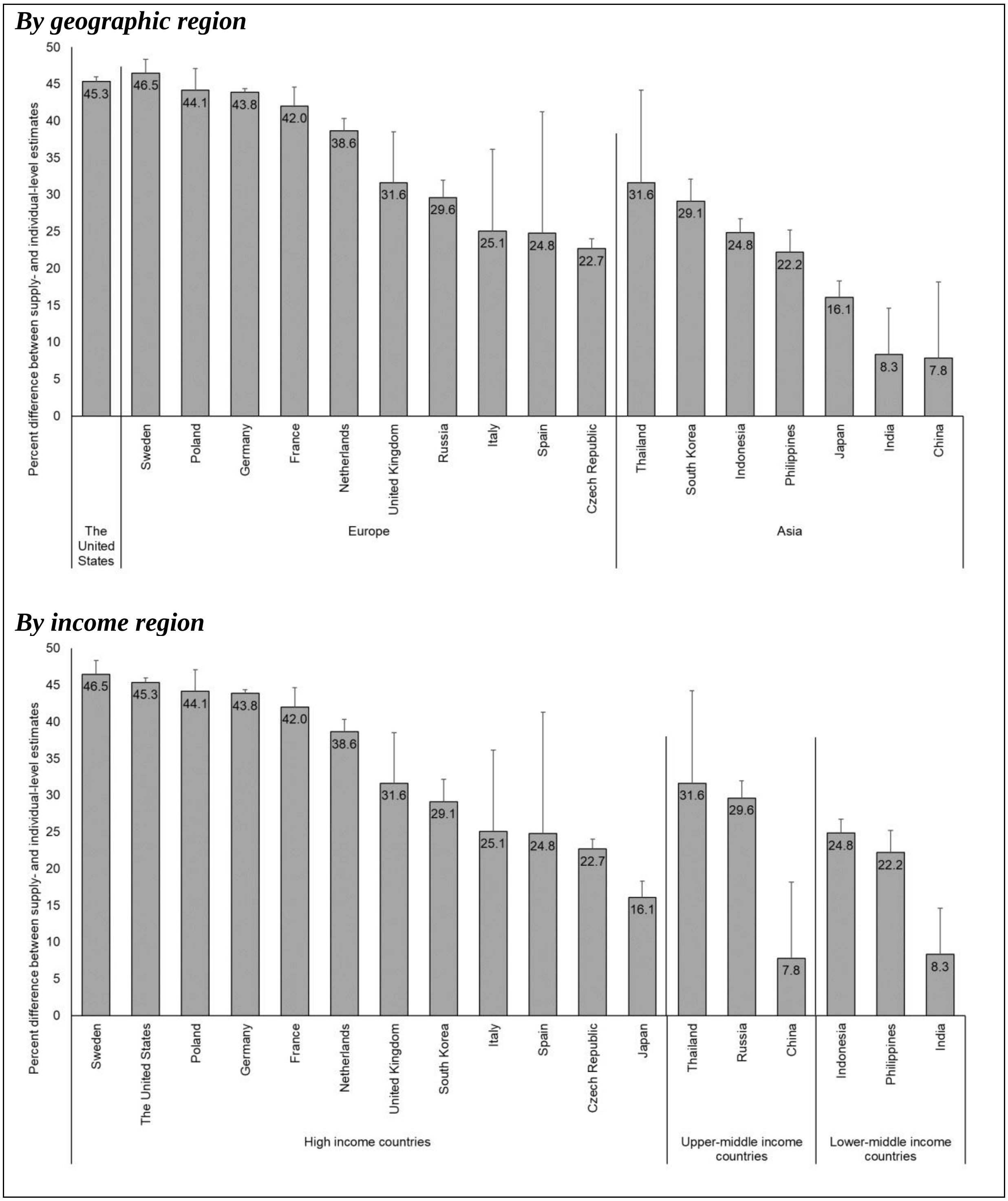
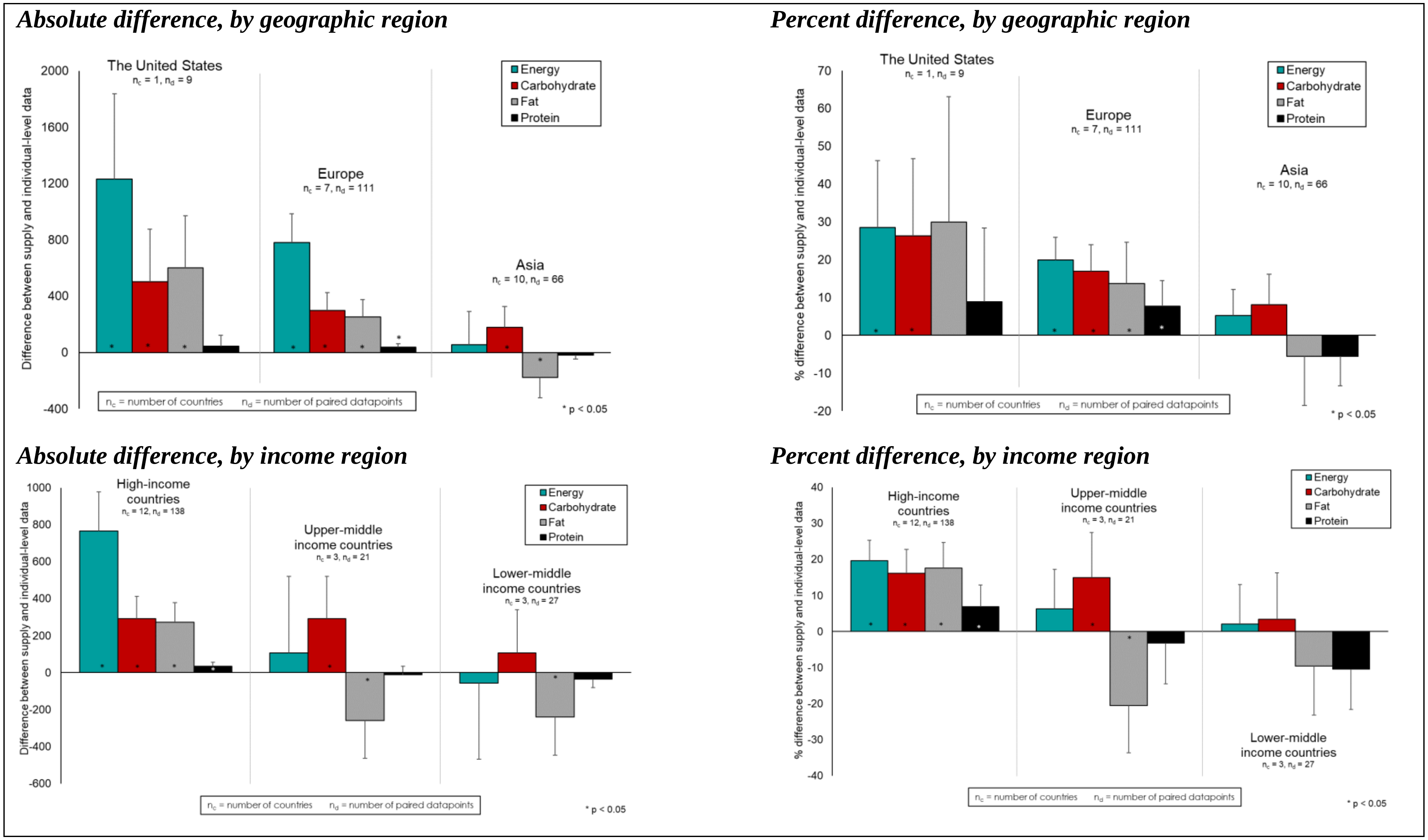


Figure 4. Absolute and percent difference between supply-level and individual-level dietary for energy and macronutrients, by geographic and income region, adjusted for time



Estimates from linear mixed-effect models, with the difference between supply- and individual-level estimates as response variable, region as independent variable, adjusted for period of data collection (1961-1970, 1971-1980, 1981-1990, 1991-2000, 2001-2011), with random intercept for country.

Supplementary Material

Supplement to: Comparison of individual-level and supply-level estimates of dietary intake over a 50-year period (1961-2011) in 18 countries in Asia, North America, and Europe

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Supplementary Table 1. Characteristics of studies and reports using individual-level dietary assessments, by region

Author, year, country	Data source	Study design	Sample size (% male)	Years of collection (total length)	Population age	Population type	Method of dietary assessment	Nutrients and food groups assessed	Adjustments
A. EAST ASIA (3 COUNTRIES)									
He et al., 2019, China[1]	China National Nutrition Surveys (CNNS)	Cross-sectional, stratified multi-stage cluster random sampling	Range 39008 to 58316 (45.9-49.7%)	1982, 1992, 2002, 2010-2012 (30 years)	20+	Nationally representative, men and women, covering 27-31 provinces (30-35% urban 1982-2002, 50% in 2010-2012)	1982: 5-day dietary record 1992+: 3 consecutive 24-hour recalls	Energy, macronutrients, SFA, PUFA	Calculated stratum-specific mean intakes, adjusted for total energy
Li et al. 2017, Shen et al., 2017, & CHNS website, China[2–5]	China Health and Nutrition Survey (CHNS)	Prospective household-based study, multi-stage random cluster design, including low, middle, and high-income rural/urban communities.	Range 6978 to 11892 across years 1989-2015 (48.0-49.3%)	1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011, 2015 (26 years)	CHNS raw data[5]: 18+ Li et al., 2017: 20+ Shen et al., 2017: 18+	Nationally representative, men and women in 9 provinces. Although prospective study, new households added if older households cannot participate. Li et al. excluded pregnant women.	3 consecutive 24-hour recalls and food weighing	Energy and macronutrients calculated from raw data[5]. Li et al: refined grain, SSB, red meat, processed meat, whole grains, dairy, nuts, fruits, vegetables, fish Shen et al: used for types of fat (SFA, MUFA, PUFA), dairy, eggs, animal and vegetable oils	Raw data: urban/rural, community. Li et al.: age, urban/rural, province, education, and occupation Shen et al.: age, area type
National Institute of Health and Nutrition Reports, Japan[6]	National Nutrition Survey (NNS) and the National Health Nutrition Survey (NHNS)	Cross-sectional surveys, multi-stage, stratified sampling, 5000-6000 households annually	About 15000 annually (% male NR)	Every year 1946-2018 (72 years)	All ages	Nationally representative, men and women, from 1948 onwards (excluding Okinawa until 1972), women and men.	1-day semi-weighed household dietary record	Energy, macronutrients, cereals, potatoes, sugars, beans, nuts, vegetables, fruit, seaweed, fish and shellfish, meats, eggs, milk and dairy products, oils and fats, sweets, condiments and beverages	Results weighted to compensate for difference in # of households
Kim et al., 2000, South Korea[7]	National Nutrition Survey	Cross-sectional, multistage cluster sampling with probability proportional to size	543 to 2000 house-holds, all member (% male NR)	1940, 1948, 1950, 1960, 1969, every 5 years 1970-1995 (55 years)	All ages	Nationally representative, non-institutionalized, women and men	2-day dietary record, weighted all food	Energy, macronutrients, cereals, legumes, potatoes, vegetables, fruits, seaweed, oils and fats, meat and poultry, eggs, fish, milk and dairy	No

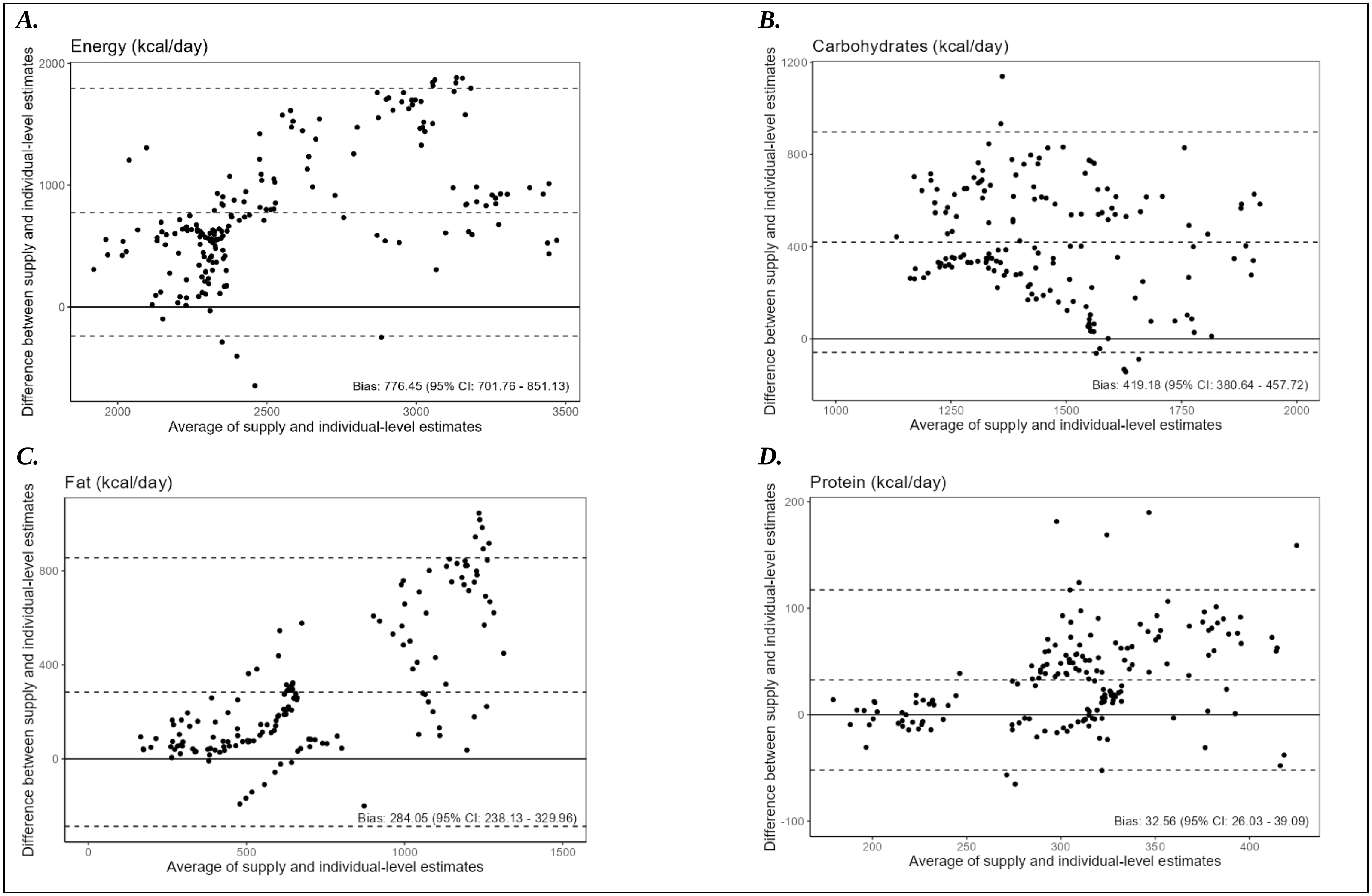
Author, year, country	Data source	Study design	Sample size (% male)	Years of collection (total length)	Population age	Population type	Method of dietary assessment	Nutrients and food groups assessed	Adjustments
Yun et al., 2017 & Song et al., 2019, South Korea[8,9]	The Korea National Health and Nutrition Examin-ation Survey	Cross-sectional, households selected based on multi-stage, stratified area probability on geographic area, age, and sex	Range 6526 to 17394 (40.7-46.4%)	1998, 2001, 2005, 2007-2009, 2010-2012, 2013-2015 (17 years)	Yun et al. 19+ Song et al. 19+	Nationally representative, men and women, non-institutionalized civilians aged 1 year and older (19+ for this study)	24-hour recall	Yun et al. energy, macronutrients, cereals, vegetables, fruit, meat, fish/shellfish, milk and products, and alcohol Song et al. types of fats (SFA, MUFA, PUFA)	Age standardized using the 2005 Korea Census population estimates
B. INDIA (1 COUNTRY)									
Misra et al., 2011 & Government of India, 2014, India[10,11]	National Sample Survey Organizati on (NSSO)	Cross-sectional, urban and rural villages selected	Between 4224 and 4436 (% male NR)	1972-1973, 1983-1984, 1993-1994, 1999-2000, 2004-2005 (33 years)	All ages	Nationally representative, women and men urban and rural population, all States, excluding Nagaland, Andaman, and Nicobar. Assumed that 59% rural, 41% urban over time (15)	Diet records (length not specified)	Energy, macronutrients, cereals (jowar, bajra, maize), pulses and pulse products, meat, fish, poultry, milk	No
C. SOUTHEAST ASIA (3 COUNTRIES)									
Linando et al., 2018, Statistik Reports, Indonesia[12–14]	The National Socioecon omic Survey	Cross-sectional surveys	10000 to 315672 house-holds per year (NR)	1984, every 3 years 1990-2002, every year 2002-2021 (37 years)	All ages	Nationally representative, urban and rural, women and men	Interview with head of household (1 week consumption)	Energy, macronutrients, cereals, tubers, fish, meat, eggs and milk, vegetables, legumes, fruits, oil and fat, beverages, prepared food and beverages	No
Pedro et al., 2006, FNRI report, Angeles-Agdeppa et al., 2019, Philippines[16–17]	National Nutrition Survey	Cross-sectional, multi-staged stratified sampling to represent all 80 provinces	Range 2280 to 8592 house-holds; 20749	1978, 1982, 1987, 1993, 2003, 2008, 2013 (35 years)	Pedro et al. & FNRI report age not specified Angeles-Agdeppa et al.: 19+	Nationally representative, urban and rural, men and women	Average of two non-consecutive 24-hour recalls	Energy, macronutrients cereals, starchy roots and tubers, sugars, fats and oils, meats, poultry, milk, eggs, fruits, vegetables, beans	No
Chavasit et al., 2017, Thailand[18]	The National Food and Nutrition Survey and NHES	Cross-sectional, multi-stage, stratified random sampling	Not specified	1960, 1975, 1986, 1995, 2003, 2009 (49 years)	Prior to 1995: all ages 1995 and 2003: 15+ 2009: all ages	Nationally representative, women and men, military and civilian populations, non-nationalized, all ages (prior to 1995 and 2009), including pregnant and lactating women.	Prior to 1995: weighting method Post 1995: 24-hour recall	Energy, macronutrients, animal protein	No

Author, year, country	Data source	Study design	Sample size (% male)	Years of collection (total length)	Population age	Population type	Method of dietary assessment	Nutrients and food groups assessed	Adjustments
D. THE UNITED STATES OF AMERICA (1 COUNTRY)									
Bleich et al., 2009, Ford et al. 2013, Yancy et al. 2014, Zeng et al., 2019, Marriott et al., 2019 & USDA Data Tables, 2021, Ernst et al., 1997, United States[19–26]	National Health and Nutrition Examin-ation Survey	Cross-sectional, multi-stage probability sample	Prior to 1998: 9872 to 14167 (38.50-56.2%) Post 1999: 3699 to 5762 (46.3-58.5%)	1971-1974, 1976-1980, 1988-1994, 1999-2000, 2001-2002, 2003-2004, 2005-2006, 2007-2008, 2009-2010, 2011-2012, 2013-2014, 2015-2016, 2017-2018 (47 years)	20+ Ford et al., Yancy et al. & Ernst et al.: 20-74	Nationally representative, men and women, non-institutionalized civilians	24-hour recall	Energy, macronutrients, SFA, MUFA, PUFA Foods available from USDA Data Tables: 1994-2008: dairy, fats and oils, grains, vegetables, roots/tubers, fruits, meat, eggs, fish, legumes, nuts, sweeteners Zeng et al. (1999-2016): meat, processed meat Bleich et al. & Marriott et al.: SSB	Yancy et al.: age, BMI, race, physical activity, marital status, education, employment, day of week of recall, dieting Ford et al., Bleich et al. & Marriott et al.: age
E. EASTERN EUROPE (5 COUNTRIES)									
Jahns et al., 2003 & Dellava et al., 2010, Russia[27,28]	Russian Longitu-dinal Monitor-ing Survey	Cross sectional, stratified 3- stage cluster (20 regions, 10 districts using probability proportional to size)	Range 8342 to 10670 (% male NR)	1992, 1993,1994, 1995,1996, 1998, 2000, 2001, 2002, 2003, 2004, 2005 (13 years)	Jahns et al.: 19-55 Dellava et al.: 25-55	Nationally representative, women and men, random sample of working-age adults. Each year same housing units were surveyed, if original occupant moved, both current and former residents interviewed	24-hour recall	Jahns et al.: energy, macronutrients Dellava et al. fat intake	No
Franz-Zunft et al., 1999 & Dofkova et al., 2001, Czech Republic[29,30]	House-hold budget survey of Czech Statis-tical Office	Household budget survey, 420 households each year	Not reported	1980-1997 (17 years)	All ages	Nationally representative, collection occurred over the full year	Diary of all foods bought for the household or obtained from own production over 1 month	Energy, macronutrients., meat, fish, milk, eggs, fats and oils, sugar, bread, cereals, pulses, potatoes, vegetables, fruit	No

Author, year, country	Data source	Study design	Sample size (% male)	Years of collection (total length)	Population age	Population type	Method of dietary assessment	Nutrients and food groups assessed	Adjustments
Franz-Zunft et al., 1999, Waśkiewicz et al., 2015, Poland[29,31]	Waśkiewicz et al: Pol-MONICA and WAW-KARD project (2012)	Franz-Zunft et al.: household budget survey Waśkiewicz et al: Cross-sectional, part of MONICA project, selected from electoral and population register	Franz-Zunft et al.: NR Waśkiewicz et al: 614 to 2552 (49.1-53.3%)	Franz-Zunft et al.: 1980-1989, 1990-1992, 1993-1997 Waśkiewicz et al: 1984, 1988, 1993, 2001, 2012 (28 years)	Franz-Zunft et al.: all ages Waśkiewicz et al: 35-64	Franz-Zunft et al.: nationally representative Waśkiewicz et al.: Representative of Warszawa (urban), men and women	Franz-Zunft et al.: foods purchased Waśkiewicz et al: 24-hour recall	Franz-Zunft et al.: carbohydrate, protein Waśkiewicz et al: energy, fat, SFA, animal fat	Waśkiewicz et al: age, season, smoking
F. NORTHERN EUROPE (2 COUNTRIES)									
Krachler et al., 2005 & Johansson et al., 2012, Sweden[32,33]	MONICA Project; Västerb-otten Interven-tion Program (VIP)	MONICA: Cross-sectional, from population registry VIP: Cross-sectional, recruited from primary health care centres	MONICA: 1353 to 1608 (47.7-50.9%) VIP: NR for each year	MONICA: 1986, 1994, 1999 (13 years) VIP: every 2 years 1986-2010 (24 years)	25-65	MONICA: Men and women from Vasterbotten and Norrbotten VIP + MONICA: men and women from Västerbotten, recruited when they turn 30, 40, 50 or 60 years	FFQ	MONICA: energy MONICA + VIP: macronutrients	Age and BMI for macronutrient intakes
Pryer et al., 2001, Marriot et al., 2003. Whitton et al., 2011, Govern-ment of UK 2019, Johnson et al., 1991, United Kingdom[34–38]	National Food Survey, National Diet and Nutrition Survey	Cross-sectional, multi-stage random probability by region and electoral wards of different SES	965 to 2197 (38.7-49.5%)	1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1986-1987, 2000-2001, 2008-2010, 2010-2012, 2012-2014, 2014-2016, 2016-2019 (59 years)	19-64	Nationally representative (Scotland, Wales, London), living in private households	7-day diet record, weighted	Energy, macronutrients, SFA, MUFA, PUFA	No
G. WESTERN EUROPE (5 COUNTRIES)									
Gose et al., 2016, Germany[39]	German National Nutrition Monitor-ing Study	Longitudinal study	1840 (42.3%)	2005-2007, 2008-2009, 2009-2010, 2010-2011, 2012-2013 (8 years)	14-80 at baseline (mean age men: 50.1, women: 48.6)	Drawn from the nationally representative German National Nutrition Survey, men and women	24-hour recall	Energy, macronutrients, SFA, MUFA, PUFA, bread, cereals, pastries, vegetables, fruits, fruit juice, fats, dairy, eggs, meats, fish, soft drinks, confectionary, alcohol	Tested age*time interaction and was not significant

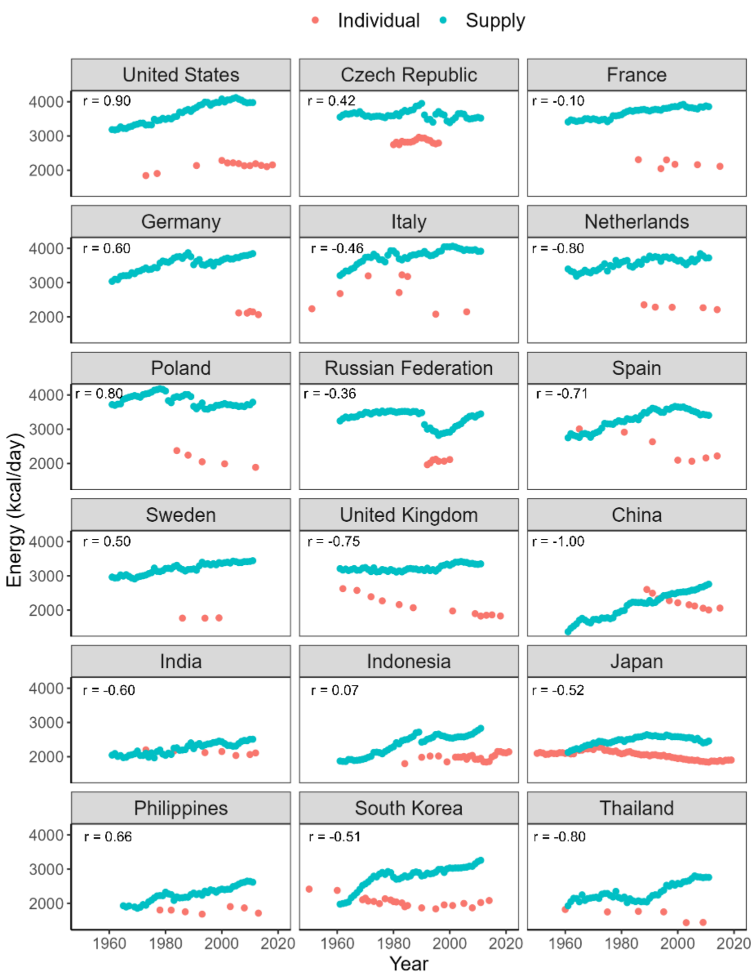
Author, year, country	Data source	Study design	Sample size (% male)	Years of collection (total length)	Population age	Population type	Method of dietary assessment	Nutrients and food groups assessed	Adjustments
Hulshof et al., 2003 & National Reports Nether-lands[40–42]	Dutch National Food Consum-ption Survey	Cross-sectional, stratified probability sample selected from consumer panel	2078 to 4466 (46.1-50.9%)	1987-1999, 1992, 1997-1998, 2007-2010, 2012-2016 (29 years)	19+	Nationally representative based on age, sex, region, urbanization, education, excluding institutionalized, households with a house-keeper aged 75+, pregnant or lactating women	2-day diet record	Energy, macronutrients, SFA, MUFA, PUFA, bread, cereals, potatoes, vegetables, fruit, milk, cheese, meat, fats, sugar, cakes, soft drinks, alcohol	No
Nicolosi et al., 1988, Turrini et al, 1999, Carnovale et al., 2000, Turrini et al, 2001, Leclercq et al., 2009, Sette et al., 2011, Italy[43–48]	ISTAT National Surveys; INN Food Consum-ption Surveys; INRAN-SCAI	ISTAT: stratified random sample of municipalities INN and INRAN-SCAI: stratified random sample of households in main areas of Italy	Prior to 1994: NR 1994-1996: 1844 (46.4%) 2005: 2312 (46.2%)	1951, 1961, 1971, 1980-1984, 1983, 1985, 1994-1996, 2005-2006 (55 years)	Prior to 1994: 35-74 1994-1996: 18-60 2005-2006: 18-64.9	Nationally representative, men and women	Interviews, food inventory, 7-day dietary diary, 3-day diet record	Energy, macronutrients, animal fat, vegetable fat Turrini et al. 2001 & Leclercq et al: grains, pastries, vegetables, fruits, oils, dairy, eggs, nuts, meats, fish, sweets, alcohol	No
Volatier et al., 1999, Perrin et al., 2002, Dubuisson et al., 2010 & ANSES, 2017, France[49–52]	MON-ICA Project; ASPCC; INCA surveys	Cross-sectional, MONICA: multi-stage sampling by age & town size; INCA: stratified sample by region & urban area, probability proportional to size	802 to 3157 (41.8-51.1%)	1985-1987, 1993-1994, 1995-1997, 1998-1999, 2006-2007, 2014-2015 (30 years)	MONICA: 35-64 ASPCC: 19-64 INCA: 18-79	MONICA: in Bas-Rhin, Eastern France, men and women ASPCC and INCA: Nationally representative, men and women based on region, age, sex, occupation, urbanization, excluding under-reported based on energy intake	MONICA: 3-day diet record, FFQ ASPCC and INCA1-2: 7-day diet record INCA3: 24-hour recall and FFQ	Energy, macronutrients, SFA, MUFA, PUFA, cereals, pizza, pulses, potatoes, pastries, sweets, dairy, fats and oils, eggs, meats, fish/shellfish, fruits, vegetables, alcohol	MONICA: age
Serra-Majem et al., 1995, Moreno et al., 2002, Varela-Moreiras et al., 2010, Rodríguez, et al., 2016, Spain[53–56]	House-hold budget & expen-diture surveys, National Institute of Statistics	Two-stage stratified sampling (towns and households)	1964-91: 20800-28000 house-holds 2000-14: 12000 house-holds	1964-1965, 1980-1981, 1990-1991, 2000,2005, 2010, 2014 (50 years)	All ages	Nationally representative, 50 provinces into 17 regions, 20800 households in 1964-1965, 24000 in 1980-1981, 28000 in 1990-1991	Surveys collected $ spent on food, trained interviewer visited household daily or every other day for 1 week	Energy, macronutrients, SFA, bread, pasta, rice, potatoes, vegetables, pulses, fruits, meat, fish, eggs, dairy, sugar, fats/oil	No

Supplementary Figure 1. Bland–Altman plots of agreement between supply-level and individual-level dietary data for energy and macronutrients (kcal/day)

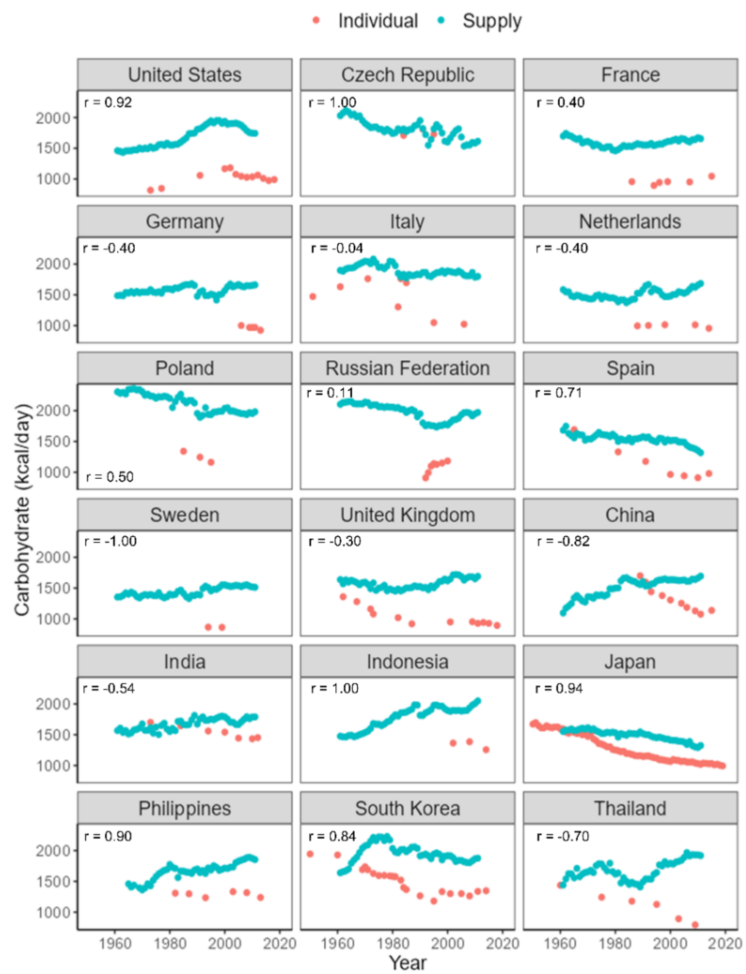


Supplementary Figure 2. Comparison of supply-level and individual-level dietary data for energy and macronutrients (kcal/day) over time, by country

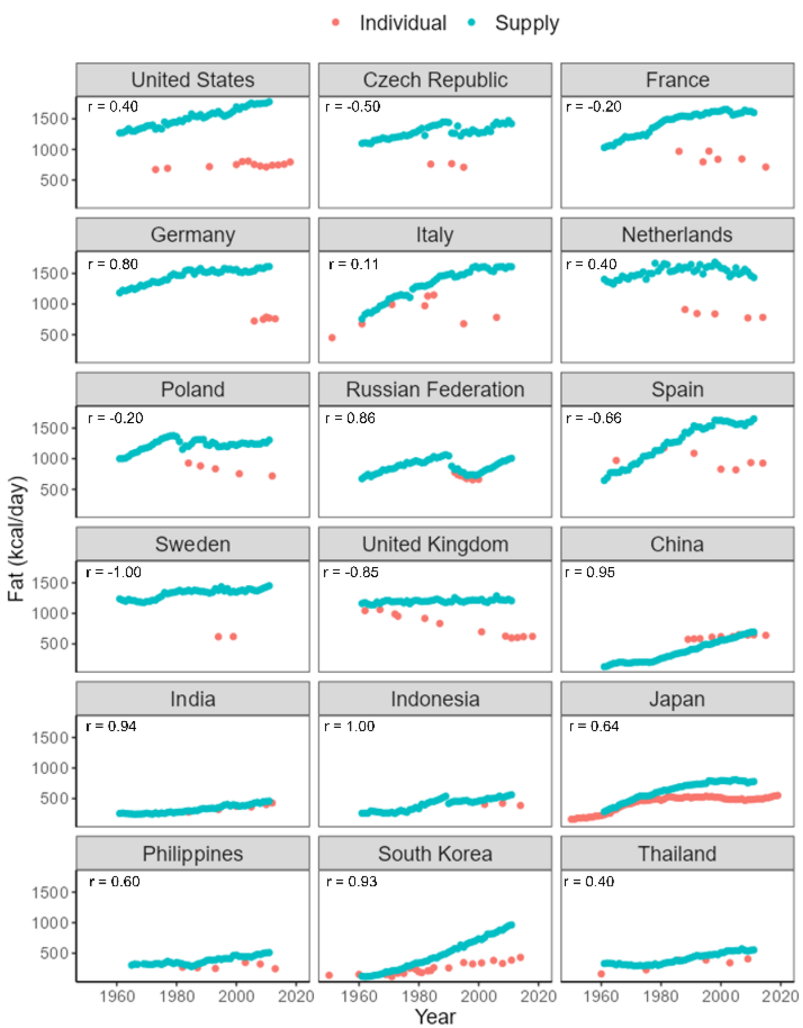
A. Energy (kcal/day)



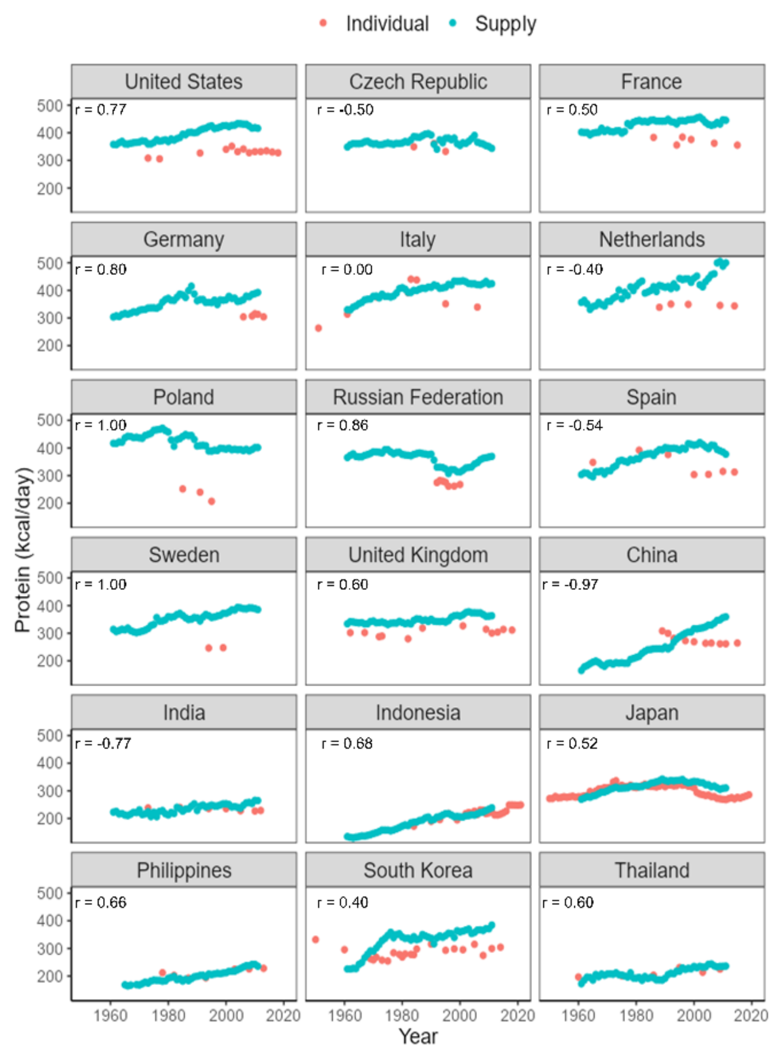
B. Carbohydrate (kcal/day)



C. Fat (kcal/day)



D. Protein (kcal/day)



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Chapter 5

Discussion and Concluding Remarks

Overview of main findings

The systematic monitoring of dietary trends using accurate and comprehensive data is essential as diet is an important modifiable risk factor for malnutrition and non-communicable diseases globally. The findings from this thesis complement existing efforts to understand dietary changes, both in the short- and long-term, leveraging data from several study designs, including repeat cross-sectional surveys, prospective cohort studies, and national dietary supply estimates in several world regions.

In the systematic review and meta-analysis presented in Chapter 2, individual-level diet trends measured between 1950 to 2019 from 47 countries were collated. In Southeast Asia and East Asia, carbohydrate intake decreased, and fat consumption increased, while the opposite pattern occurred in North America. In Europe, Australia, and New Zealand, fat intake decreased, while carbohydrate intake remained unchanged. There was little change in the consumption of carbohydrate and fat in South Asia, Latin America, and the Middle East, but data were sparse in these regions. A greater increase in the national gross domestic product over time was associated with decreased carbohydrate and increased fat and protein intake. Changes in foods varied by region, for example, East Asia and Southeast Asia increased meat, fish, dairy, egg, and fruit consumption, and decreased intake of grains, roots/tubers, and legumes. Consumption of eggs, fruits, nuts, legumes, and roots/tubers were below recommendations in most regions, highlighting key targets for future nutritional policies and interventions. Our findings show considerable regional variation in dietary trends, identify countries where excessive carbohydrate consumption remains persistent, and recognize gaps in dietary data in several countries around the world.

Chapter 3 presents the findings from an analysis of trends in key food and beverages in the international PURE cohort study of sixteen countries on five continents. Over fifteen years of follow-up, dietary change was modest, with variations by geographic and income region. Milk consumption increased in China, South Asia, Africa, and South America, decreased in Malaysia and North America/Europe, and was unchanged in the Middle East. Egg, chicken, and fish consumption either increased or remained unchanged in all regions over follow-up. Red meat consumption increased in China and the Middle East, while decreased in South America, and change was minimal in North America/Europe, South Asia, Malaysia, and Africa. Fruit intake increased in the Middle East, China, and South Asia, decreased in North America/Europe, Malaysia, and Africa, and was stable in South America. Fresh vegetable consumption decreased in North America/Europe, South America, and the Middle East, increased in South Asia, while was unchanged in China, Malaysia, and Africa. Cooked vegetable consumption increased in South Asia, and decreased in other regions. Low-income countries had some improvements in diet, as milk, chicken, fish, and fruit intakes increased. High- and middle-income countries generally experienced a similar pattern of changes where milk, fruit, and vegetable consumption decreased, while egg, chicken, and fish intakes increased over follow-up.

In Chapter 4, individual-based dietary survey estimates were compared to supply-level dietary trend estimates for total energy and macronutrient intakes across the years 1961 to 2011 in eighteen countries and three country income groupings. Overall, correlations between supply- and individual-level measures were moderate for dietary energy and carbohydrate (Spearman correlation range 0.34 to 0.39), and strong for fat (r_s = 0.85) and protein (r_s = 0.69). Trends in total energy supply and total energy measured by individual-level surveys were positively correlated in less than half of all countries, suggesting caution for future studies that use supply estimates as a proxy for individual-level estimates. In most countries, trends in macronutrients aligned between supply and individual-level estimates when expressed as a percentage of total energy. Overall, our findings generally support the use of supply-level data when individual-level data cannot be collected to monitor dietary changes in populations over time in Asia and lower-income countries, but not in higher-income countries. This consistency could be related to the smaller sample size or inaccurate national food supply data in these regions.

Methodological considerations

This section addresses key methodological considerations, including internal validity (selection bias, information bias, social desirability bias, and confounding), external validity, and effect modification within the context of the findings of this thesis.

Internal validity

Internal validity refers to how well a study was designed and conducted, and the level of confidence in the strength of the inferences of study findings (15). There are several potential threats to internal validity, including selection bias, information bias, and confounding.

Selection bias

Non-participation bias

Non-participation bias can occur during study recruitment, including when participants are not equally selected for a study (16-19). As a result, the study population may not be representative of the target population at recruitment (16-17). For Chapter 3, the PURE Study recruited several countries and communities for a representative sample of adults aged 35 to 70 years at baseline, including both urban and rural communities based on national definitions. Within the PURE Study, in rural areas, participants were invited to join the study through an announcement from a community leader, followed by in-person visits of all households (20). In urban areas, initial contact was made via postal invitations, followed by telephone invitations (20). In both urban and rural communities, at least three contact attempts were made (20). Moreover, when an eligible individual refused to participate, key demographics, risk factors, and event history within the two previous years were recorded for eligible non-participating individuals (20). While slightly more females were enrolled (56.0%) compared to eligible (52.9%), eligible and enrolled participants had a similar mean age, smoking history, education, and history of hypertension, diabetes, cardiovascular disease, and cancer, supporting minimal non-participation bias (20). As follow-up data from the PURE Study was used for analyses in Chapter 3, it was also necessary to compare participant characteristics among those enrolled at baseline relative to participants at follow-up. The population of participants at follow-up visit one had a similar distribution of sex, urban/rural location (e.g., 53.3% urban at baseline, 54.1% at follow-up), education, smoking, physical activity, alcohol use, diabetes, hypertension, cancer, stroke, heart disease, body mass index, waist-to-hip ratio, and average energy intake, compared to participants at baseline.

Loss to follow-up

In prospective studies, bias can be introduced if participants have differential follow-up, as participants continuing in the study may have different characteristics compared to those lost to follow-up (16-19). For the PURE cohort study in Chapter 3, 75.5% of participants completed two or more follow-up visits, while 42.7% had three or more follow-up visits. Moreover, participant demographic characteristics were similar over follow-up, and therefore any losses to follow-up did not significantly change the composition of the study population. The population of participants at follow-up visit one had a similar distribution of sex (e.g., 59.0% female at follow-up visit one, and 59.3% female at visit four), urban/rural location, education, smoking, physical activity, alcohol use, diabetes, hypertension, cancer, stroke, heart disease, body mass index, waist-to-hip ratio, and average energy intake, compared to participants at follow-up visit four.

Representativeness

A study population is representative when the participants included in the study reflect the characteristics of a broader population. For instance, are the participants sampled from Canada in the PURE Study in Chapter 3 comparable to the national adult Canadian population? A previous publication from the PURE study found that participant characteristics (e.g., age, sex, education, mortality rates) were comparable to national data from the United Nations World Population Prospects, supporting the representativeness of the PURE Study (20-21). Most of the primary studies in Chapter 2 and Chapter 4 are representative as participants were specifically selected to generate nationally representative study populations when examining dietary trends.

Selection bias in systematic reviews

In the context of a systematic review, selection bias can be introduced while searching for the primary studies. For example, selection bias can be introduced if only one or two databases are searched, grey literature is not searched, and if any personal bias is present when reviewers are selecting the primary studies. For the systematic review presented in Chapters 2 and 4, an extensive search strategy was developed to avoid selection bias. Three large databases were searched, including Medline, EMBASE, CINAHL, as well as 327 grey literature sources of key nutrition organizations, institutes of nutrition, and government websites. Hand searching of reference lists of included articles was performed. Reviewers were provided with clear inclusion and exclusion criteria, pilot testing for article screening and data extraction was performed with several examples, and a standardized data collection form was employed to limit reviewer selection bias. Selection bias of primary studies was also assessed as a domain during the formal risk of bias assessment required for the systematic review in Chapter 2 and Chapter 4, and 84.4% (92 of 109) of studies had a low risk of selection bias.

Publication bias

The systematic review presented in Chapters 2 and 4 may be subject to publication bias, which refers to when available data are not published due to their findings, which could distort conclusions as to the true dietary trends in populations. Although difficult to completely rule out, publication bias was minimized through an extensive search of journal databases, and through searching 327 grey literature sources of key nutrition organizations, institutes of nutrition, and government websites. Grey literature sources may be more likely to publish all data, even if no trends were observed, compared to studies in traditional publishing channels. Also, investigators of included studies and known collaborators who may have access to additional trend data were contacted for estimates that may not be publicly available. Moreover, studies investigating dietary trends may be more likely to be published with “negative” results, as a lack of dietary change is typically considered an important finding.

Information bias

Information bias, specifically misclassification bias, refers to error that can occur when study exposures and/or outcomes are measured inaccurately or misclassified (16-19). In the context of this thesis, nondifferential misclassification bias, a type of random measurement error, is possible as participants may not have accurately recollected all food and beverage consumption at the time of measurement. In Chapter 3, as the short FFQ employed to collect dietary data in the PURE study was comparable over time and participants have similar characteristics over time, nondifferential misclassification bias is likely consistent over follow-up, and therefore should not influence measures of dietary change. Also, standardized participant diet history in the PURE study was recorded by research staff who were extensively trained in accurate data collection methodology (e.g., use of prompts) with a thorough operations manual to limit misclassification bias.

Findings from the systematic review in Chapter 2 and Chapter 4 rely on diet measured using self-reported or interviewer-guided tools, including 24-hour recalls, FFQs, and dietary records. There may be differences in the estimation of absolute intakes between measures as the 24-hour dietary recall requires participants to recollect consumption in the past 24 hours, while dietary records are typically over three to seven days. FFQs typically ask participants to recall average food and beverage consumption over the long term (e.g., over the past year, sometimes over the past week). As a result, FFQs may have more random measurement error compared to 24-hour recalls and dietary records. However, in Chapter 2 and Chapter 4, estimates of dietary changes were similar across all three methods of dietary assessment, and therefore, any bias that occurred during diet measurement due to the different instruments did not influence the outcome of dietary change. Also, the adequacy of outcome (dietary change) measurement was formally assessed as a risk of bias domain for the systematic review in Chapter 2 and Chapter 4, and 83.0% of studies had a low risk of outcome measurement bias. The dietary supply data, as used in Chapter 4, is specifically compiled, and validated to be comparable across countries and time (22). For example, food products are expressed using an international statistical classification structure to ensure the same product is being compared across settings, products are reported in common units, and consistent reference periods are employed during data collection (22).

Social desirability bias

Social desirability bias, a type of non-random measurement error is possible, in which participants answer questions in a manner that would be viewed favorably by others (16).

For example, participants may underreport consuming soft drinks, while overreport consuming vegetables. This bias may vary by subgroup, such as men compared to women or among participants who are overweight compared to normal weight. While this is a possibility and a limitation in any study employing dietary questionnaires, given that participant characteristics are similar over follow-up (Chapter 3) and nationally representative samples of the population are selected over time (Chapters 2 and 4), any social desirability that is present should be present at all follow-up visits, and therefore should not distort the outcome of dietary change.

Confounding

Observational study designs are subject to confounding. Therefore, it is important to identify potential sources of confounding to minimize this bias. Confounding variables are typically accounted for at the design stage (e.g., through matching), and/or during the statistical analysis stage by adjusting for confounders in multivariable models. In the context of temporal data presented in this thesis, confounding bias can occur when additional factors are associated with both the exposure (time) and outcome (consumption of energy, macronutrients, foods), but are not in the causal pathway between exposure and outcome (17-19).

Maturation bias

One source of confounding can be maturation bias, which can occur, especially in prospective studies, as participant characteristics inevitably change as a function of time (18). For example, in the PURE study in Chapter 3, participants age over time, and observed dietary changes may be related to the change in age, as opposed to population-level dietary changes. The age and sex distribution of a population over time are key confounders to consider, therefore, the models that estimated dietary change adjusted for sex and age at baseline. Although the PURE cohort is aging over time, the cohort includes mostly middle-aged adults (82.3% are <65 years old at the first follow-up visit). Dietary change usually occurs in older adults (e.g., >70 years old) as their need for calories decreases, and only 5.2% of the PURE cohort was >70 years old at the first follow-up visit. Nevertheless, to test if dietary change over time differed from dietary change related to aging, dietary change estimates in the overall population (aging over time), were compared to two subsets that are the same age (55-60 years old) at different time points. Dietary changes in the subset of participants aged 55-60 at two different time points were similar to dietary changes observed in the overall population, suggesting that observed changes are likely not related to the aging of the cohort. Participant demographic characteristics (sex, region, income, education, BMI, smoking, physical activity) were consistent over follow-up, and therefore these characteristics should not confound the results.

Maturation bias is less of a concern for the validity of findings from Chapter 2 and Chapter 4 as these studies primarily rely on data from repeat cross-sectional surveys to assess national or sub-national dietary changes. In repeat cross-sectional studies, new participants are selected for each round of data collection, participants are specifically selected to create a nationally representative sample, and additional adjustments or standardization for age and sex were typically performed. Comparability was assessed as a formal risk of bias domain for the systematic review in Chapter 2 and Chapter 4, and

47.7% of studies had a low risk of comparability bias. The comparability domain assesses if participants were similar over time, including if studies accounted for important confounders of age and sex over time. When estimating dietary changes, models accounted for the clustering of country, as well as for the median age over time (to adjust for changes in population age distributions over time), dietary assessment method, and year of initial data collection. While unadjusted and adjusted models produced similar estimates of dietary change, residual confounding is possible.

Contextual factors

Several other factors can influence dietary change, including changes to food prices, accessibility, environmental events (e.g., droughts, floods), food industry marketing, government subsidies, education, public health policies, consumer attitudes, and cultural influences. Rather than confounders, these are considered contextual factors in this thesis, as our objectives were to understand dietary changes in overall populations (e.g., regions, countries) in their existing context, and not to isolate dietary changes adjusted for all other potential factors that also changed during the same period. For instance, chicken consumption slightly increased in South Asia in the PURE study, and while a potential confounder may be the introduction of subsidies for poultry farmers, this is considered an important contextual factor, rather than a confounder.

Effect Modification

In addition to time, dietary change could depend on other factors, or “effect modifiers”, such as geography, income region, age, and sex (19). Suspected effect modifiers can be statistically identified through the use of interaction testing, and if significant, stratum-specific estimates can be presented. All chapters in this thesis present results stratified by geographic region and country income grouping as these were significant and expected effect modifiers. For the meta-analysis components in Chapter 2 and Chapter 4, potential effect modifiers were tested and not significant, including population type, survey population, study design, risk of bias, and dietary assessment method. In Chapter 3, testing for effect modification was conducted by age grouping (older vs. younger adults), participants who had events during follow-up, and participants who self-reported changing their diet. Overall, results were similar across strata.

External validity

External validity refers to how well results from one study can be applied or generalized to different populations and settings (15). For instance, a study in a single geographic setting is typically not considered externally valid, as results must be replicated in different geographic regions and settings where participant characteristics vary (15). The PURE study in Chapter 3 included 16 low-, middle-, and high-income countries in 626 communities in North America and Europe, South America, the Middle East, South Asia, China, Southeast Asia, and Africa. While recruitment of additional countries would improve the generalizability of findings, the existing PURE study countries are generally representative and include countries of varying economic development with varying dietary patterns (20-21). As a result, the PURE study enabled the examination of dietary trends in lower-income countries where previously there was little to no data on dietary trends.

Chapter 2 collated data from 47 countries in nine regions, including East Asia, South Asia, Southeast Asia, Western Europe and Australasia, Northern Europe, Eastern Europe, North America, Latin America, and the Middle East. By including many countries, results are more likely to be applicable internationally. Chapter 3 pooled data from 18 countries in East Asia, India, Southeast Asia, Western Europe, Eastern Europe, Northern Europe, and the United States. Despite an extensive search strategy in Chapter 2 and Chapter 4, generalizability may be reduced as countries where dietary trend data were not available are not reflected in estimates. For instance, several lower-income countries and countries in Latin America, the Caribbean, the Middle East, and Africa did not have adequate individual-level diet measures.

Implications for nutrition policy

Our findings show considerable regional variation in dietary trends and highlight targets for nutritional policies and interventions as consumption of fruits, nuts, legumes, and roots/tubers were below recommended intakes in most regions. Seafood consumption was also below recommendations in North America, Northern and Eastern Europe, the Middle East, and South Asia. Our study identifies specific countries where excessive carbohydrate consumption remains persistent (e.g., India, Philippines, and Vietnam). In Chapter 2, gaps in national diet trend surveillance in several lower-income countries around the world and countries in Latin America, the Caribbean, the Middle East, and Africa were recognized. In Chapter 3, our findings contribute to filling this gap of inadequate monitoring by using the PURE Study, the first cohort study to estimate dietary changes in countries of varying economic positions in seven geographic regions across five continents. Both favorable and unfavorable shifts in key foods and beverages were observed over fifteen years of follow-up. Our results in low-income countries in the PURE Study suggest some improvements in diet quality as there were increases in milk, chicken, fish, and fruit intakes. However, fruit and vegetables decreased in high- and middle-income countries, and there was no change in vegetable intake in low-income countries. Collectively, our findings suggest that the burden of diets low in fruit and vegetables has not improved. The findings from Chapter 4 suggest caution should be applied if using food supply data to estimate dietary trends or diet-disease relationships. Diet trends between the two measures do not align for all countries, which should be considered if using supply data as a proxy for individual-level surveys.

Future directions

The findings from this thesis contribute to existing efforts to improve the estimation of dietary changes in multiple world regions. An important next step is to test if dietary trends are related to changes in disease patterns. The work from Chapter 2 and Chapter 4 can be expanded to compare estimated dietary change to changes in the prevalence of mortality and non-communicable disease as reported from national sources and previously published literature. In the context of Chapter 3, the associations between food and beverages measured at follow-up and future events can be compared to diet-disease associations from baseline. This future work would contribute to the ongoing debate that in prospective cohort studies, diet should be re-measured in full every 3-4 years to account for dietary changes when estimating disease risk.

Concluding remarks

Amid continuing efforts to improve the availability and affordability of healthy foods in several world regions, the standardized assessment of dietary trends using comprehensive data is essential. This thesis estimated dietary changes both over the long term (1950-2019) in a systematic review of trends in 47 countries and over the short term (2007-2022) in a cohort of 16 countries. Collectively, the findings from this thesis inform existing efforts to estimate and compare dietary changes in multiple world regions of various levels of socioeconomic development using multiple national and sub-national data sources.

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