Global Food Security 17 (2018) 21–29

Contents lists available at ScienceDirect

Global Food Security

journal homepage: www.elsevier.com/locate/gfs

The global burden of chronic and hidden hunger: Trends and determinants

Theda Gödecke[a,*], Alexander J. Stein[b], Matin Qaim[a]

[a] Department of Agricultural Economics and Rural Development, University of Goettingen, Platz der Goettinger Sieben 5, 37073 Goettingen, Germany
[b] Directorate-General for Agriculture and Rural Development, European Commission, 1049 Brussels, Belgium

ARTICLE INFO

Keywords:
Hunger
Micronutrient malnutrition
Measurement
DALYs
Determinants
Cross-country regressions

ABSTRACT

Eradicating hunger in all its forms, including chronic and hidden hunger, requires good understanding of the problem's magnitude, trends, and determinants. Existing studies measure "hunger" through proxies that all have shortcomings. We use a more comprehensive metric, Disability-Adjusted Life Years (DALYs), to quantify the burden of hunger and show related trends. While the burden of chronic hunger more than halved since 1990, it remains larger than the burden of hidden hunger. Cross-country regressions show that economic growth was a major determinant of reducing the hunger burden. However, growth and other country-level determinants have larger effects on the burden of chronic hunger than on the burden of hidden hunger. Complementary micro-level interventions are required to end hunger in all its forms.

1. Introduction

Worldwide, about 800 million people are chronically hungry, meaning that they are undernourished in terms of calories (FAO et al., 2017). More than 2 billion people are affected by hidden hunger, meaning that they suffer from micronutrient deficiencies (WHO, 2006). Although progress was made in reducing these problems, ending hunger in all its forms – as stated in the Sustainable Development Goals (SDGs) – remains a global challenge (FAO et al., 2017; Barrett, 2010; Stokstad, 2015; Obersteiner et al., 2016; Allen and de Brauw, 2018). The goal of ending hunger in all its forms involves a broad definition of hunger, including calorie deficiencies (chronic hunger), micronutrient deficiencies (hidden hunger), and related health problems.

Achieving the SDGs requires political commitment and knowledge about the types of actions that can help to reduce different forms of hunger effectively. While evidence to support concrete nutrition interventions at the community, household, or individual level is accumulating (Bhutta et al., 2013; Ruel and Alderman, 2013), lack of reliable country-level data makes it difficult to describe and monitor the magnitude of global hunger in all its forms over time (IFPRI, 2017). Given this lack of country-level data, the country-level determinants of hunger are also not yet sufficiently understood (IFPRI, 2017; Gillespie et al., 2013). The few existing cross-country studies that investigated determinants of hunger relied on data covering only a small number of countries and years (Headey, 2013; Smith and Haddad, 2002, 2015; Haddad et al., 2003; Vollmer et al., 2014; Headey et al., 2017). Nor did these existing studies solve the issue of how to measure "hunger" in its different forms. Various proxy measures were used that all quantify only selected dimensions of hunger or individual health outcomes, therefore not capturing hunger in all its forms in the broader SDG sense.

To overcome these shortcomings, Disability-Adjusted Life Years (DALYs) were suggested as a more nuanced and comprehensive measure to analyze the burden of hunger (Black et al., 2008; Muthayya et al., 2013; Stein, 2014). DALYs are a metric to quantify the burden of health problems in terms of healthy (disability-adjusted) life years lost (IHME, 2018; Murray et al., 2012; Murray and Lopez, 1996). A common metric is useful to compare the magnitude of very different types of health problems. In a hunger context, DALYs can be calculated for different risk factors, such as protein-energy malnutrition, childhood underweight, iron deficiency, or vitamin A deficiency, just to name a few. The DALYs metric was used to quantify the burden of different forms of hunger (Black et al., 2008; Lim et al., 2012; Murray et al., 2012; Muthayya et al., 2013; Stein, 2014). However, no previous study has used the DALYs metric to explicitly compare the burden of chronic hunger and the burden of hidden hunger over time and analyze the country-level determinants of these burdens with cross-country regression models. Here, we address these research and knowledge gaps.

We show that the combined burden of chronic and hidden hunger, as measured with DALYs, has been reduced by more than half since 1990. However, the burden of chronic hunger has fallen more rapidly than the burden of hidden hunger. Economic growth was a key determinant of reducing the burden of chronic and hidden hunger over time. Other country-level determinants with significant effects include urbanization, democracy, temperate-zone climates, larger food supplies, food diversity, female schooling, and access to improved sanitation and health. However, our analysis also reveals that all country-

* Corresponding author.
E-mail address: tgoedec@uni-goettingen.de (T. Gödecke).

https://doi.org/10.1016/j.gfs.2018.03.004
Received 22 December 2017; Received in revised form 18 March 2018; Accepted 23 March 2018

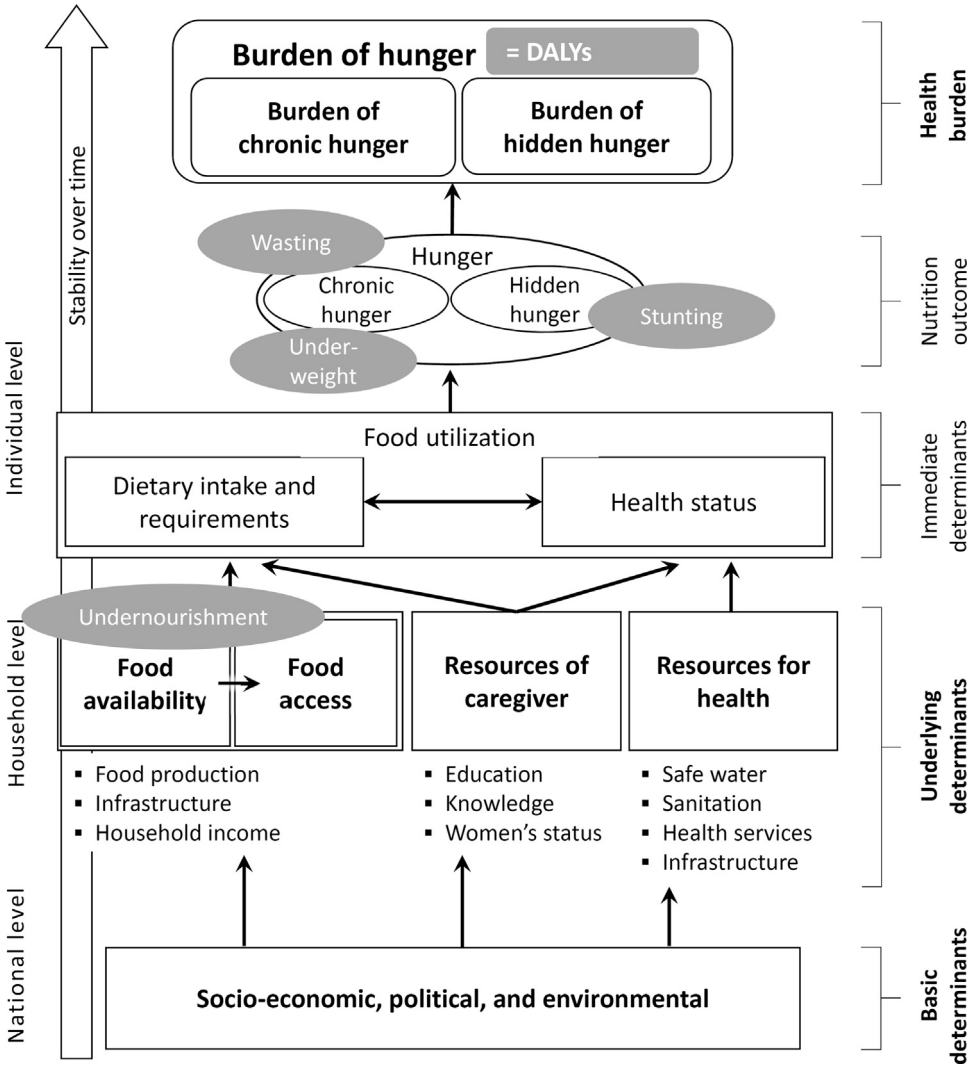

Fig. 1. Determinants of hunger including related proxy measures. The conceptual framework is based on (UNICEF, 1990), with the elements in grey showing which indicators are used in the literature to analyze hunger and measure food insecurity. DALYs, Disability-Adjusted Life Years.

level determinants are more effective in reducing the burden of chronic hunger than the burden of hidden hunger. This means that the burden of hidden hunger may persist even if appropriate policies at the national level were put in place everywhere. These results suggest that additional micro-level interventions are required to eradicate the burden of hunger in all its forms.

2. Conceptual framework

In analyses of hunger and food security, undernutrition is commonly explained using variants of UNICEF's conceptual framework for "causes of malnutrition and death" (Black et al., 2008; Engle et al., 1999; Smith and Haddad, 2015, 2002; UNICEF, 1990). We build on this framework with a few adjustments, as shown in Fig. 1. Using common terminology, a country's socio-economic, political, and environmental characteristics are referred to as "basic determinants", which are seen as indirect determinants of food insecurity at the national level. At the household level, food availability and access, as well as the caregivers' resources and the resources for health, represent the so-called "underlying determinants", which are influenced by the basic determinants and which, in turn, influence the "immediate determinants" one further level up.

Immediate determinants are individuals' dietary intakes and requirements as well as their health status that also influences food utilization. All these factors ultimately determine the nutrition status of individuals and the extent to which they suffer from adverse health outcomes due to chronic or hidden hunger. These adverse health outcomes measured in terms of DALYs are what we refer to as the burden of chronic and hidden hunger. When simply talking of the "burden of hunger", we refer to both the burden of chronic hunger and the burden of hidden hunger combined (Table 1).

The elements of this framework also reflect the widely accepted definition of food security, namely that "food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996). This definition is generally understood to comprise three dimensions – "availability" of sufficient quantities of food of appropriate quality, "access" by households to adequate resources to acquire appropriate foods for a nutritious diet, and "utilization" of food by individuals through adequate diet, water, sanitation, and health care. The three dimensions are

Table 1
Explanation of key terms used in this study.

Term	Definition	Proxies used in this and other cross-country studies
Chronic hunger	Insufficient intake or poor biological use of macronutrients or dietary energy (calories) to meet the dietary requirements (similar terms: undernourishment, macronutrient deficiency).	Typical proxies used in other cross-country studies: prevalence of undernourishment (PoU)[a]; number of people undernourished (NoU)[a]; prevalence of child stunting[a]; prevalence of child wasting[a]; prevalence of child underweight[a].
Burden of chronic hunger	Health burden as a consequence of chronic hunger (expressed as the number of healthy life years lost in a population due to disability and premature death attributable to chronic hunger).	DALYs lost due to chronic hunger. Using available and relevant data from IHME (IHME, 2013a, 2013b), our proxy includes all DALYs lost due to protein-energy malnutrition and childhood underweight.[b]
Relative burden of chronic hunger	Burden of chronic hunger per 1000 capita.	DALYs lost due to chronic hunger divided by the total population (in 1000 capita) of a country.[b]
Hidden hunger	Insufficient intake or poor biological use of micronutrients (similar terms: micronutrient malnutrition; vitamin and mineral deficiencies).	Typical proxies used in other cross-country studies: prevalence of child stunting[a]; prevalence of child wasting[a]; prevalence of average micronutrient availability below recommended thresholds.
Burden of hidden hunger	Health burden as a consequence of hidden hunger (expressed as the number of healthy life years lost in a population due to disability and premature death attributable to hidden hunger).	DALYs lost due to hidden hunger. Using available and relevant data from IHME (IHME, 2013a, 2013b), our proxy includes all DALYs lost due to iodine deficiency, iron deficiency, vitamin A deficiency, zinc deficiency, and other nutritional deficiencies.[b]
Relative burden of hidden hunger	Burden of hidden hunger per 1000 capita.	DALYs lost due to hidden hunger divided by the total population (in 1000 capita) of a country.[b]
Hunger[c]	Combination of chronic hunger and hidden hunger (see above) (similar term: undernutrition).	See above for chronic hunger and hidden hunger.
Burden of hunger	Combination of the burden of chronic hunger and the burden of hidden hunger (see above).	DALYs lost due to chronic and hidden hunger (see above).[b]
Hunger in all its forms	This includes chronic and hidden hunger as well as the burden of chronic and hidden hunger (see above).	

Notes:
[a] For further definitions of these proxies, see Supplementary material online (Table S8).
[b] For further details of the DALY calculations, see Supplementary material online (Text S1).
[c] In the literature, the term hunger is used with different definitions (e.g. FAO, 2008; FAO et al., 2017). Here, we equate the term hunger with undernutrition in terms of both calories and micronutrients (combination of chronic hunger and hidden hunger).

complemented by "stability" over time. In our framework, the inherent hierarchy of these concepts is presented at the different levels: food availability is necessary but not sufficient to ensure food access, access is necessary but not sufficient for effective utilization (Barrett, 2010).

3. Measuring the burden of chronic and hidden hunger with DALYs

In previous cross-country analyses of hunger and its causes, various proxy measures were used that generally quantify only selected determinants of food security or individual health outcomes of hunger. The most common proxy measures are FAO's food availability-based indicator for undernourishment (Kaur and Kaur, 2016; Klasen, 2008; Palma et al., 2009; Soriano and Garrido, 2016) and child anthropometric indicators, such as the prevalence of stunting (Frongillo et al., 1997; Headey, 2013; Kimenju and Qaim, 2016; Klasen, 2008; Smith and Haddad, 2015; Vollmer et al., 2014), underweight (Haddad et al., 2003; Kimenju and Qaim, 2016; Klasen, 2008; Smith and Haddad, 2002; Vollmer et al., 2014), or wasting (Frongillo et al., 1997; Klasen, 2008; Vollmer et al., 2014). In addition, composite indices that combine various single indicators to construct abstract index values are sometimes used. Examples of such composite indices are the Global Hunger Index or the Global Food Security Index (Stein, 2014).

As shown schematically in Fig. 1, all these measures and indices can capture (only) certain dimensions of food security or individual health outcomes of hunger, but fail to provide a full picture of the extent of hunger and its health problems. In other words, the common proxies used are not suitable for measuring the burden of hunger in all its forms. In addition, some of the proxies focus on children only and are therefore not suitable to describe, compare, and monitor the magnitude of hunger in all its forms of the entire population. Even when a suite of indicators, covering various forms of hunger or related health outcomes, is used, the different indicators cannot be employed easily for consistent comparisons or informed decision-making, as they fail to address questions such as: Is hunger a bigger problem in a population where 10% of the people lack access to food calories, where 10% of the children are stunted, or where 40% of the people are iron deficient?

3.1. Calculating DALYs

Disability-Adjusted Life Years (DALYs) do not measure hunger directly, but can be used as a comprehensive metric of the health burden of hunger. Doing so can help to address many of the shortcomings of the other hunger proxies. DALYs account for the duration and severity of health conditions and quantify the health burden by measuring the number of healthy life years lost in a population due to disability and premature death (Murray et al., 2012). As mentioned, DALYs can be calculated for very different health conditions. For the calculations in this study, we only consider the DALYs that are directly attributable to (chronic and hidden) hunger.

Hunger negatively affects people's functioning. The burden of hunger calculated with DALYs offers a meaningful way to measure this loss of functioning by expressing it in an intuitive way, namely in terms of healthy life year equivalents lost due to different forms of hunger.

Very generally, the DALYs lost due to certain health conditions are calculated as:

$$DALYs_{lost} = YLL + YLD_{weighted} \quad (1)$$

where YLL are "years of life lost" due to premature death, and YLD are weighted "years lost due to disability" attributable to certain health conditions. To produce an aggregate burden measured in DALYs, YLL and $YLD_{weighted}$ are summed up across all health conditions of interest

(Stein, 2014). This means that DALYs can be used to quantify the burden of different forms of hunger, such as chronic and hidden hunger, separately. But – given that the different problems are all quantified with the same metric – the separate burdens can also be added up to result in the overall burden of hunger in all its forms.

Different forms of hunger are associated with different types of health conditions (Lim et al., 2012). Calorie and vitamin A deficiencies are associated with child mortality and certain infectious diseases. Zinc deficiency is also associated with child mortality and additionally with child stunting. Iron deficiency is associated with reduced physical activity and impaired child mental development. These are just a few of the health conditions included in the DALYs calculations for chronic and hidden hunger (IHME, 2013a, 2013b). Many of the relevant health conditions have multiple causes, not all of which are related to nutrition. For instance, measles are related to vitamin A deficiency but also to several other risk factors. In such cases, the fraction of the health condition attributable to each risk factor is determined based on effect-size estimates, often building on meta-analyses in the health and nutrition literature (Lim et al., 2012; Stein et al., 2005).

The Institute for Health Metrics and Evaluation (IHME) uses a large team of experts that calculates and updates DALYs for more than 300 health conditions and associated risk factors (IHME, 2018). For this study, we extracted a set of DALYs from the IHME that are relevant to undernutrition to quantify the burden of different forms of hunger. In particular, we quantify the burden of chronic hunger and the burden of hidden hunger (both expressed in terms of the number of DALYs lost) for 187 countries and three years (1990, 2005 and 2010) for which the estimates were available (IHME, 2013a, 2013b).

We define the burden of chronic hunger as the sum of DALYs lost due to protein-energy malnutrition (PEM) and child underweight. The burden of hidden hunger is the sum of DALYs lost due to different forms of micronutrient deficiencies. An overview of the key terms and concepts used in this study is shown in Table 1. Further details of the data and calculation methods used are provided in the Supplementary material online.

3.2. Comparing DALYs with other hunger proxies

DALYs are a comprehensive metric of the health burden of hunger. Other measures of hunger are narrower and focus only on certain aspects of hunger, such as food availability or stunting. However, in spite of their broader scope, DALYs are not necessarily a complete measure of all health issues related to chronic and hidden hunger, because data on the prevalence and health consequences of certain rarer vitamin or mineral deficiencies may simply not be available. The advantage of the DALYs method is that the estimates can be extended and updated when new or improved data become available. This is not possible with other measures. For instance, it is impossible to sum up the prevalence of stunting with the prevalence of a previously disregarded deficiency, but combining the DALYs lost due to stunting with the DALYs lost due to a newly quantified deficiency produces a meaningful result.

Another strength of DALYs is their greater nuance compared to other hunger measures. DALYs calculations differentiate between very severe (or disabling) health conditions and less severe or transient conditions. Thus, DALYS are capable of capturing degrees of hunger. In contrast, head-count approaches like the FAO's prevalence of undernourishment or the prevalence of stunting, where people are either affected or not, do not take into account the depth and duration of the problems. However, one drawback that applies to all common measures of hunger, including DALYs, is that only actually occurring hunger is captured, not people's vulnerability to hunger, which may also be of interest to policy-makers.

Finally, while DALYs were not specifically designed to indicate productivity losses, they cover both adverse physical and cognitive health outcomes. Therefore, if desired, DALYs can also be used to approximate the economic cost of hunger by valuing each DALY with a country's mean per-capita income (Stein, 2014). Adding such a monetary dimension to the measurement of hunger is more difficult when using other hunger measures, such as prevalence rates or composite indices. However, in this study we do not calculate the economic cost and use DALYs only to measure the health burden of hunger.

4. Trends of the burden of chronic and hidden hunger

Between 1990 and 2010, the global burden of chronic hunger diminished by more than 50%, while the burden of hidden hunger diminished by about 30% (Fig. 2A). Relative to population size, the burden of chronic hunger and hidden hunger diminished by around 70% and 50%, respectively (Fig. 2B). Nevertheless, in 2010 the global burden of chronic hunger was still larger than the burden of hidden hunger. This may seem counter-intuitive given that fewer people suffer from chronic hunger than from hidden hunger. However, as explained, DALYs go beyond a simple head-count approach: while hidden hunger is more prevalent, the health consequences of chronic hunger are more severe, thus causing a bigger number of DALYs lost.

Wide differences persist across regions. In 1990, the biggest burden of chronic hunger was observed in South Asia, followed by Sub-Saharan Africa (Fig. 2C). Since then, the burden of chronic hunger declined in all regions, but at different pace. Because progress in South Asia was particularly fast, Sub-Saharan Africa had the biggest burden of chronic hunger in 2010. Starting from lower levels, the burden of hidden hunger also declined in all regions, but at slower pace (Fig. 2D). South Asia remains the region with the largest burden of hidden hunger in 2010.

However, while telling us where the biggest burdens are, absolute numbers are “biased” in that (all other things being equal) regions with bigger populations will have a bigger burden. To understand how severe the problem is in a given region, looking at relative numbers – in this case DALYs lost per 1000 capita – is more useful. When doing so, the regional patterns change. For both chronic hunger and hidden hunger, Sub-Saharan Africa is by far the region with the biggest relative burden (Figs. 2E and 2F).

5. Determinants of the burden of chronic and hidden hunger

To study the determinants of the burden of hunger, we estimate cross-country panel data regressions, using the logarithm of the number of DALYs lost due to chronic and hidden hunger in a country per 1000 capita as dependent variables. We estimate separate models for the burden of chronic hunger and the burden of hidden hunger. The choice of independent variables is guided by the conceptual framework (Fig. 1). Further details of model specification and of the data sources used for compiling the independent variables are provided in the Supplementary material online. Estimation results are summarized and discussed below.

5.1. The role of economic growth and demographic trends

Regression results indicate that higher per capita GDP (gross domestic product) is strongly associated with a lower burden of chronic and hidden hunger (Table 2). This is consistent with earlier studies that had used other measures of hunger as dependent variables, such as the prevalence of undernourishment (e.g. Klasen, 2008) or the prevalence of stunting or underweight (e.g. Smith and Haddad, 2002, 2015). Our estimates suggest that a 1% increase in GDP is associated with a 0.4–0.5% decrease in the burden of chronic hunger, and a 0.2–0.3%

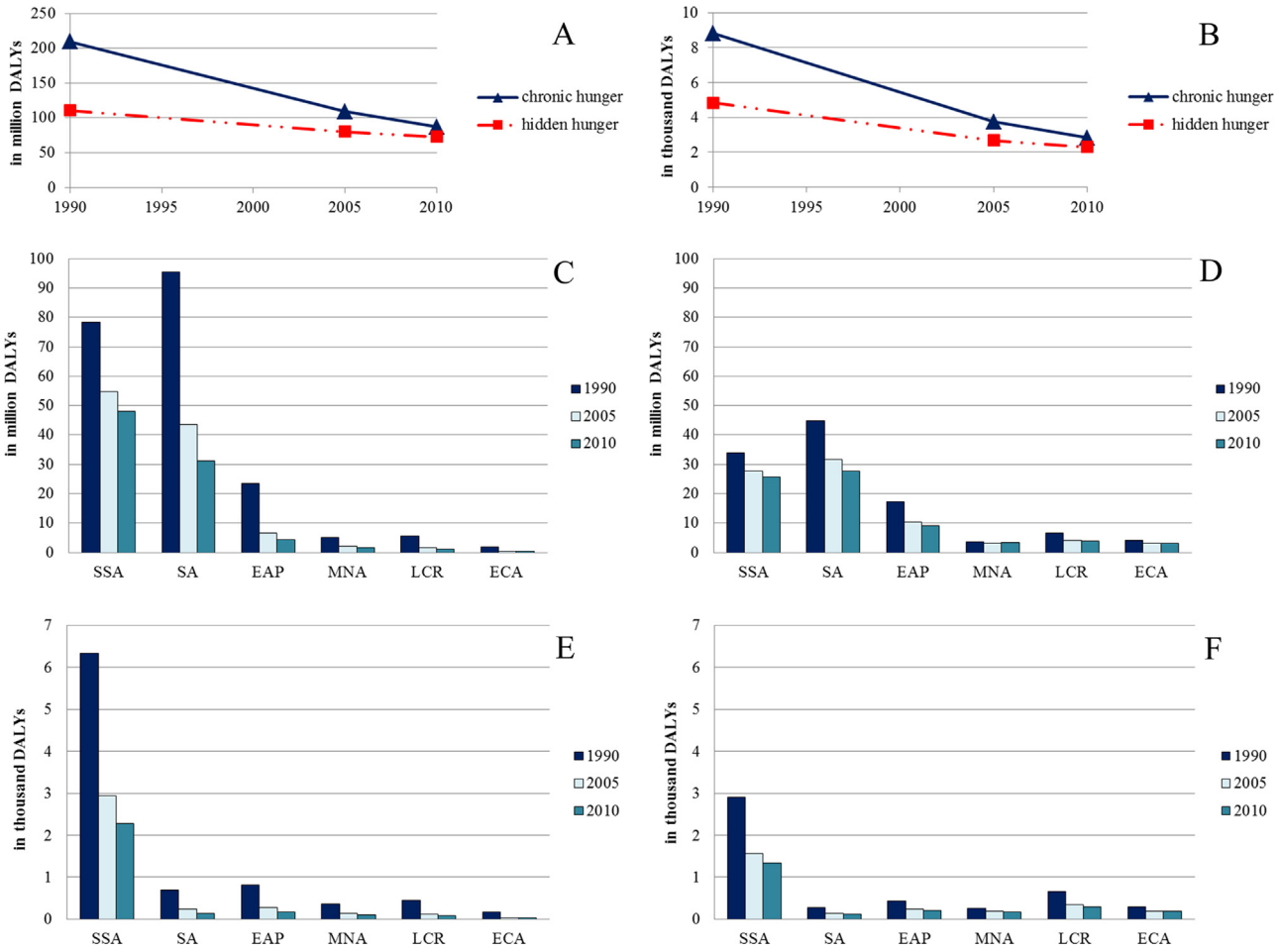

Fig. 2. Development of the burden of hunger over time and by region. (A) DALYs lost due to chronic hunger and hidden hunger between 1990 and 2010. (B) DALYs per 1000 capita lost due to chronic hunger and hidden hunger between 1990 and 2010. (C) DALYs lost due to chronic hunger by region. (D) DALYs lost due to hidden hunger by region. (E) DALYs per 1000 capita lost due to chronic hunger by region. (F) DALYs per 1000 capita lost due to hidden hunger by region. DALYs, Disability-Adjusted Life Years. SSA, Sub-Saharan Africa. SA, South Asia. EAP, East Asia Pacific. MNA, Middle East and North Africa. LCR, Latin America and Caribbean. ECA, Europe and Central Asia. Further details in Tables S2–S5 (Supplementary material online).

decrease in the burden of hidden hunger.

Beyond GDP, the burden of chronic hunger is higher in countries with a larger share of children under 14 years. This is in line with expectations, given that the health consequences of hunger are particularly severe for children. In addition, countries with high population growth, and thus a large share of children in the total population, might have problems with expanding their food supply. This is disquieting, as populations will continue to grow, especially in Africa (UN, 2015a).

The world's population is also becoming increasingly urban, not least in Africa and Asia (UN, 2015b). While rapid urbanization entails risks for food security (e.g. emergence of slums), it also bears opportunities (e.g. easier access to markets) (Ruel et al., 2017). Our results suggest that the positive aspects of urbanization prevail, as higher levels of urbanization are associated with a lower burden of hunger (Table 2).

5.2. The role of political and environmental factors

In previous studies, it was shown that better political governance tends to reduce child undernutrition (Smith and Haddad, 2002, 2015) and that democracy helps to prevent famines (Burchi, 2011). In line with these arguments, our estimates confirm that democracies are associated with a lower burden of chronic and hidden hunger (Table 2).

In terms of environmental factors, higher levels of rainfall and more land in temperate zones are associated with a lower burden of chronic and hidden hunger. While this is an intuitive result, it may have further implications in the context of climate change, as the burden of hunger is set to increase in regions where rainfall decreases and temperatures rise.

5.3. The role of food availability and food access

In Table 3, we concentrate on the role of food availability and access. For our analyses, we used estimates of food supply expressed in kilocalories per capita per day (kcal/capita/day) obtained from FAO's food balance sheets (FAO, 2016). Food supply available for human consumption at the level of individual countries takes into account domestic production, trade, stock changes, and non-food uses of all relevant food commodities (FAO et al., 2017). Our regressions show that a higher total food supply (kcal/capita/day) is associated with a lower burden of chronic and hidden hunger, even after controlling for GDP (Table 3). While this is expected, it clearly underlines that increases in food supply quantities continue to play an important role in the fight against the different forms of hunger.

Disaggregating the total food supply in our analysis, we show that

Table 2
Associations of basic determinants with the burden of chronic and hidden hunger.

	Burden of chronic hunger		Burden of hidden hunger	
	(1) FE	(2) RE	(1a) FE	(2a) RE
Log(GDP per capita, PPP)	− 0.4045***	− 0.5047***	− 0.1889***	− 0.3100***
	(0.070)	(0.071)	(0.047)	(0.040)
Urban population (% of total)	− 0.0215***	− 0.0136***	− 0.0142***	− 0.0120***
	(0.008)	(0.004)	(0.005)	(0.003)
Population aged 0–14 years (% of total)	0.0876***	0.1158***	0.0038	0.0177***
	(0.010)	(0.008)	(0.006)	(0.005)
Electoral democracy (dummy = 1)	− 0.1530 *	− 0.2173***	− 0.1022**	− 0.1398***
	(0.084)	(0.078)	(0.048)	(0.050)
Average rainfall (mm)	− 0.0034**		− 0.0014*	
	(0.001)		(0.001)	
% land area in temperate zones		− 0.8240***		− 1.0633***
		(0.226)		(0.166)
% land area in tropics and subtropics		0.0503		− 0.0085
		(0.193)		(0.110)
Constant	3.6974***	3.1811***	4.8646***	5.5787***
	(0.737)	(0.772)	(0.500)	(0.433)
Number of observations	409	427	409	427
Number of countries	148	153	148	153
R-squared	0.792391	0.928062	0.751629	0.828406
Hausman test (p-value)	0.0000		0.0000	

Notes: These are results from cross-country panel regressions where the dependent variable is the logarithm of DALYs per 1000 capita lost due to chronic hunger (models 1–2) and hidden hunger (models 1a–2a). Cluster-robust standard errors are shown in parentheses. FE, fixed effects. RE, random effects. GDP, gross domestic product. PPP, purchasing power parity. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively.

calories from both plant and animal products matter in general, but that the effects differ across food groups. The supply of cereals does not show any significant associations, neither with the burden of chronic hunger nor with the burden of hidden hunger. For hidden hunger this is plausible, because most cereals are not particularly rich in micronutrients. For chronic hunger, this result is more surprising, because cereals are the most important source of calories, especially in poor population segments. While this aspect is worth further analysis, it seems that increasing the supply of cereals alone is insufficient to have a clear effect on the burden of hunger. This is an interesting finding, given that many countries still consider cereal supply a key food security indicator. Several countries also have policies in place to increase the level of self-sufficiency in cereals. Additional analyses that we present in the Supplementary material online (Table S11) show no significant correlation between either the countries' domestic production or the import of cereals and the burden of chronic hunger.

The supply of meat, eggs, milk, pulses, roots and tubers, and vegetables and fruits seems to be more relevant than the supply of cereals for reducing the burden of chronic and hidden hunger. These results are consistent with micro-level evidence on the importance of dietary diversity and the consumption of fruits and vegetables for wholesome nutrition (Choudhury and Headey, 2017; Schreinemachers et al., 2018; Sibhatu et al., 2015).

5.4. The role of health and gender

Table 4 presents results of regressions to analyze the role of food utilization and health for the burden of chronic and hidden hunger. Among other factors, food utilization and health are both determined by resources of the caregiver, especially levels of education and women's status (Fig. 1). The regression results show that female school enrollment and the female-to-male life expectancy ratio are both associated with a significantly lower burden of chronic and hidden hunger. Similarly, access to improved sanitation is associated with a lower burden of chronic and hidden hunger, whereas immunization – another proxy to capture the impact of the public health system – seems to be particularly relevant for reducing the burden of hidden hunger. These associations remain significant also after controlling for GDP. Overall, results in Table 4 suggest that education, especially for women, and improving public health and sanitation also have considerable potential to reduce the burden of hunger.

6. Conclusions

Using DALYs, we quantified and compared the burden of chronic and hidden hunger in a large set of countries over a period of 20 years. The combined burden of chronic and hidden hunger has declined significantly. Between 1990 and 2010, the global burden of chronic hunger diminished by more than 50%, while the burden of hidden hunger diminished by about 30%. Nevertheless, in 2010 the global burden of chronic hunger was still larger than the global burden of hidden hunger.

We also studied key country-level determinants of the burden of chronic and hidden hunger with cross-country regression models. Economic growth has been a key factor in reducing the burden of chronic and hidden hunger. Furthermore, urbanization, democracy, temperate-zone climates, larger food supplies, food diversity, female schooling, and access to improved sanitation and health care are all variables that are significantly associated with a lower burden of chronic and hidden hunger.

Some of the regression results confirm earlier research with cross-country data. For instance, economic growth has long been identified as an important factor to reduce hunger and undernutrition (e.g. Haddad et al., 2003; Klasen, 2008; Smith and Haddad, 2015, 2002; Vollmer et al., 2014). However, earlier studies relied on data covering a much smaller number of countries and years (Headey, 2013; Smith and Haddad, 2002, 2015; Haddad et al., 2003; Vollmer et al., 2014; Headey et al., 2017). More importantly, the various proxy measures used in previous research only quantified certain forms of hunger or selected health outcomes of specific population groups, which has drawbacks

Table 3
Associations of food supply with the burden of chronic and hidden hunger.

	Burden of chronic hunger		Burden of hidden hunger	
Models with total per capita food supply	(1)	(2)	(1a)	(2a)
	FE	FE	FE	FE
Log(GDP per capita, PPP)		− 0.7035***		− 0.1319 *
		(0.144)		(0.071)
Food supply (kcal/capita/day)	− 0.0008***	− 0.0005**	− 0.0005***	− 0.0004***
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	3.9049***	9.2597***	3.6936***	4.6591***
	(0.471)	(1.254)	(0.261)	(0.643)
Number of observations	482	452	482	452
Number of countries	170	163	170	163
R-squared	0.705988	0.712290	0.746673	0.745492
Hausman test (p-value)	0.0000	0.0000	0.0000	0.0000
Disaggregation of food supply (A)	(3)	(4)	(3a)	(4a)
	FE	FE	FE	FE
Log(GDP per capita, PPP)		− 0.6055***		− 0.0808
		(0.154)		(0.081)
Supply of animal products (kcal/capita/day)	− 0.0020***	− 0.0012**	− 0.0008***	− 0.0007***
	(0.000)	(0.001)	(0.000)	(0.000)
Supply of plant products (kcal/capita/day)	− 0.0004**	− 0.0004*	− 0.0004***	− 0.0003***
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	3.7036***	8.4776***	3.6308***	4.2500***
	(0.432)	(1.321)	(0.270)	(0.723)
Number of observations	469	446	469	446
Number of countries	165	160	165	160
R-squared	0.721945	0.716434	0.752947	0.750346
Hausman test (p-value)	0.0000	0.0000	0.0000	0.0000
Disaggregation of food supply (B)	(5)	(6)	(5a)	(6a)
	FE	FE	FE	FE
Log(GDP per capita, PPP)		− 0.5548***		− 0.1672
		(0.180)		(0.103)
Supply of meat (kcal/capita/day)	− 0.0017*	− 0.0010	− 0.0009**	− 0.0008*
	(0.001)	(0.001)	(0.000)	(0.000)
Supply of fish (kcal/capita/day)	− 0.0047	0.0017	− 0.0015	0.0015
	(0.003)	(0.005)	(0.001)	(0.002)
Supply of eggs (kcal/capita/day)	− 0.0100**	− 0.0077	− 0.0039*	− 0.0037*
	(0.005)	(0.005)	(0.002)	(0.002)
Supply of milk (kcal/capita/day)	− 0.0014*	− 0.0012	− 0.0005	− 0.0005
	(0.001)	(0.001)	(0.000)	(0.000)
Supply of cereals (kcal/capita/day)	0.0002	0.0002	− 0.0001	− 0.0001
	(0.000)	(0.000)	(0.000)	(0.000)
Supply of pulses (kcal/capita/day)	0.0005	− 0.0008	− 0.0012*	− 0.0012*
	(0.001)	(0.001)	(0.001)	(0.001)
Supply of vegetables and fruits (kcal/capita/day)	− 0.0016*	− 0.0011	0.0002	0.0004
	(0.001)	(0.001)	(0.000)	(0.000)
Supply of roots and tubers (kcal/capita/day)	− 0.0011**	− 0.0012**	− 0.0010***	− 0.0009***
	(0.001)	(0.001)	(0.000)	(0.000)
Constant	2.9807***	7.3453***	3.2136***	4.5105***
	(0.375)	(1.431)	(0.201)	(0.903)
Number of observations	467	444	467	444
Number of countries	164	159	164	159
R-squared	0.742160	0.729083	0.754853	0.751264
Hausman test (p-value)	0.0000	0.0000	0.0000	0.0000

Notes: These are results from cross-country panel regressions where the dependent variable is the logarithm of DALYs per 1000 capita lost due to chronic hunger (models 1–6) and hidden hunger (models 1a–6a). Cluster-robust standard errors are shown in parentheses. FE, fixed effects. GDP, gross domestic product. PPP, purchasing power parity. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively.

when the goal is to end hunger in all its forms. In particular, previous cross-country studies could not explicitly analyze determinants of hidden hunger, because the proxies used were not capable of comprehensively measuring the problem of micronutrient deficiencies. The DALYs approach, as used here, has clear advantages. It captures the health burden of the different forms hunger with a consistent metric, which also allows meaningful comparisons.

Our results show that, by and large, the same determinants are linked to decreases in both the burden of chronic hunger and the burden of hidden hunger, meaning that the same types of national policies can be recommended. However, for almost all determinants the effects on the burden of chronic hunger are larger than the effects on the burden of hidden hunger, which is probably also why the burden of hidden hunger has decreased more slowly over time. In other words,

Table 4
Associations of food utilization and public health with the burden of chronic and hidden hunger.

	Burden of chronic hunger				Burden of hidden hunger			
	(1) FE	(2) FE	(3) FE	(4) FE	(1a) FE	(2a) FE	(3a) FE	(4a) FE
Log(GDP per capita, PPP)		.0212		− 0.4473***		0.0554		− 0.0877
		(0.344)		(0.151)		(0.098)		(0.067)
School enrollment, primary female (% net)	− 0.0078*	− 0.0078*			− 0.0059***	− 0.0058***		
	(0.004)	(0.005)			(0.002)	(0.002)		
Ratio of female to male life expectancy at birth	− 8.4139**	− 8.4413*			− 3.6524***	− 3.7243***		
	(4.145)	(4.277)			(1.180)	(1.192)		
Access to safe water (% of population)	0.0154	0.0156	− 0.0075	− 0.0092	− 0.0043	− 0.0036	− 0.0122***	− 0.0143***
	(0.014)	(0.014)	(0.006)	(0.006)	(0.005)	(0.005)	(0.003)	(0.003)
Access to improved sanitation (% of population)	− 0.0479***	− 0.0482***	− 0.0409***	− 0.0349***	− 0.0079*	− 0.0087*	− 0.0128***	− 0.0102***
	(0.013)	(0.014)	(0.007)	(0.006)	(0.005)	(0.005)	(0.003)	(0.003)
Immunization DPT (% of children ages 12–23 months)	− 0.0005	− 0.0006	− 0.0031	− 0.0032	− 0.0031*	− 0.0032*	− 0.0052***	− 0.0045***
	(0.004)	(0.004)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)
Constant	13.1241***	12.9515***	5.2586***	8.8739***	7.7989***	7.3803***	4.6570***	5.3537***
	(4.325)	(4.510)	(0.527)	(1.234)	(1.295)	(1.409)	(0.249)	(0.526)
Number of observations	249	247	486	465	249	247	486	465
Number of countries	136	134	182	175	136	134	182	175
R-squared	0.720384	0.720411	0.754711	0.757676	0.812259	0.813147	0.837430	0.839386
Hausman test (p-value)	0.0000	0.0010	0.0000	0.0021	0.0000	0.0000	0.0000	0.0000

Notes: These are results from cross-country panel regressions where the dependent variable is the logarithm of DALYs per 1000 capita lost due to chronic hunger (models 1–4) and hidden hunger (models 1a-4a). Cluster-robust standard errors are shown in parentheses. FE, fixed effects. GDP, gross domestic product. PPP, purchasing power parity. DPT, diphtheria, pertussis, tetanus. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively.

the burden of hidden hunger may persist if country-level policies are not complemented by more specific and targeted interventions that operate at the community, household, or individual level. Cost-effective micronutrient interventions that can have an impact in the short to medium term include biofortification, industrial fortification, and food supplementation (Bhutta et al., 2013; Bouis and Saltzman, 2017; IFPRI, 2017; Ruel and Alderman, 2013). Recent studies showed that feasible and affordable options for ending hunger exist (Fan et al., 2018; Kummu et al., 2017). However, achieving the SDGs requires not only knowledge about feasible options but also political commitment.

Acknowledgments

We would like to thank Ilari Määttä and Tatiana Orozco Garcia for their research assistance and Peter Speyer and colleagues for answering our questions related to the IHME data sets. TG, AJS, MQ designed the study. TG, AJS compiled the data and TG performed data analysis. TG, AJS, MQ wrote the paper. The views expressed are those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

Conflict of interest statement

The authors declared that they have no competing interests.

Data statement

The data used in this article were gathered from various secondary data bases that are all publicly available online (more details in the Supplementary material online).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.gfs.2018.03.004.

References

Allen, S., de Brauw, A., 2018. Nutrition sensitive value chains: theory, progress, and open questions. Glob. Food Secur. 16, 22–28. http://dx.doi.org/10.1016/j.gfs.2017.07.002.

Barrett, C.B., 2010. Measuring food insecurity. Science 327, 825–828. http://dx.doi.org/10.1126/science.1182768.

Bhutta, Z.A., Das, J.K., Rizvi, A., Gaffey, M.F., Walker, N., Horton, S., Webb, P., Lartey, A., Black, R.E., 2013. Evidence-based interventions for improvement of maternal and child nutrition: what can be done and at what cost? Lancet 382, 452–477. http://dx.doi.org/10.1016/S0140-6736(13)60996-4.

Black, R.E., Allen, L.H., Bhutta, Z.A., Caulfield, L.E., de Onis, M., Ezzati, M., Mathers, C., Rivera, J., 2008. Maternal and child undernutrition: global and regional exposures and health consequences. Lancet 371, 243–260. http://dx.doi.org/10.1016/S0140-6736(07)61690-0.

Bouis, H.E., Saltzman, A., 2017. Improving nutrition through biofortification: a review of evidence from HarvestPlus, 2003 through 2016. Glob. Food Secur. 12, 49–58. http://dx.doi.org/10.1016/j.gfs.2017.01.009.

Burchi, F., 2011. Democracy, institutions and famines in developing and emerging countries. Can. J. Dev. Stud. 32, 17–31. http://dx.doi.org/10.1080/02255189.2011.576136.

Choudhury, S., Headey, D., 2017. What drives diversification of national food supplies? A cross-country analysis. Glob. Food Secur. 15, 85–93. http://dx.doi.org/10.1016/j.gfs.2017.05.005.

Engle, P.L., Menon, P., Haddad, L., 1999. Care and nutrition: concepts and measurement. World Dev. 27, 1309–1337. http://dx.doi.org/10.1016/S0305-750X(99)00059-5.

Fan, S., Headey, D.D., Laborde, D., Mason-D'Croz, D., Rue, C., Sulser, T.B., Wiebe, K., 2018. Quantifying the Cost and Benefits of Ending Hunger and Undernutrition: Examining the Differences among Alternative Approaches (IFPRI Issue Brief). IFPRI, Washington, D.C.

FAO, 2016. Data Domains [WWW Document]. FAOSTAT. URL ⟨http://www.fao.org/faostat/en/#data⟩.

FAO, 2008. An Introduction to the Basic Concepts of Food Security (Practical Guides), Food Security Information for Action. FAO, Rome.

FAO, 1996. Rome Declaration on World Food Security and World Food Summit plan of action. World Food Summit, 13–17 November, Rome.

FAO, IFAD, UNICEF, WHO, 2017. The State of Food Security and Nutrition in the World: Building Resilience for Peace and Food Insecurity. FAO, Rome.

Frongillo, E.A., Onis, M., de, Hanson, K.M.P., 1997. Socioeconomic and demographic factors are associated with worldwide patterns of stunting and wasting of children. J. Nutr. 127, 2302–2309.

Gillespie, S., Haddad, L., Mannar, V., Menon, P., Nisbett, N., 2013. The politics of reducing malnutrition: building commitment and accelerating progress. Lancet 382, 552–569. http://dx.doi.org/10.1016/S0140-6736(13)60842-9.

Haddad, L., Alderman, H., Appleton, S., Song, L., Yohannes, Y., 2003. Reducing child malnutrition: how far does income growth take us? World Bank Econ. Rev. 17, 107–131. http://dx.doi.org/10.1093/wber/lhg012.

Headey, D., Hoddinott, J., Park, S., 2017. Accounting for nutritional changes in six success stories: a regression-decomposition approach. Glob. Food Secur. Stories Change Nutr. 13, 12–20. http://dx.doi.org/10.1016/j.gfs.2017.02.003.

Headey, D.D., 2013. Developmental drivers of nutritional change: a cross-country analysis. World Dev. 42, 76–88. http://dx.doi.org/10.1016/j.worlddev.2012.07.002.

IFPRI, 2017. Global Nutrition Report 2017: Nourishing the SDGs. IFPRI, Washington, D.C.

IHME, 2018. The Global Burden of Disease: a critical resource for informed policymaking [WWW Document]. URL ⟨http://www.healthdata.org/gbd/about⟩ (Accessed 17 March 2018).

IHME, 2013a. GBD 2010: Results by cause 1990–2010 [WWW Document]. URL ⟨http://ghdx.healthdata.org/record/global-burden-disease-study-2010-gbd-2010-results-cause-1990-2010-country-level⟩ (Accessed 10 July 2015).
IHME, 2013b. GBD 2010: Results by risk factor 1990–2010 [WWW Document]. URL ⟨http://ghdx.healthdata.org/record/global-burden-disease-study-2010-gbd-2010-results-risk-factor-1990-2010⟩ (Accessed 10 July 2015).
Kaur, S., Kaur, H., 2016. Determinants of food security in Sub-Saharan Africa, South Asia and Latin America. In: Kathuria, R., Nagpal, N.K. (Eds.), Global Economic Cooperation. Springer, India, pp. 81–102. http://dx.doi.org/10.1007/978-81-322-2698-7_6.
Kimenju, S.C., Qaim, M., 2016. The nutrition transition and indicators of child malnutrition. Food Secur. 8, 571–583. http://dx.doi.org/10.1007/s12571-016-0566-x.
Klasen, S., 2008. Poverty, undernutrition, and child mortality: some inter-regional puzzles and their implications for research and policy. J. Econ. Inequal. 6, 89–115. http://dx.doi.org/10.1007/s10888-007-9056-x.
Kummu, M., Fader, M., Gerten, D., Guillaume, J.H., Jalava, M., Jägermeyr, J., Pfister, S., Porkka, M., Siebert, S., Varis, O., 2017. Bringing it all together: linking measures to secure nations' food supply. Curr. Opin. Environ. Sustain. 29, 98–117. http://dx.doi.org/10.1016/j.cosust.2018.01.006.
Lim, S.S., Vos, T., Flaxman, A.D., Danaei, G., Shibuya, K., Adair-Rohani, H., AlMazroa, M.A., Amann, M., Anderson, H.R., Andrews, K.G., et al., 2012. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet 380, 2224–2260. http://dx.doi.org/10.1016/S0140-6736(12)61766-8.
Murray, C.J.L., Lopez, A.D., 1996. The Global Burden of Disease, The Global Burden of Disease and Injury. Harvard University Press, Cambridge.
Murray, C.J.L., Vos, T., Lozano, R., Naghavi, M., Flaxman, A.D., Michaud, C., Ezzati, M., Shibuya, K., Salomon, J.A., Abdalla, S., et al., 2012. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet 380, 2197–2223. http://dx.doi.org/10.1016/S0140-6736(12)61689-4.
Muthayya, S., Rah, J.H., Sugimoto, J.D., Roos, F.F., Kraemer, K., Black, R.E., 2013. The global hidden hunger indices and maps: an advocacy tool for action. PLoS One 8, e67860. http://dx.doi.org/10.1371/journal.pone.0067860.
Obersteiner, M., Walsh, B., Frank, S., Havlík, P., Cantele, M., Liu, J., Palazzo, A., Herrero, M., Lu, Y., Mosnier, A., Valin, H., Riahi, K., Kraxner, F., Fritz, S., Vuuren, D. van, 2016. Assessing the land resource–food price nexus of the sustainable development goals. Sci. Adv. 2, e1501499. http://dx.doi.org/10.1126/sciadv.1501499.
Palma, M.A., Ortiz, R., Alvarez-Dardet, C., Ruiz, M.T., 2009. Policy determinants affecting the hunger millennium development goal. Soc. Sci. Med. 68, 1788–1792. http://dx.doi.org/10.1016/j.socscimed.2009.02.044.
Ruel, M.T., Alderman, H., 2013. Nutrition-sensitive interventions and programmes: how can they help to accelerate progress in improving maternal and child nutrition? Lancet 382, 536–551. http://dx.doi.org/10.1016/S0140-6736(13)60843-0.
Ruel, M.T., Garrett, J., Yosef, S., Olivier, M., 2017. Urbanization, food security and nutrition. In: Pee, S., de, Taren, D., Bloem, M.W. (Eds.), Nutrition and Health in a Developing World, Nutrition and Health. Springer International Publishing, New York, pp. 705–735. http://dx.doi.org/10.1007/978-3-319-43739-2_32.
Schreinemachers, P., Simmons, E.B., Wopereis, M.C.S., 2018. Tapping the economic and nutritional power of vegetables. Glob. Food Secur. 16, 36–45. http://dx.doi.org/10.1016/j.gfs.2017.09.005.
Sibhatu, K.T., Krishna, V.V., Qaim, M., 2015. Production diversity and dietary diversity in smallholder farm households. Proc. Natl. Acad. Sci. USA 112, 10657–10662. http://dx.doi.org/10.1073/pnas.1510982112.
Smith, L.C., Haddad, L., 2015. Reducing child undernutrition: past drivers and priorities for the post-MDG era. World Dev. 68, 180–204. http://dx.doi.org/10.1016/j.worlddev.2014.11.014.
Smith, L.C., Haddad, L., 2002. How potent is economic growth in reducing undernutrition? What are the pathways of impact? New cross-country evidence. Econ. Dev. Cult. Change 51, 55–76. http://dx.doi.org/10.1086/345313.
Soriano, B., Garrido, A., 2016. How important is economic growth for reducing undernourishment in developing countries? Food Policy 63, 87–101. http://dx.doi.org/10.1016/j.foodpol.2016.07.004.
Stein, A.J., 2014. Rethinking the measurement of undernutrition in a broader health context: should we look at possible causes or actual effects? Glob. Food Secur. 3, 193–199. http://dx.doi.org/10.1016/j.gfs.2014.09.003.
Stein, A.J., Meenakshi, J.V., Qaim, M., Nestel, P., Sachdev, H.P.S., Bhutta, Z.A., 2005. Analyzing the Health Benefits of Biofortified Staple Crops by Means of the Disability-adjusted Life Years Approach: A Handbook Focusing on Iron, Zinc and Vitamin A, HarvestPlus Technical Monograph No. 4. IFPRI,, Washington, D.C.; CIAT, Cali.
Stokstad, E., 2015. Sustainable goals from U.N. under fire. Science 347, 702–703. http://dx.doi.org/10.1126/science.347.6223.702.
UN, 2015a. World population prospects: the 2015 revision, key findings and advance tables (DESA Working Paper No. ESA/P/WP.241). UN, DESA, New York.
UN, 2015b. World urbanization prospects: the 2014 revision (DESA Working Paper No. ST/ESA/SER.A/366). UN, DESA, New York.
UNICEF, 1990. Strategy for Improved Nutrition of Children and Women in Developing Countries. UNICEF, New York.
Vollmer, S., Harttgen, K., Subramanyam, M.A., Finlay, J., Klasen, S., Subramanian, S.V., 2014. Association between economic growth and early childhood undernutrition: evidence from 121 Demographic and Health Surveys from 36 low-income and middle-income countries. Lancet Glob. Health 2, e225–e234. http://dx.doi.org/10.1016/S2214-109X(14)70025-7.
WHO, 2006. Guidelines on Food Fortification with Micronutrients. World Health Organization, Geneva.