Long-term scenarios for global child mortality: the role of food, water and energy

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Abstract

The environment is important for human development and quality of life. Unequal access and reduced resource quality have an unequivocal effect on peoples livelihoods, leading to reduced welfare and health loss. We analyse long-term developments in access to food, clean drinking water, basic sanitation and modern energy sources, and their implications for child mortality. Furthermore, we address the impacts on child mortality of going to 'zero poverty', i.e. full global access to these basis services. The analyses are based on long-term scenarios from GISMO model, a system dynamic model that addresses changes in human development as the result of economic, social and environmental changes. Providing full global access can improve child mortality by 26% in 2050 compared to business-as-usual development. This improvement can increase to 34% when also tackling some quality aspects of access, as well as specifically targeting female education. A substantial proportion of health outcomes is not only be determined by health policies but also by policies in adjacent policy domains such as agriculture and energy. Thus, policies on energy (including those on climate change), water and agriculture (including those on biodiversity) should also be assessed in terms of possible health impacts.

1 Introduction

The environment is important for human development and quality of life, especially for people in developing countries. Peoples livelihoods are based on the quantities and qualities of the resources they have access to. Rising global demand for food, water and energy will impact the quantity and quality of scarce natural resources, such as fertile land, potable water and forest resources (IPCC, 2007; UNEP, 2012), while unequal access and reduced resource quality have an unequivocal effect on peoples livelihoods, leading to reduced welfare and health loss (Millennium Ecosystem Assessment, 2005; World Bank, 2008).

The Millennium Development Goals (MDGs) aim to improve human development by formulating the ambition to 'free our fellow men, women and children from the abject and dehumanising conditions of extreme poverty' (UN, 2000). They formulate global goals accompanied by quantified, time-bound targets on a broad set of themes, including poverty, education and health. Furthermore, they address issues such as hunger, drinking water and sanitation and, more loosely, environmental sustainability. The overarching health goal is to 'reduce child mortality' (MDG4), accompanied by the target to 'reduce by two-thirds the mortality rate among children under five' between 1990 and 2015.

Of the estimated 8.8 million annual child deaths in 2008, the vast majority were related to preventable and treatable infectious diseases and conditions, including pneumonia (18%) and diarrhoea (15%) (Black et al., 2010) with undernutrition being an important

underlying factor responsible for about 35% of child deaths (Black et al., 2008). Pneumonia is strongly related to indoor air pollution resulting from traditional fuel use for cooking and heating, and diarrhoea to lack of access to safe drinking water and basic sanitation. Thus, reaching the MDG target on child mortality relates strongly to developments with respect to food (hunger), water (drinking water and sanitation) and energy (the use of modern energy sources).

Currently, the world is not on track to reach the MDG target on child mortality (You et al., 2010a; You et al., 2010b). Furthermore, with the MDGs coming to an end by 2015, the discussion has started on a new development framework addressing human development and environmental sustainability beyond 2015. Although current discussions on development and environmental goals tend to be separately under the post-2015 umbrella and Sustainable Development Goals (SDGs) (Evans, 2012), the general ambition is that both tracks come together and one set of global goals will be agreed upon at the end of 2015 (UN, 2012).

Where the MDGs held the ambition to halving poverty, current discussions for the post-2015 development framework focus on finishing the job by aiming at 'zero poverty'. Furthermore, there is the ambition to tackle some of most persistent environmental issues generally framed under planetary boundaries (Rockstrom et al., 2009). There are important interactions between poverty and environmental, as well as trade-offs between policies aiming at tackling these issues due to these interactions (Raworth, 2011). Therefore, when designing long-term goals and related policies these interactions should be taken into account.

This paper addresses the following two questions:

- What are future developments in access to food, clean drinking water, basic sanitation and modern energy sources without additional policy, and what are the implications for child mortality?
- What are the implications of aiming at 'zero poverty' with respect to access to food, clean drinking water, basic sanitation and modern energy sources for child mortality?

The analysis is based on a study done by the Netherlands Environmental Assessment Agency (PBL, 2012) for the United Nations Conference on Sustainable Development (UN, 2012). The study explores the efforts needed to achieve a set of ambitious long-term sustainable development goals - consistent with existing international agreements – including both development and environmental goals. To take account of important interactions, the Integrated Assessment Model IMAGE (Bouwman et al., 2006) was used, including the GISMO1.0 model that addresses human development as a result of economic, social and environmental changes. Here, the focus is on the human health implications, i.e. the GISMO model results.

The paper is structures as follows. Section two describes GISMO1.0 health model, focusing on access to food, water and energy and the health model. Section three presents results for the different scenarios analyzed, i.e. a business-as-usual scenario and two scenarios, including different levels of ambition, addressing 'zero poverty'. Finally, section 4 discusses the results and draws some general conclusions.

2 The GISMO1.0 model

The Global Integrated Sustainability Model (GISMO1.0) is a system dynamic model used for creating long term scenarios addressing interactions between human well-being (income, education and health) and global change, including environmental changes (Hilderink and Lucas, 2008). It addresses human development and quality of life, including its distribution, improvement and continuation, as a result of changes in the three underlying sustainability domains, i.e. economic, social and environmental. The

model quantifies human development in terms of access to food, water and energy, the Human Development Index (HDI), Population Health measures (such as Disability-Adjusted Life Years; DALY), and many indicators of the Millennium Development Goals (MDGs).

The impacts of global (environmental) change on human development are mainly modeled through impacts on human health, either directly through for example the impact of climate change on malaria, or indirectly through for example the impact of climate change on food availability. Next to environmental factors, human health is also driven by socio-economic factors, including per capita GDP and educational attainment. To take account of these different factors and their interrelation, the GISMO model consists of three distinct modules, addressing health, poverty and education. The modules are linked through a cohort component population model, including endogenous fertility and mortality (Hilderink, 2000). Fertility levels are modeled using a convergence level, determined by female education levels, and a speed of convergence, determined by the HDI. Mortality rates are determined by the health module. Future trends in migration, including urbanization, are taken exogenously to the model.

The health model describes the burden of disease by sex and age. The methodology used for communicable (infectious) diseases (malaria, diarrhea, pneumonia / acute respiratory infections and protein deficiency) is a multi-state modeling approach that largely follows the approach described in the World Health Report 2002 (WHO, 2002) and the Disease Control Priorities Project (DCPP) (Cairncross and Valdmanis, 2006). The states distinguished are exposure, disease and death. This implies that for various health risk factors, incidence and case fatality rates (i.e. the ratio of the number of deaths caused by a specific disease over the number of diagnosed cases of that disease) are taken into account. The level of health services modify case fatality rates. The method for projecting the other causes of death (non-communicable (chronic) diseases, other communicable diseases and injuries) follow the global burden of disease (GBD) approach that uses linear regression with GDP, smoking behavior and human capital, based on Mathers and Loncar (2006).

Table 1: cause-specific death and their risk factors of mayor communicable diseases

Cause-specific death	Main risk factor
Protein deficiency	Food availability
Diarrhea	Lack of safe drinking water and basic sanitation
Pneumonia, chronic obstructive pulmonary disease (COPD) and lung cancer	Use of solid fuels (traditional biomass or coal) for cooking and heating

Incidence and case fatality rates of mayor communicable (infectious) diseases are driven by access to food, water and energy and climatic conditions (see Table 1). Access to food, water and energy here is defined by per capita food availability, population with access to safe drinking water and improved sanitation, and population with access to modern energy sources for cooking and heating:

Undernutrition

Maternal and child undernutrition is an important underlying cause of mortality and overall disease burden and is attributable to more than 3.5 million deaths, annually (Black et al., 2008). Undernutrition is the result of protein-energy malnutrition (a lack of sufficient proteins and calories) and deficiencies in micronutrients (essential vitamins and minerals). It reinforces the mortality of diseases, such as pneumonia, diarrhoea and malaria (Caulfield et al., 2004), and also has a direct effect on mortality through deficiencies of micronutrients. Undernutrition can result in limited physical and neurological development and low productivity among current and future generations. It

is therefore also a major constraint to a country's ability to develop economically, socially and politically (UN Millennium Project, 2005).

In the model, undernutrition has both a direct as an indirect effect on mortality. For children under five undernutrition is expressed as child underweight, while for older ages the prevalence of undernourishment is used. The direct effect of undernutrition becomes visible through protein deficiency. For children, current protein deficiency mortality rates are scaled based on their underweight status, while for the higher age groups mortality rates are scaled to the prevalence of undernourishment. Indirectly, undernutrition enhances the incidence and case fatality of diarrhea and pneumonia. This effect is only modeled for children under five.

Child underweight (the result of chronic undernutrition) is modeled as a function of improvements in average food intake, the ratio of female to male life expectancy at birth, female enrolment in secondary education and access to clean drinking water (Smith and Haddad, 2000). Based on a normal distribution, the total number of underweight children is divided into a mild, a moderate and a severe underweight group (De Onis and Blossner, 2003). The per capita food availability (average food intake) is modeled using the volume growth rates in food consumption from the MAGNET model (Van Meijl et al., 2006) and FAOSTAT base year data of per capita food intake (FAO, 2011).

The prevalence of undernourishment is derived from dietary energy consumption in relation to the minimum energy requirement norms (FAO, 2003). The calculations uses a lognormal distribution function determined by the mean food consumption and a coefficient of variation. The coefficient of variation change over time as a function per capita GDP. Finally, the minimum dietary energy requirement is derived by aggregating the region specific sex-age energy requirements weighted by the proportion of each sex and age group in the total population, including a so-called pregnancy allowance.

Diarrhea

The lack of a safe water supply and adequate sanitation exposes people to pathogenic micro-organisms and is responsible for around 1.6 million deaths annually, mainly due to diarrhoea. Approximately 88% of all diarrhoeal deaths globally are caused by unsafe water, sanitation or hygiene, and 99% of these are in developing countries (WHO, 2009). Children are most affected, with almost 30% of all diarrhoea-related deaths in children under five (Prüss-Üstün and Corvalán, 2006).

Access to safe drinking water and improved sanitation are modeled separately for urban and rural populations by applying linear regressions using data from Joined Monitoring Programme for water and sanitation (WHO/UNICEF, 2010). The explanatory variables include GDP per capita, urbanization rate and population density. Developments in access follow a pathway from no access to improved access, and for water supply further to a household connection. Developments in water supply are assumed to be implemented ahead of sanitation.

Incidence rates of diarrhea are determined by the different levels of connection to water supply and sanitation facilities. The incidence rates are increased by the level to which a child is underweight and by temperature increase. The case fatality rates are increased by underweight levels and decreased by the level of oral rehydration therapy.

Pneumonia

Lack of access to modern energy sources causes indoor air pollution, resulting in almost two million premature deaths, per year, with approximately a million of these deaths caused by lower respiratory infections or pneumonia in children, and the other million due to chronic lung disease and lung cancer, which occurs primarily in the elderly (WHO and UNDP, 2009). Indoor air pollution is caused by the burning of traditional fuels such as coal and traditional biomass (e.g. cow dung, wood) on an open fire or on an inefficient

traditional stove – exposing people to a dangerous cocktail of pollutants, primarily carbon monoxide and fine particles.

Access to modern energy sources for cooking and heating distinguish between the use of 1) traditional biomass and coal on traditional stoves; 2) traditional biomass and coal on improved stoves; and 3) the use of modern fuels (electricity, natural gas, LPG, kerosene, modern biofuels and solar stoves) using the trends in access to modern energy sources from the IMAGE-REMG model (Daioglou et al., 2012).

Incidence rates of pneumonia, chronic obstructive pulmonary disease (COPD) and lung cancer are determined by cooking and/or heating with solid fuels, causing indoor air pollution. Incidence rates and case fatality rates are increased by child underweight levels.

3 Long-term scenarios for global child mortality

The scenarios discussed here are based on the report 'Roads from Rio+20' (PBL, 2012). The study uses a backcasting approach, thereby designing pathways that achieve a comprehensive set of sustainability goals, to explore the level of effort involved. In total, four scenarios or pathways were designed: a trend scenario and three challenge pathways. The trend scenario is a business-as-usual scenario that describes future trends in environmental change and human development in the absence of strengthened policies. The three challenge pathways all achieve the comprehensive set of sustainability goals, deviating from the trend scenario. The pathways consist of different technological and consumption change measures. The scenario analysis concentrated on the physical changes required, taking into account, as much as was possible, the limitations in terms of physical and economic feasibility (e.g. potential for improving yields and the capital turnover rate in the energy system).

Although the pathways follow different trajectories, involving different choices with respect to energy and food projection, their end-points with respect to food, water and energy are all the same, i.e. 'zero poverty' by 2050. Thus, next to trend scenario, in this paper we only discuss one pathway, focusing on this end-point and the related health impacts. We do not include feedbacks on population growth and economic development as a result of these impacts. Therefore, both scenarios have the same population and economic projection.

The world population is projected to continue to grow from around 7 billion people in 2010 to 9 billion by 2050 (UNDESA, 2011). This growth mostly occurs in sub-Saharan Africa and South Asia. At the same time, economic projection, based on the OECD Environmental Outlook to 2050 (OECD, 2012), shows a further increase in per-capita GDP in all world regions. Most economic growth is expected in developing countries. Towards 2040, the highest growth rates are projected for Asia. After 2040, the highest per capita growth rates are projected for Africa, although it will remain the continent with the lowest per capita income levels.

3.1 The trend scenario

In the trend scenario, as a consequence of population and economic growth and an absence of strengthened or new policies, a strong increase in the demand for energy and agricultural products and related demand for fossil fuels, land and water is projected. As a result, a further decline in biodiversity is projected. Although, historically, habitat loss has been the most important driver of biodiversity loss, for the future, climate change, forestry and infrastructure development are projected to become important factors, as well. Due to increase fossil fuel use, greenhouse gas emissions are projected to grow by 60% between 2010 and 2050, resulting in a global mean temperature increase surpassing 2 °C goal well before 2050 and more than 4 °C by the end of the century.

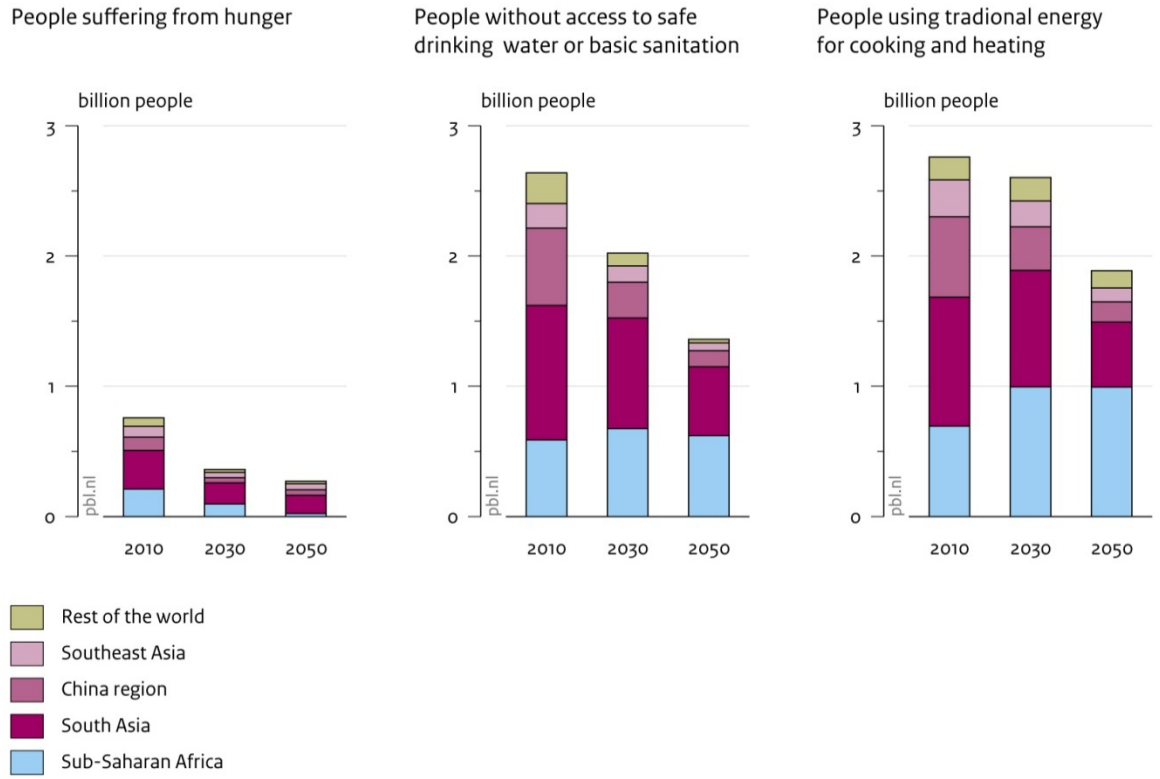

Figure 1: People without adequate access to food, safe drinking water and basic sanitation, and improved energy sources for cooking and heating under the trend scenario

Still, access to food, improved drinking water, basic sanitation and modern energy sources increases significantly (see Figure 1). Yet even with this large increase, a significant proportion of the population will still be without adequate services, mainly in sub-Saharan Africa and South Asia. By 2050, around 300 million people will be without adequate access to food, 250 million people without sustainable access to safe drinking water, 1.4 billion people without basic sanitation and 1.9 billion people without access to modern energy sources for cooking and heating.

In the trend scenario, global child mortality is projected to reduce significantly, from 67 child deaths per 1000 children born in 2010 to less than 45 in 2030 and 28 in 2050, with large improvements in all world regions (see Figure 2 and 3). To achieve MDG4, child mortality should be reduced to around 30 child deaths per 1000 children born in 2015. Without new policies, this target will not be reached before 2030, mainly due to persistent high levels of child mortality in sub-Saharan Africa and South Asia (see also PBL, 2009).

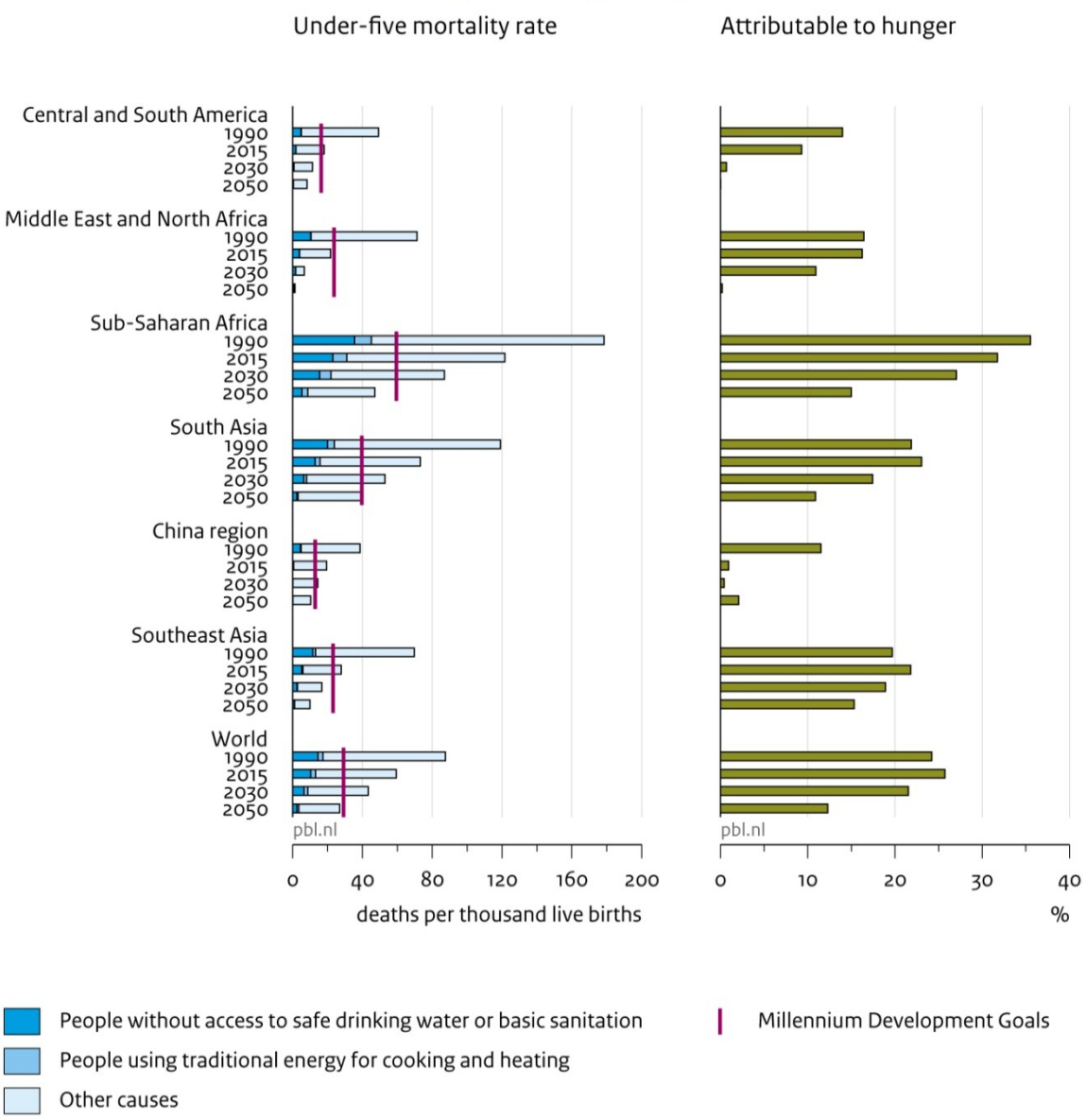

Figure 2: Child mortality under the trend scenario, attributable to hunger, traditional fuel use, and a lack of access to safe drinking water and improved sanitation, and the 2015 MDG target

3.2 The 'zero poverty' scenarios

Policy interventions to decrease human health loss and child mortality rates can be classified as 1) (primary) prevention, i.e. eliminating or reducing the health risk, and 2) cure, i.e investing in curative health systems which lowers the chances of dying of a particular disease or health risk. Prevention generally relates to taking away the risks through: 1) increasing access levels by lowering prices and investing in infrastructure; 2) improving the quality of access through for example a household connection for drinking water supply and LPG or kerosene instead of using improved biomass stoves; 3) improving behavior through women education, hygiene measures and good ventilation; and 4) mitigating environmental changes such as climate change, biodiversity loss and water stress.

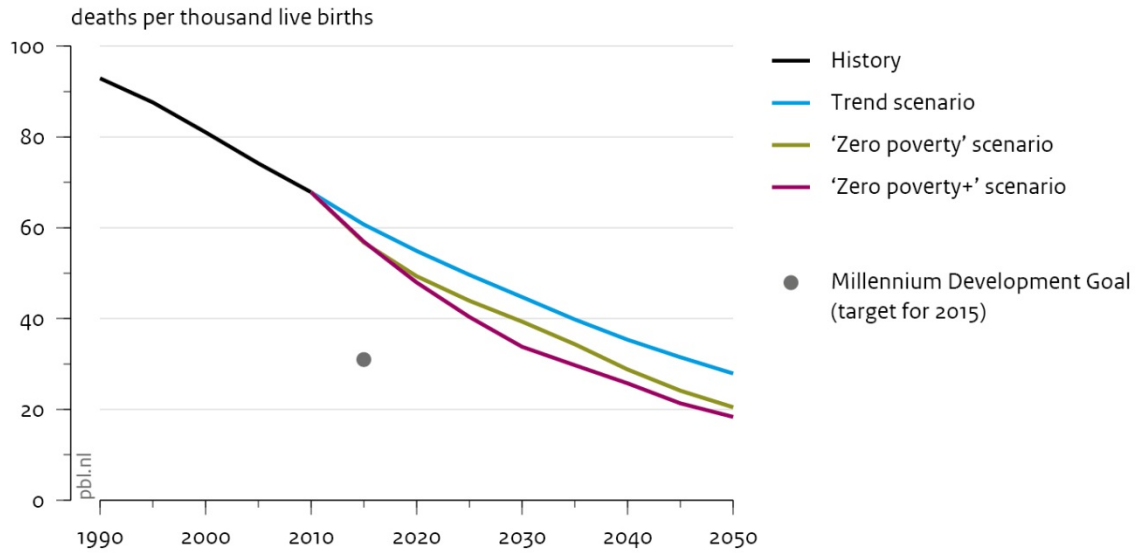

Figure 3: Global under-five mortality rates in the trend scenario, the 'zero poverty' scenario and in the 'zero poverty+' scenario

Figure 3 presents the impacts on the global under-five mortality rate of improving access to food, water and energy, i.e. 'zero poverty':

- By 2050 hunger is eradicated
- By 2050 all people have access to save drinking water and improved sanitation
- By 2030 all people have access to modern energy sources or at least use improved biomass stoves for cooking

Eradicating hunger by 2050 decreases the prevalence of child underweight by approximately 50%. The remaining underweight – mainly in sub-Saharan Africa and South Asia – can be explained by the low level of education of mothers and the status of women in society. In fact, between 1970 and 1995, improved women's education contributed to decreases in child undernutrition to a larger degree than improvements in food availability (Smith and Haddad, 2000). Furthermore, health risks are reduced by 30% when people obtain access to an improved water source such as a public standpipe or borehole rather than an unprotected dug well. Hygiene measures such as hand washing, as well as having a household connection to a drinking water supply, could further reduce water-related mortality (Prüss-Üstün et al., 2009). Providing access to modern energy sources complete eliminates the health risk, while switching to improved biomass stoves only reduces the health risk by 35% (Hutton et al., 2006). The health impacts due to indoor air pollution can be further reduced by behavioural methods, such as good ventilation or the complete transition away from traditional biomass to modern energy sources, such as electricity and LPG. See Figure 4 for remaining child mortality attributable to hunger, lack of access to safe drinking water and basic sanitation, and traditional fuel use for cooking and heating. It should be noted that substantial increases in education levels, especially of girls and women, have important implications for health too (Marmot, 2010). Education reduces poverty through increased employment and provides skills for attaining better health. Women benefit through increased knowledge of how to protect health and seek proper healthcare for themselves and their children.

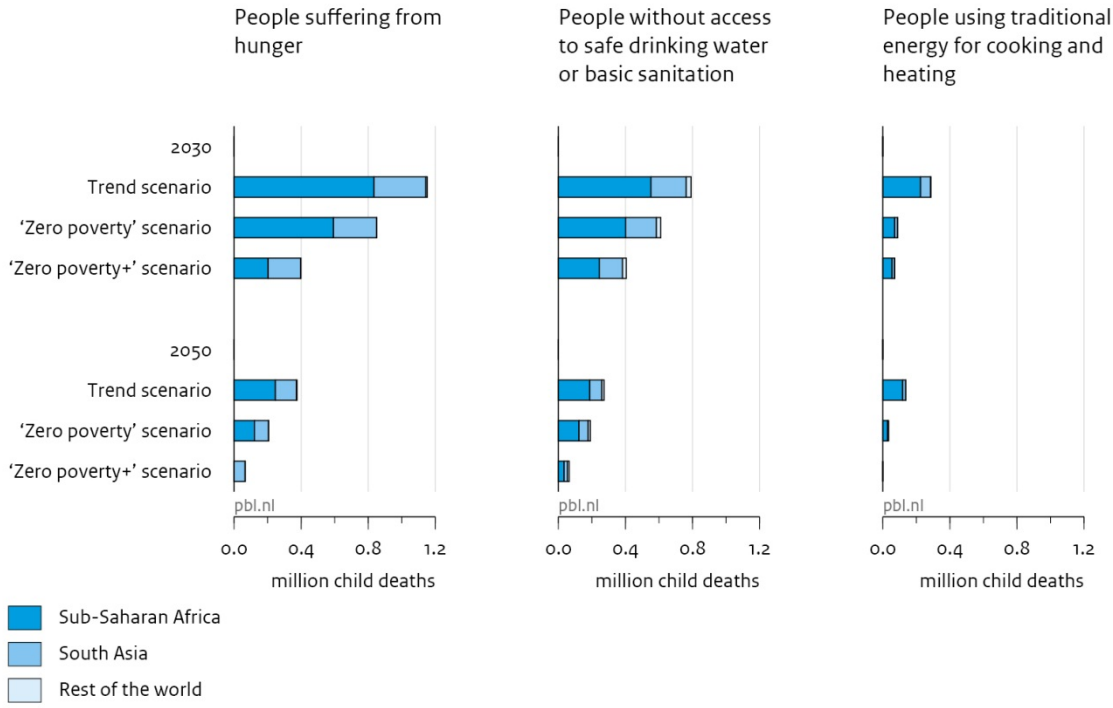

Figure 4: Child deaths attributable to hunger, lack of access to safe drinking water and basic sanitation, and traditional fuel use for cooking and heating.

Overall, in the 'zero poverty' scenario the child mortality rate is reduced by 12% by 2030 compared to the trend scenario and by more than 26% by 2050. Thus, by 2030 the child mortality rate is still slightly above the 2015 MDG target. It should be noted that, at the same time, mortality rates for the elderly will increase. This increase is the direct result of increased food availability in developing countries. Although by 2050 global hunger is eradicated, overnutrition surges. This is especially the case when hunger is eradicated by focussing on increased global food production and lowering trade barriers, as the resulting reduced global food prices also increases food consumption for the already better nourished. This double burden of disease is already observed in various developing countries where underweight and obesity are occurring simultaneously (Beaglehole et al., 2011).

In a second scenario 'zero poverty+' quality of access and some elements of behavioral change are put on top of the 'zero poverty' scenario:

- By 2050 a household connections to drinking water for all
- By 2050 a full transition towards modern fuels for cooking and heating
- By 2030 full enrolment of girls in secondary education

The extra policies in this second scenario are stylized in the sense that they do not take into account socio-economic and environmental constraints. In the 'zero poverty+' scenario the environmental health risks are almost completely eliminated (see Figure 4), improving child mortality further to almost 25% by 2030 compared to the trend scenario and 34% by 2050 (see Figure 3). Removing health risks due to further improved energy and water services eliminates most of the attributable mortality. Furthermore, targeting female education significantly improves the utilisation of food – reducing child underweight due to better nutrition – especially in sub-Saharan Africa where secondary school enrolment for women in the trend scenario is still only around 80% in 2050.

It should be noted that with respect to undernutrition, the two scenarios only capture the impacts of increased energy intake on the child mortality rate. They do not address the related effect of proteins and micronutrients (for those, historical developments were taken). However, micronutrients are still responsible for almost one-third of all

undernutrition-related child deaths, while interventions to improve micronutrient consumption of especially vitamin A, Zinc, Iron and Iodine could be very cost-effective, with cost–benefit ratios of 1:30 for salt iodination and 1:4 to 1:43 for vitamin A supplementation (World Bank and IMF, 2012).

4 Concluding discussion

Eradicating hunger, providing full access to safe drinking water, improved sanitation and modern fuels for cooking and heating, significantly improves human health and brings the MDG target on child mortality (reduce by two-thirds, between 1990 and 2015, the under-five mortality rate) closer. In general, these health risks are relatively easy to avoid. Developed countries have already shown that with the right policies and investments these risks can be almost completely eradicated and even in developing countries there are many examples of countries fighting these risks with success. Next to these factors, the broader global environmental context should be taken into account, not only through the adequate access to food, water and energy, but also more broadly for example through climate change mitigation, though these effects remain rather uncertain. Furthermore, education, and then especially female education, has many positive effects, including reduced risks of child underweight.

Concerted international effort for scaling-up essential interventions for health promotion, disease prevention, treatment and risk-factor reduction through a coordinated sector-wide approach has been advocated by several reports (WHO, 1999, 2002; World Bank, 2003). The Commission on Macroeconomics and Health (2001) estimates that around eight million deaths could be avoided through increases in investments in global health and that this will in return generate at least a USD 360 billion annual gain during the 2015–2020 period. Although these figures, both in economic and in health terms, are much higher than those discussed here - for which we looked specifically at food, water and energy - it raises two important notions: 1) health expenditures should be further increased; and 2) these increased expenditures should not be regarded as a cost but as an investment with a gain in return. Investing in health can be profitable from a national, macroeconomic perspective. And even at a lower level, investments in health have been shown to be highly cost-effective. For example, investments in water supply and sanitation have a cost–benefit ratio between 1:5 and 1:46, depending on the intervention (Hutton et al., 2007). Investments in modern energy sources for cooking and heating have average cost–benefit ratios of 1:7, with much higher benefits in rural areas and even negative when switching to improved stoves due to reduced fuel costs (Hutton et al., 2006). Finally, investments in micronutrient consumption can be even as high as 1:43 (World Bank and IMF, 2012).

A significant proportion of health outcomes is not only determined by specific health policies but also by policies in adjacent policy domains such as agriculture and energy. The inclusion of the concept of health in all policies recognises this broader interwovenness, and a plea is made for a coherent approach by integrating, wherever possible, public health impacts in all policies (Ståhl et al., 2006). Thus, policies on energy (including those on climate change), water and agriculture (including those on biodiversity), should also be assessed in terms of possible health impacts.

Finally, the benefits of a healthy population should be taken into account when designing policies. The perspective of health costs needs to be changed into health investments by also indicating socio-economic returns. These returns can be regarded in the broadest sense, from the gain in time due to no longer having to collect water or firewood for several hours a day, to being more productive and earning a higher income, and to valuing avoided morbidity and mortality.

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