Fossil Fuels, Carbon Dioxide
&
Human & Environmental Well-Being

Indur M. Goklany

Part I

Human Well-Being

Google

three warmest years on record

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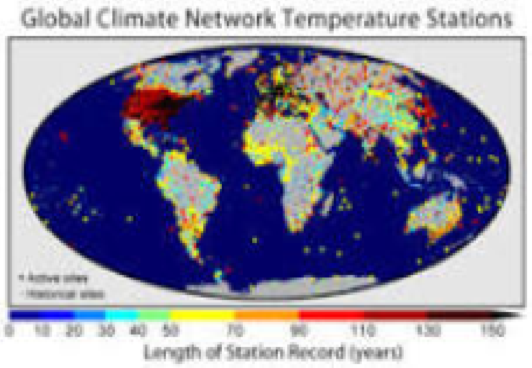
Warmest years

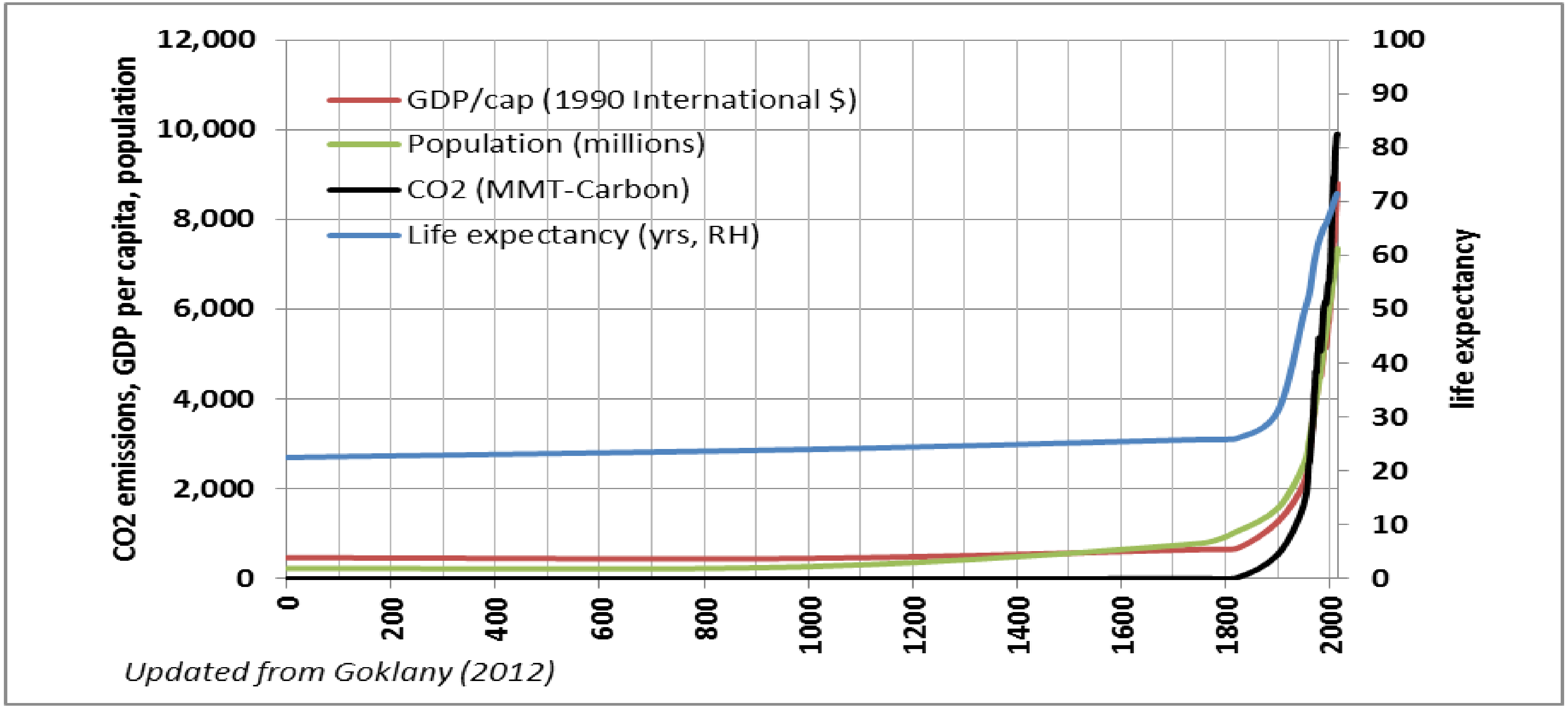
Rank	Year	Anomaly °F
1	2016	1.69
2	2015	1.62
3	2014	1.33
4	2010	1.26

8 more rows



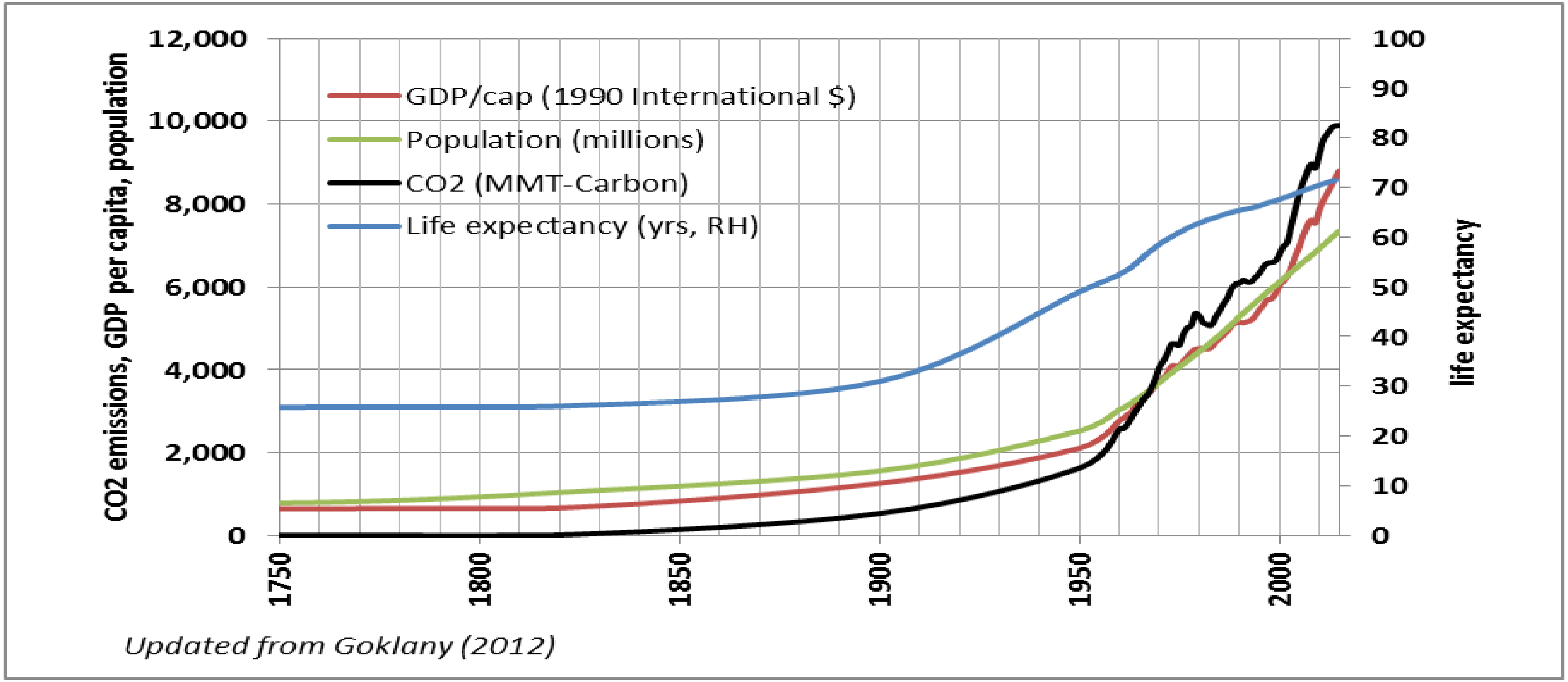
Instrumental temperature record - Wikipedia
https://en.wikipedia.org/wiki/Instrumental_temperature_record

Human Progress & CO2 Emissions, AD 1–2015



Update based on World Bank (2017); Le Quéré et al. (2016), via CDIAC

Human Progress & CO2 Emissions, AD 1750–2015



Update based on World Bank (2017); Le Quéré et al. (2016), via CDIAC

Average growth rates (%)

Population, Prosperity, Life Expectancy, & CO2 emissions, AD 1–2014

	AD 1–1000 (%)	AD 1000–1750 (%)	AD 1750–2014 (%)
Population	**0.02**	**0.14**	**0.85**
Prosperity (GDP per capita)	**0.00**	**0.05**	**0.99**
Life expectancy	**0.01**	**0.01**	**0.39**
CO2 emissions			**3.12**

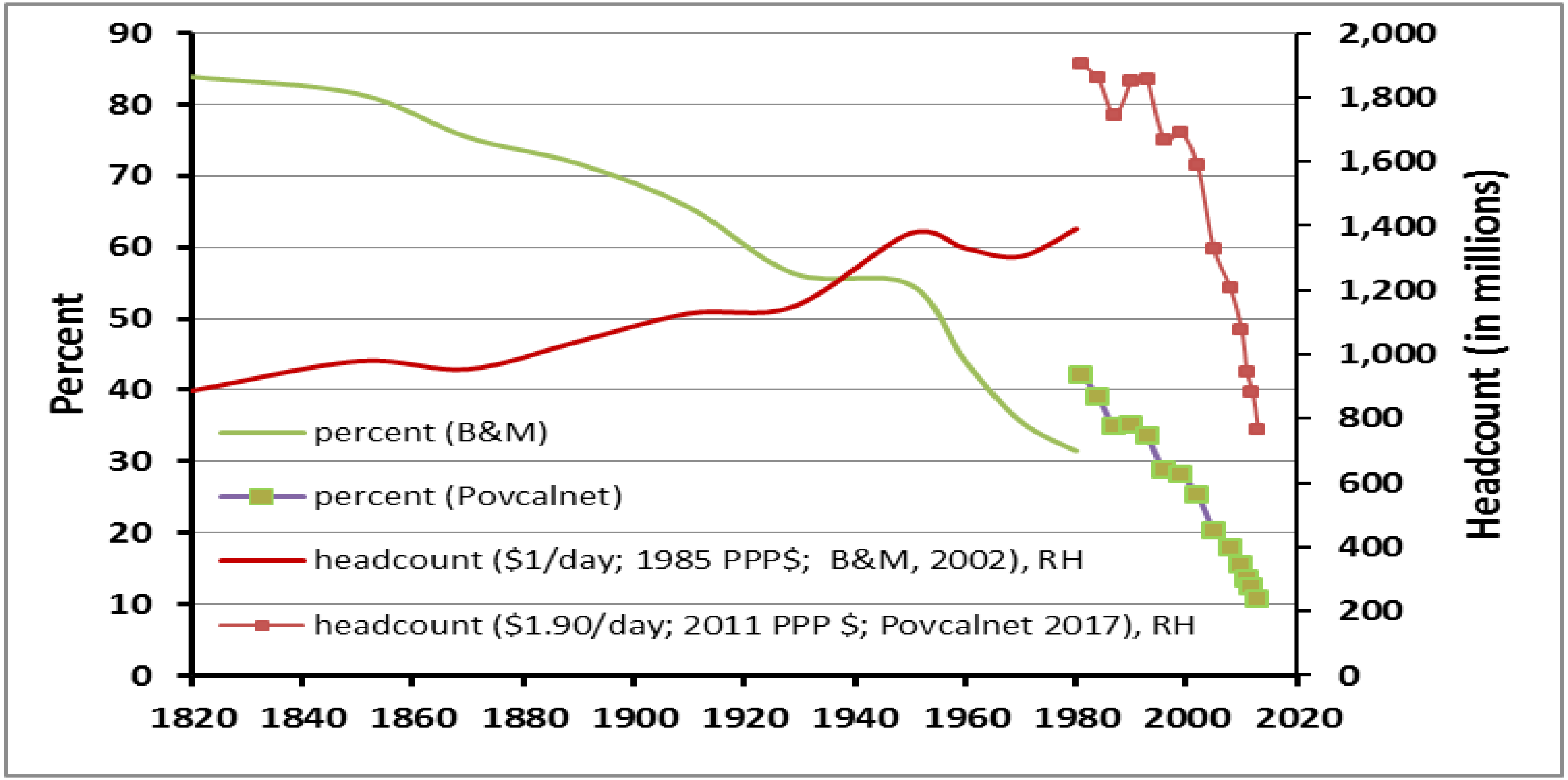
Sources: Angus Maddison, Statistics on World Population, GDP and Per Capita GDP, 1–2008 AD, University of Groningen, 2010, http://www.ggdc.net/MADDISON/Historical_Statistics/vertical-file_02-2010.xls; World Bank, World Development Indicators 2011, http://databank.worldbank.org/; T. A. Boden, G. Marland, and R. J. Andres, Global, Regional, and National Fossil-Fuel CO2 Emissions, http://cdiac.ornl.gov/trends/emis/overview_2008.html.

Living longer and healthier, but CO2 is going up!

	Life expectancy in 1950 (unadjusted) (yrs)	Health-adjusted life expectancy – 2000 (yrs)	Health-adjusted life expectancy – 2015 (yrs)
China	**41**	**64.6**	**68.5**
India	**32**	**54.2**	**59.6**
USA	**68**	**67.2**	**69.1**
World	**49**		**63.1**
Atmospheric CO2 level (ppm)	**311**	**370**	**401**

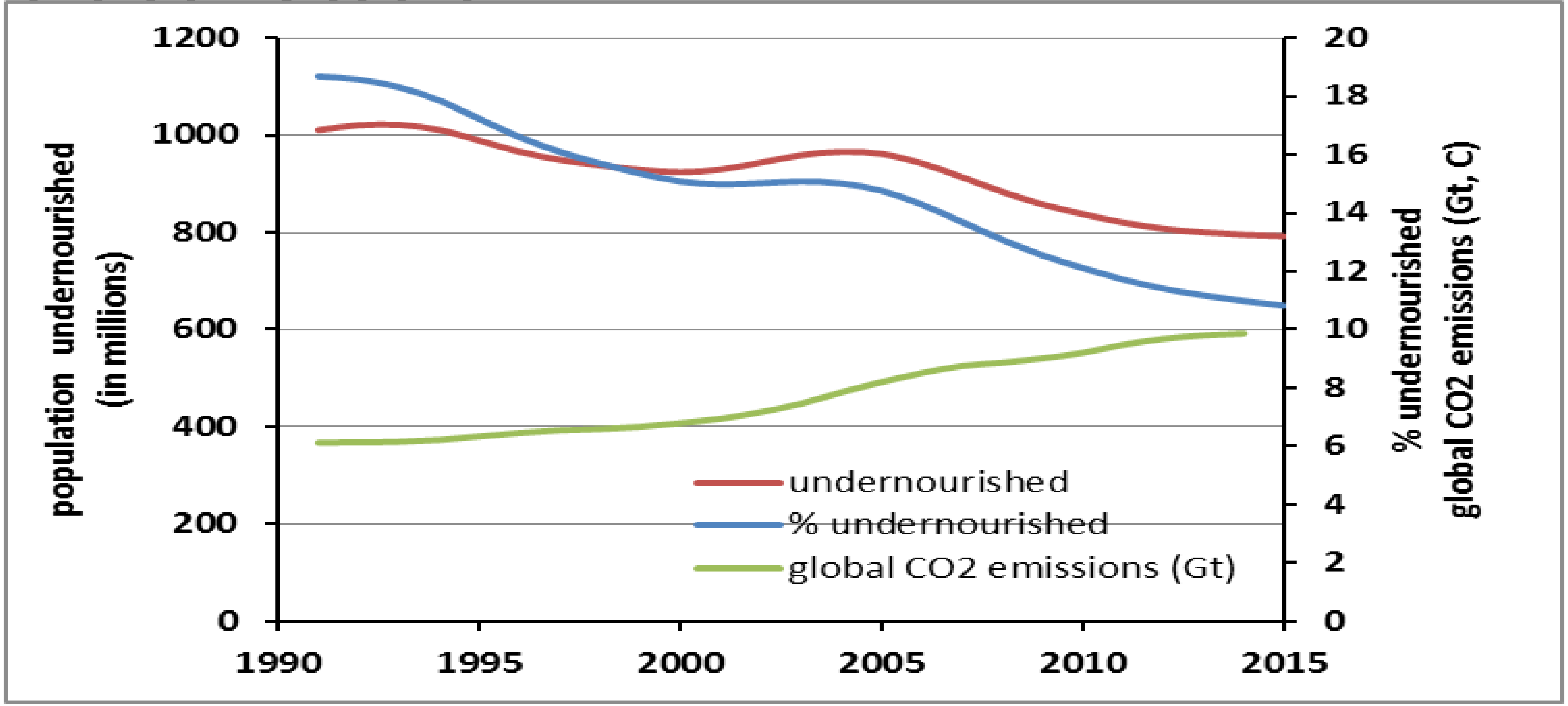
Sources: Maddisson (2001), p.30; ESRL Mauna Loa data, ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_annmean_mlo.txt; WHO (2016), http://gamapserver.who.int/gho/interactive_charts/mbd/hale_1/atlas.html .

Global Poverty, 1820–2013



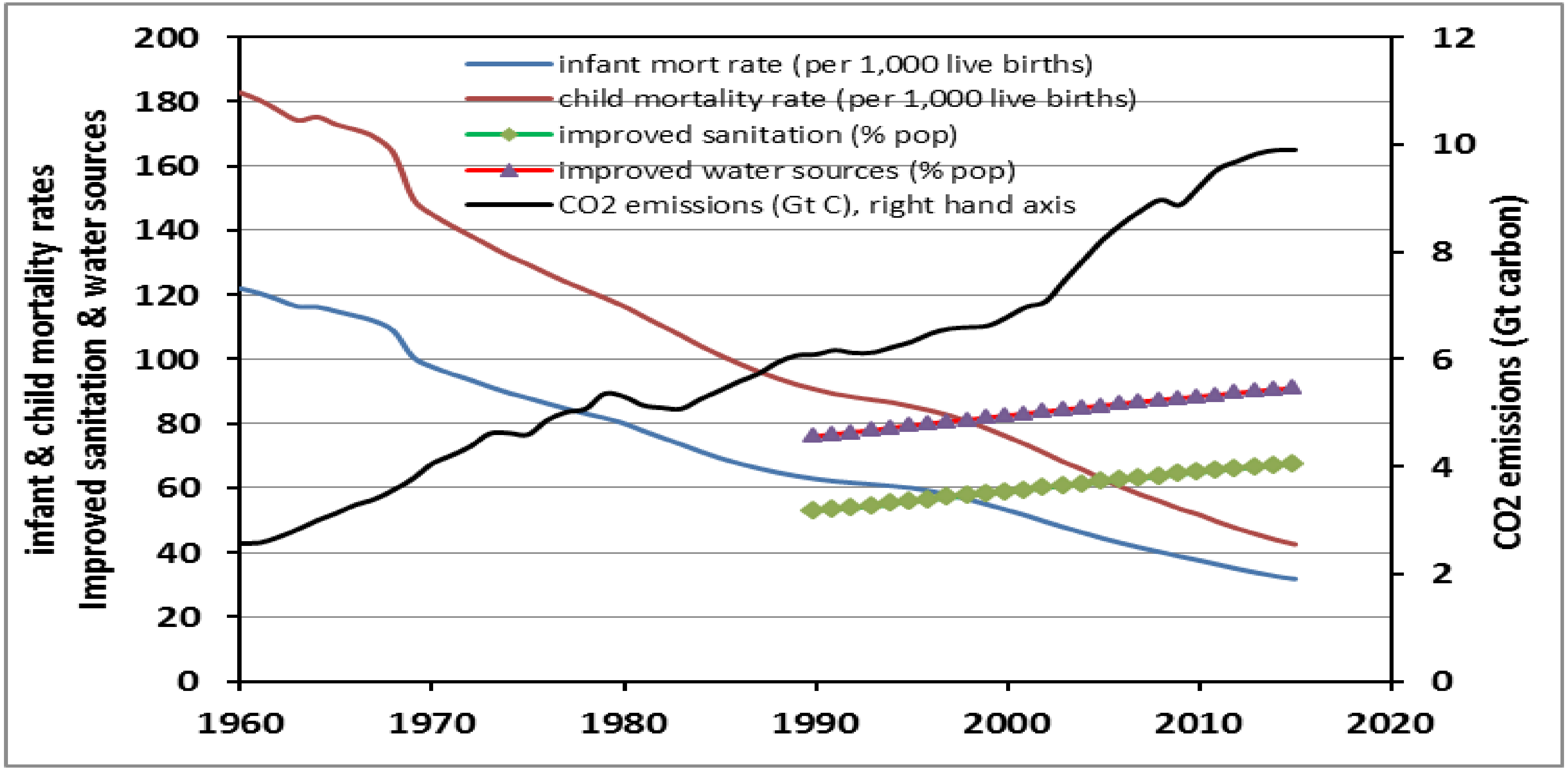
Sources: Morrison & Bourginon (2002), World Bank (2017)

Global Hunger & CO2 Emissions, 1991–2015



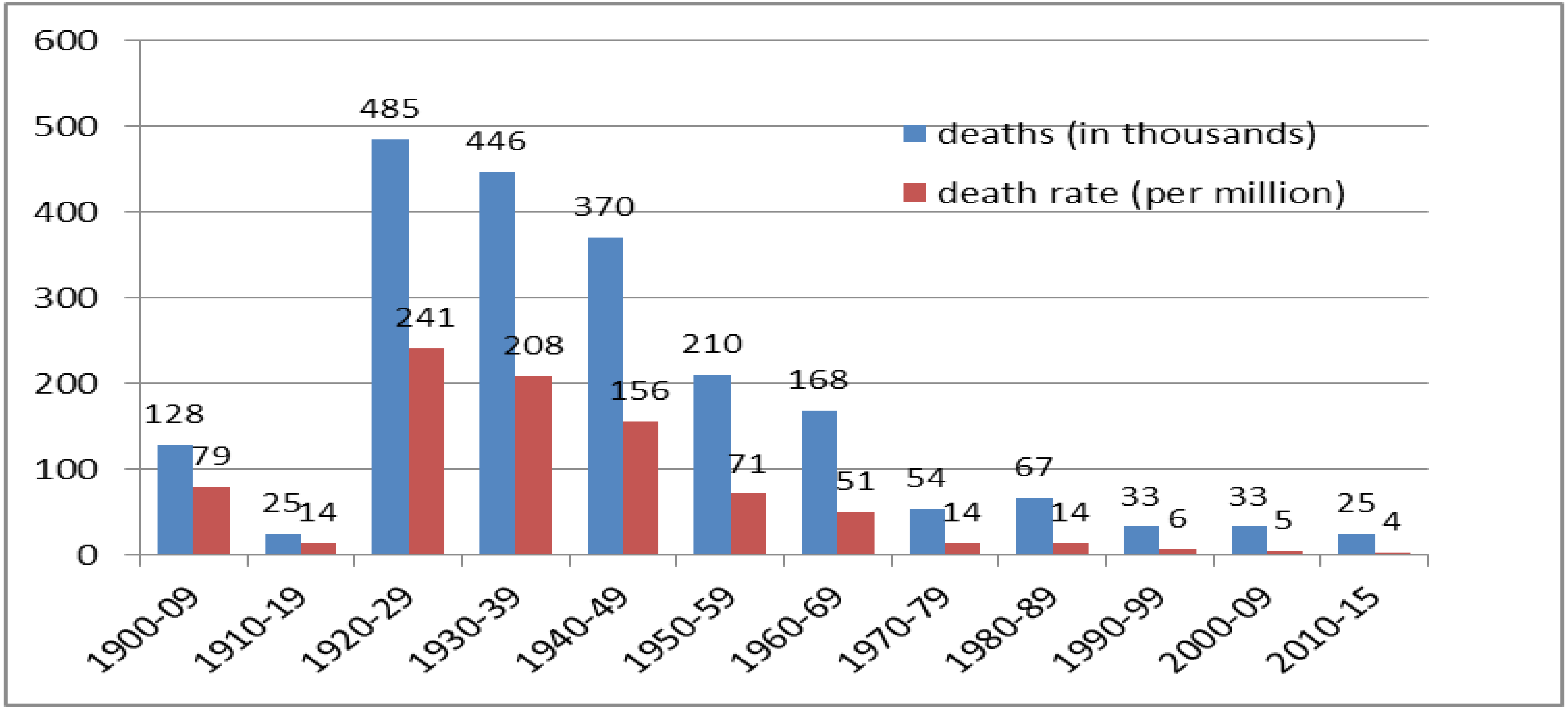
Sources: FAO (2016); Le Quéré et al. (2016), via CDIAC

Trends: CO2 Emissions & Various Measures of Human Well-Being, 1960–2015



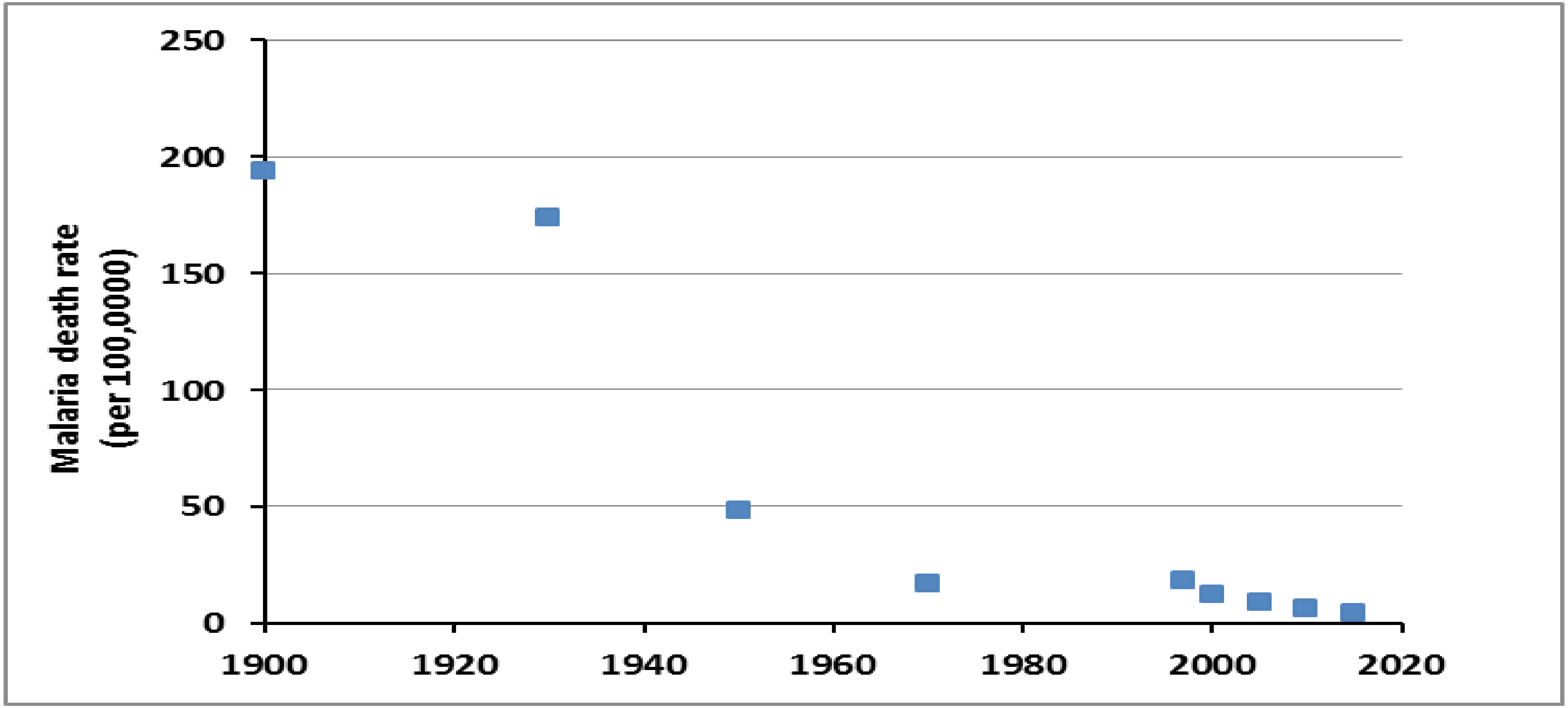
Sources: World Bank (2017); Le Quéré et al. (2016), via CDIAC

Global deaths & deaths rates from extreme weather events, 1900–2015



Sources: Updated from Goklany (2009) using EM-DAT (2017) and World Development Indicators (2017)

Global malaria death rates, 1900–2015



Sources: 1900-1997: World Health Report 1999, Chapter 4; 2000-2015: World Malaria Report 2016

Planet is greener, mainly from FF related factors (70% CO2, 9% N-deposition, 8% climate change)

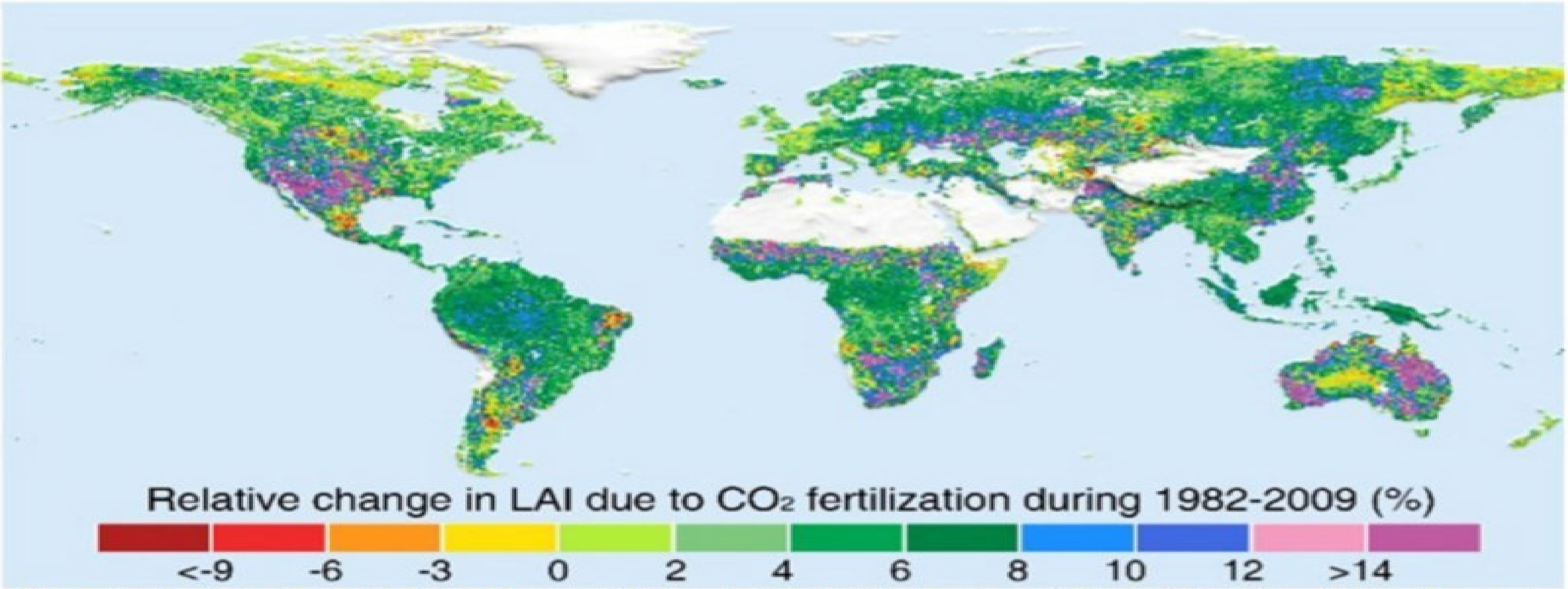
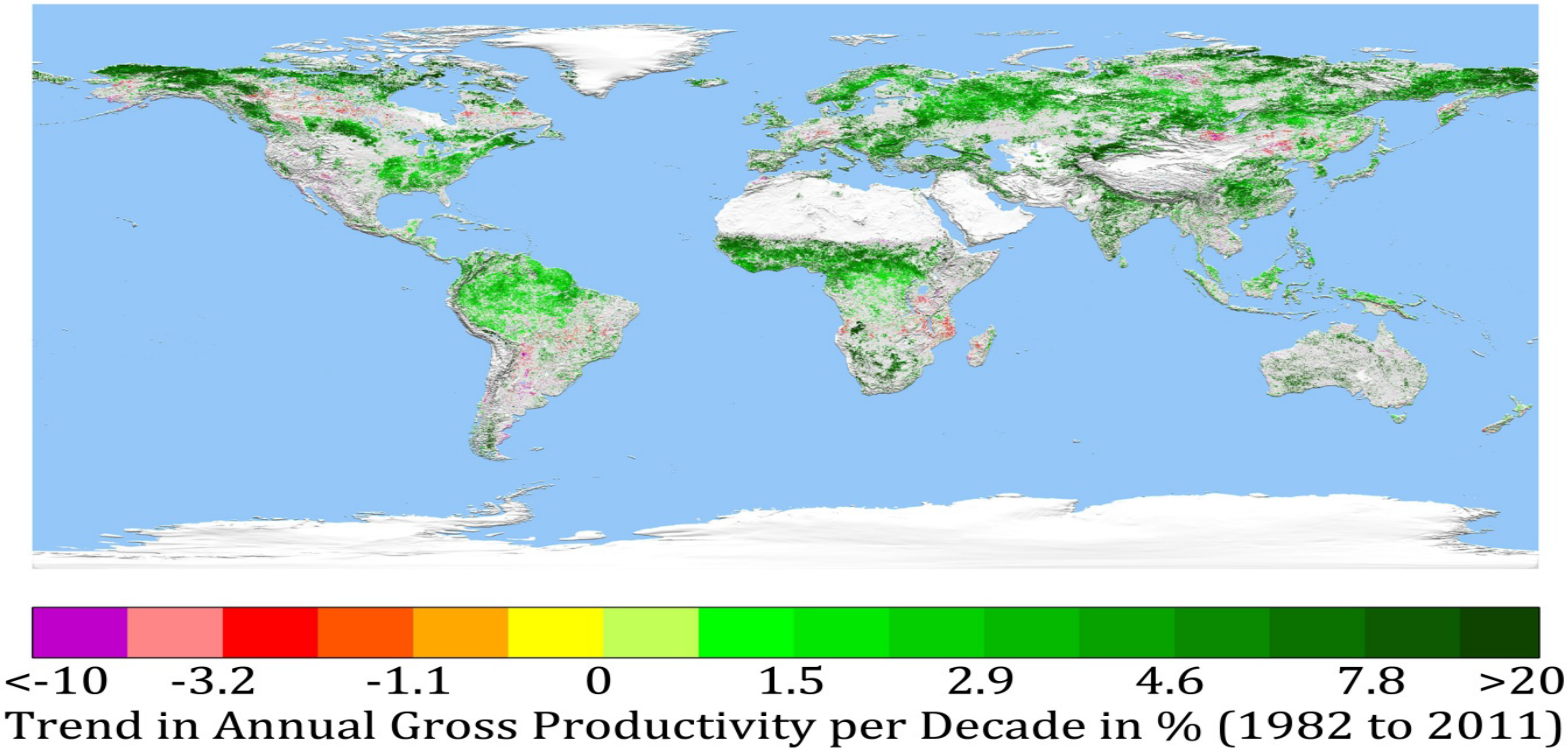


Figure 1. *Spatial pattern of relative change of LAI due to CO_2 fertilization during 1982 to 2009. The relative change of LAI in each pixel is derived from the ratio of the increment of LAI driven by elevated atmospheric CO_2 to the 28-year average value of LAI simulated by model ensemble mean under scenario S1. Source: Figure S12, supplementary information from Zhu et al. (2016)*

Earth is more productive
[14% increase in gross productivity, 1982–2011]



Zhu & Myneni (2014), A Greener Earth?, Global vegetation monitoring and modelling, Avignon, France, February 3–7, 2014.

Conclusion – Part I

As CO_2 is increasing:

- Global population is becoming wealthier. Poverty is falling
- Fewer people go hungry. Malnutrition is dropping
- People are healthier and, living longer
- Deaths from extreme weather events are down
- More people have safer water & better sanitation
- Population continues to increase
- The world is greener and more productive
- Increases in agricultural and forest productivity create more space for Rest of Nature to coexist with humans

Part II

Fossil Fuels & CO_2 Reduce Habitat Conversion & Biodiversity Losses

Habitat Loss and Threats to Ecosystems & Biodiversity

- Habitat conversion or “habitat loss” is generally recognized as the greatest current threat to ecosystems and biodiversity [see, e.g. Vié, J.-C. et al. (eds) 2009]
- Agricultural activities are the major cause of habitat conversion

Fossil fuels have forestalled habitat conversion, lowering risks to biodiversity, even as the demands of an expanding and wealthier population are being met

How do fossil fuels reduce habitat conversion?

Increase productivity of the entire food and agricultural system

→ Less habitat converted to cropland

→ More land for Rest of Nature

→ Reduced threat to ecosystems & biodiversity

How have fossil fuels increased food & agricultural productivity?

- Higher net yields on the farm (through **nitrogen fertilizer**, **pesticides**, irrigation, agricultural machinery, **CO_2 fertilization**, nitrogen deposition)
- Lower losses post-harvest and before crops/foods go to market shelves (via pest control, faster transport, refrigeration, plastic bags and containers)
- Fewer losses at markets, stores, homes restaurants, etc., and all points in-between (e.g., refrigeration, plastic bags and containers)

Farm machinery, pre-ICE era

16-horse combine. Whitman Co, Washington, circa 1938. Source: Library of Congress, via Rebecca Katzman, 13 Vintage Photos of Combines, Modern Farmer, August 8, 2014, http://modernfarmer.com/2014/08/vintage-photos-combines/

Earth is greener, mainly from FF related factors (70% CO2, 9% N-deposition, 8% climate change)

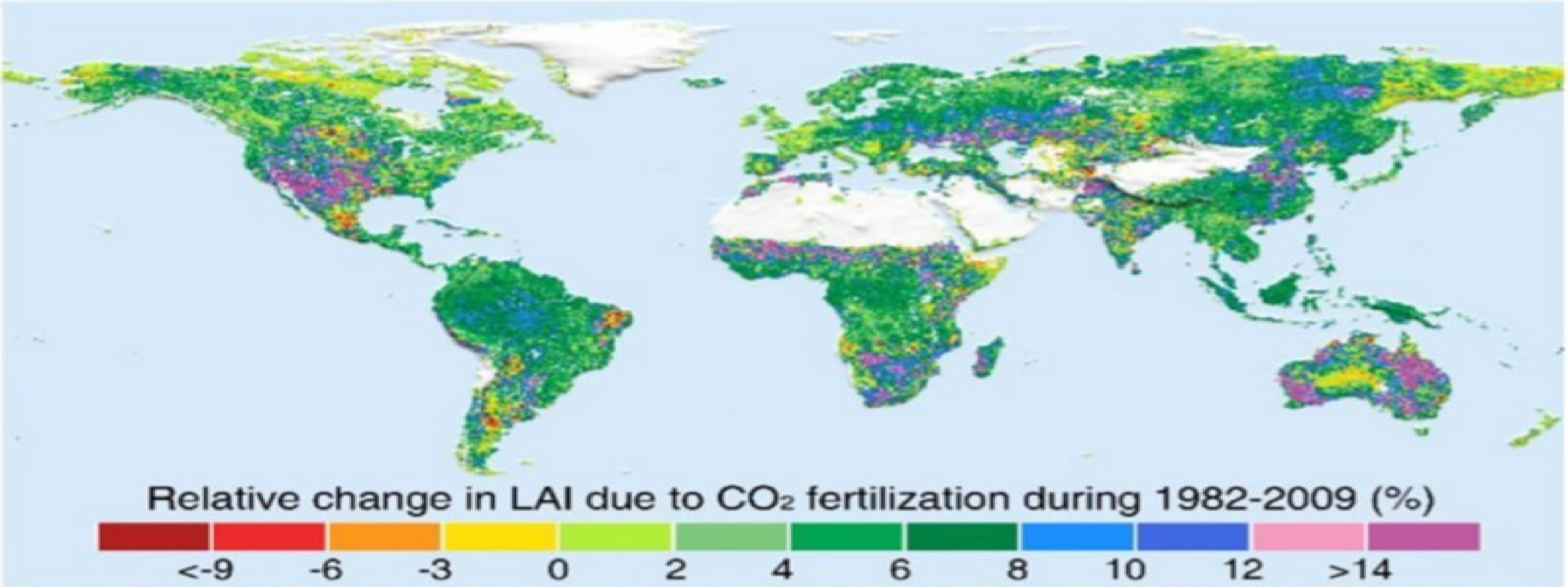
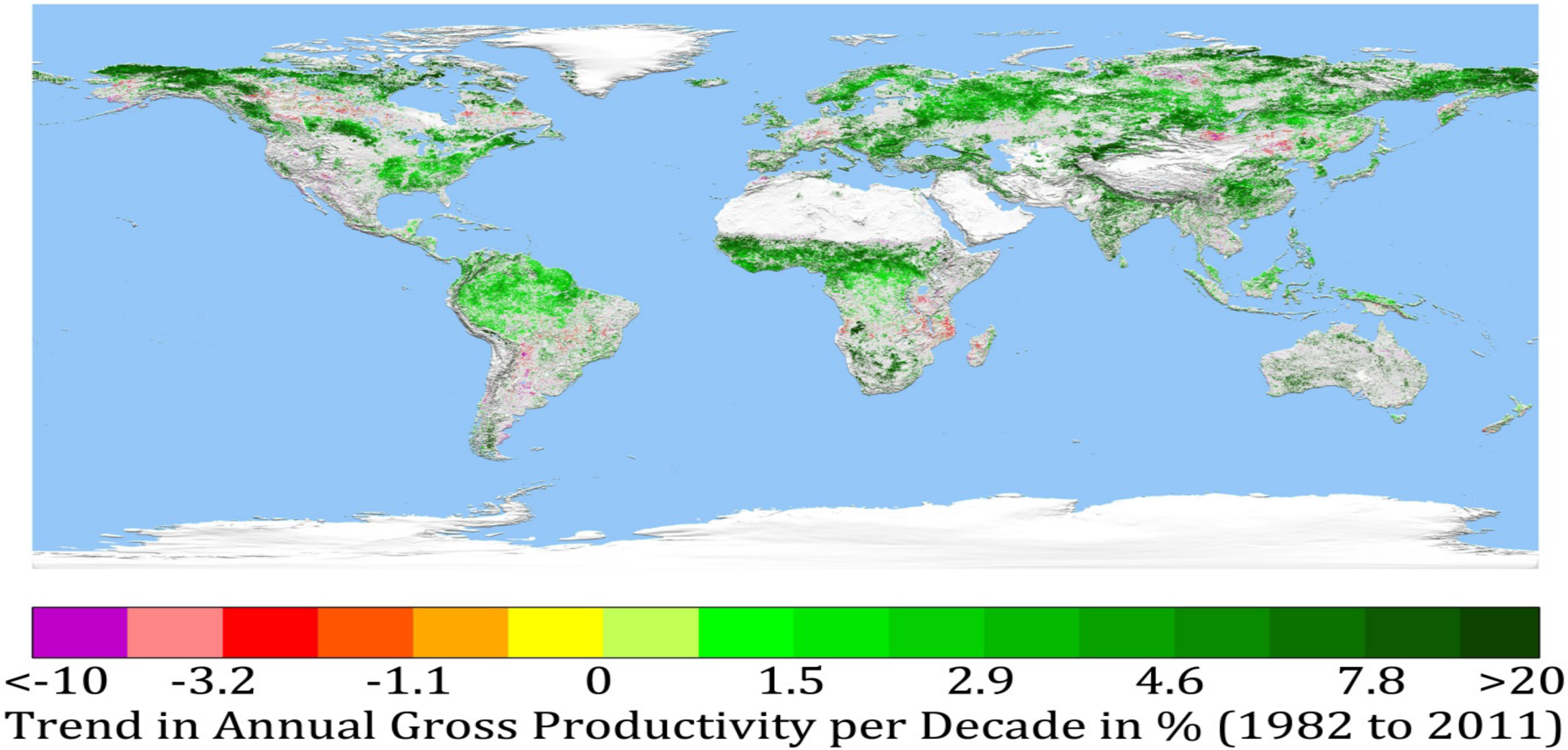


***Figure 1**. Spatial pattern of relative change of LAI due to CO_2 fertilization during 1982 to 2009. The relative change of LAI in each pixel is derived from the ratio of the increment of LAI driven by elevated atmospheric CO_2 to the 28-year average value of LAI simulated by model ensemble mean under scenario S1. Source: Figure S12, supplementary information from Zhu et al. (2016)*

The Earth is more productive [14% increase in gross productivity, 1982–2011]

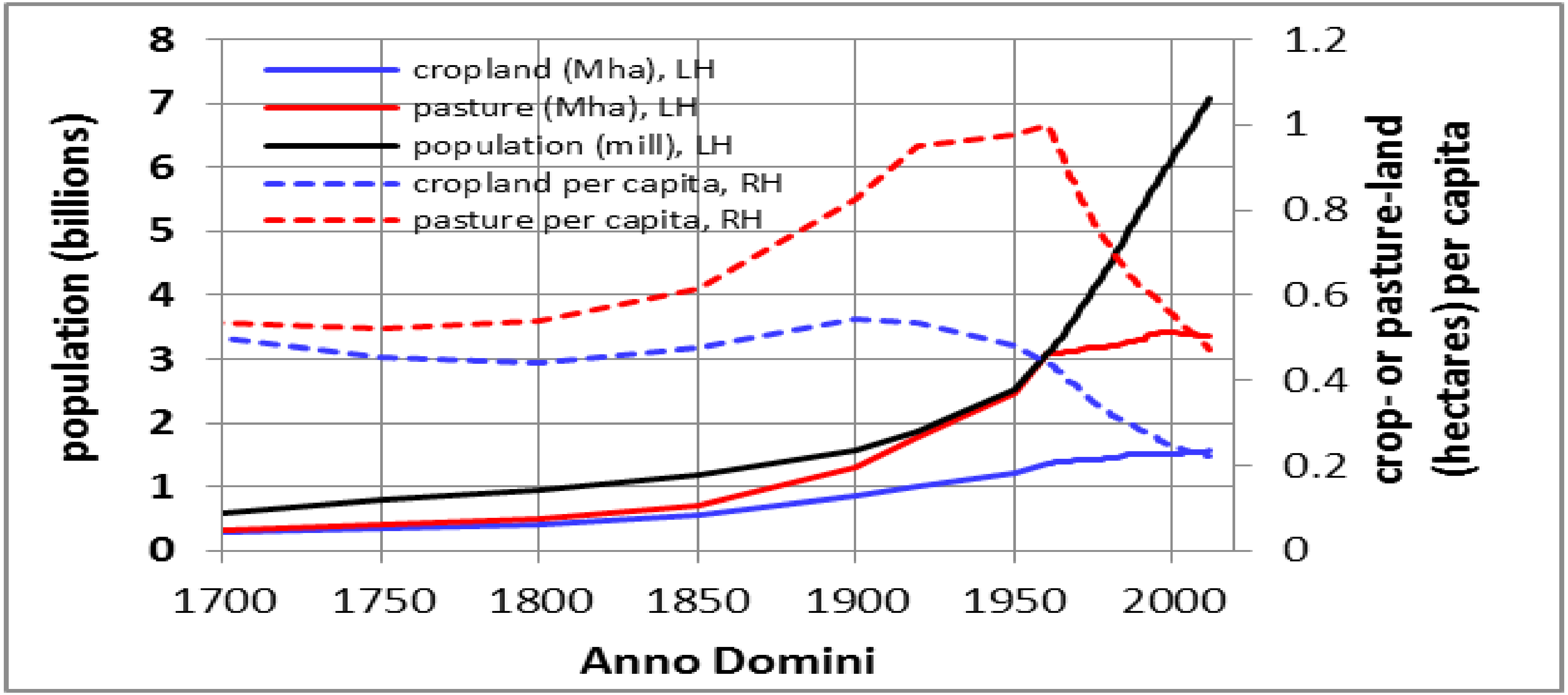


Zhu & Myneni (2014), A Greener Earth?, Global vegetation monitoring and modelling, Avignon, France, February 3–7, 2014.

Global land biological productivity may be 5% higher now than in pre-industrial times

Source: IPCC AR5 WG2, Chapter 4, p. 293

Global Habitat Conversion to Agricultural Uses (1700–2012)



Sources: Klein Goldewijk et al (2011); FAOSTAT (2015); Maddisson (2009).

How much land have fossil fuels saved for the Rest of Nature?

Calculation of **Lower Bound Estimate** of additional land needed to compensate for lost food, fiber & fuel production due to loss of fossil fuels:

- Consider only subset of fossil fuel dependent technologies enhancing productivity:
  - *Nitrogenous fertilizers*
  - *Synthetic pesticides*
  - *CO2 fertilization and nitrogen deposition*
- Assume productivity of additional cropland (on average) same as cropland currently in agricultural use (unlikely)
- Ignore that much of irrigation uses FF-powered pumps
- Ignore that FF have increased productivity of pasture land
  - *Globally pastureland is 2 times cropland*

Other sources of underestimation of land needed to compensate for loss of FF

Ignore that FFs have substituted for a variety of products that would otherwise divert land from the Rest of Nature:

- FF-derived synthetic fibers account for over 70% of global fiber production
- FF account for over 81% of Total Primary Energy Supply and would have to be replaced by lower energy-density renewables (unless nuclear becomes more popular)
- Plastics and other materials obtained directly or indirectly via FF have displaced timber and other vegetal based materials

Land saved by fossil fuels for Rest of Nature: Lower Bound Estimate for Cropland — 1

- ✓ ***Nitrogenous fertilizers,*** mainly from natural gas via Haber-Bosch process. Responsible for 48% of global food production (Erisman et al. 2008), i.e., these fertilizers have increased production by 92%
- ✓ ***Synthetic pesticides.*** Reduce losses in various food crops from 50–77% to 26–40% in the absence of any pesticides (Oerke 2006). Assuming non-synthetic pesticides are 50% as effective as synthetic pesticides implies the latter has increased production by 29%.
- ✓ ***CO2 fertilization*** from increases in Atmospheric CO2 from 277 ppm (preindustrial) to 400 ppm (current)

Land saved by fossil fuels for Rest of Nature: Lower Bound Estimate — 2

Cumulative **increase** in food production from above 3 factors = 174%

To produce same quantity of food in the absence of fossil fuels:

- Global cropland area would have to be increased from 1.6 billion hectares to 4.3 billion ha.
- **Increase = 20.4% of global land area** (excluding Antarctica)
  - About the size of South America and Europe combined
  - **FF have saved more land than ALL land conservation efforts globally (14.7%) by April, 2016**

Effect on potential species extinctions from reduced habitat conversion

- Barnosky et al. (2012) estimate that 43% of global terrestrial ecosystem has already been converted to human use
- Absent FF, we would need to convert at least 21% more land to agricultural uses to sustain humanity at its current level — total of at least 64%
- The added land conversion would have put ecosystems and species at greater risk.
- Barnosky et al.’s “tipping point” paper in *Nature* postulates a tipping point if land conversion exceeds 50%. **We would already have gone past that postulated tipping point!**

Effect of increased habitat conversion on magnitude of potential species extinctions

- Species at risk of extinction would have increased by 75–80%, based on the species-area relationship (SAR) (crude estimate)

Summary —1

- Global ecosystem productivity has increased at least 14% since 1982, mainly from indirect effects of FF usage
- FF are responsible for at least 63% of global food production

Summary —2

If there were no fossil fuels:

- We would need at least an additional 2.7 billion hectares or 20% of global land area just to meet human needs (a gross underestimate)
- The postulated tipping point for global land conversion (at 50%) would have been exceeded
- Potential species extinction would have increased over 70%

Conclusion – Part II

- Fossil fuels have saved much of the rest of nature from humanity
- Without them, other species would have been in greater jeopardy

Take Aways

- Fossil fuels allow the Rest of Nature and Humanity to Co-exist
- Without fossil fuels, humanity would be living in poverty, starving, and living shorter and unhealthier lives.

Back-up slides

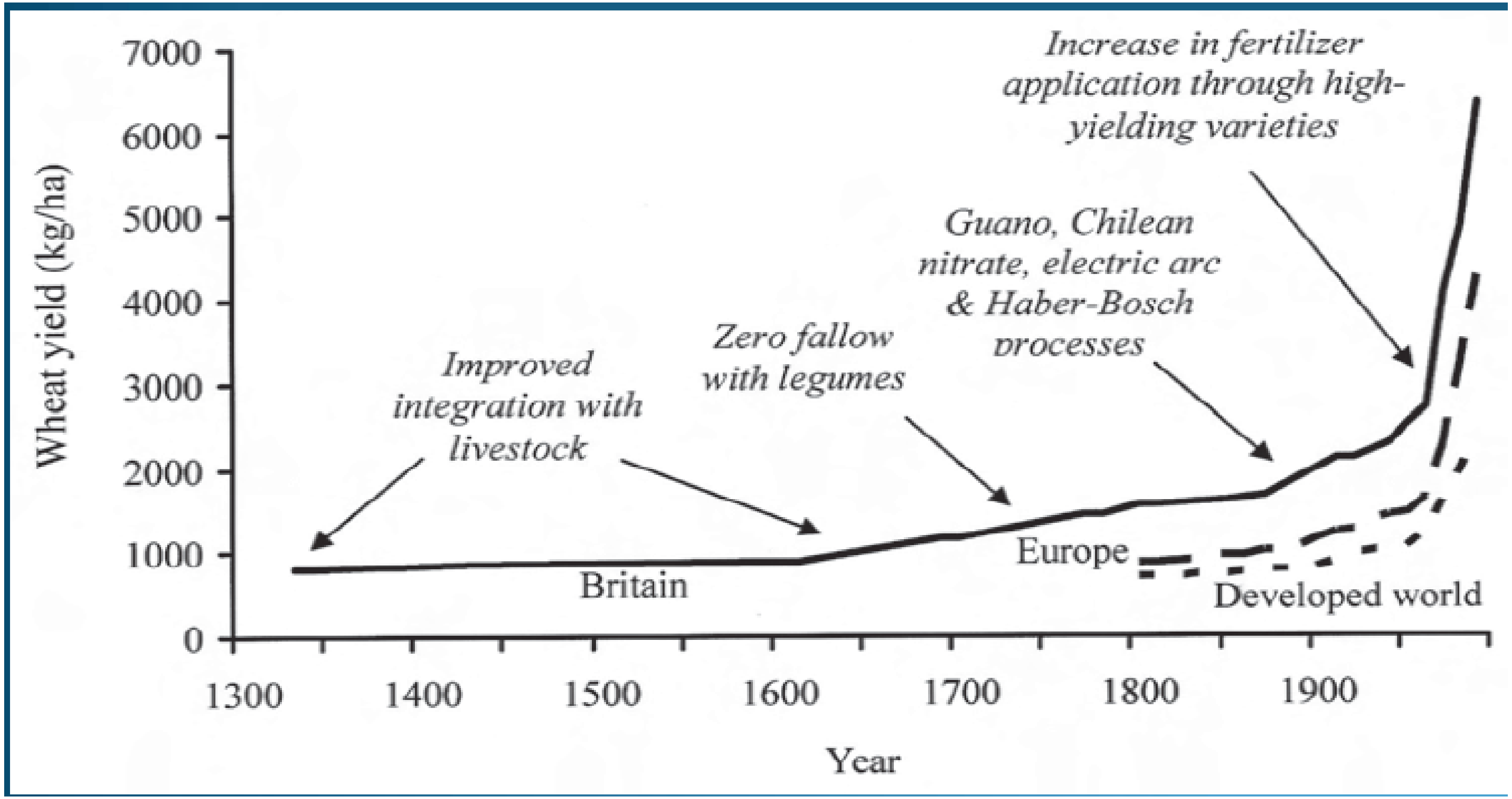
Contributions of FF to economic growth and human well-being

- Increases land productivity:
  - Increases available food
  - Reduces hunger
  - Improves health
  - Enhances human capital
- Substitutes for human and animal labor
  - Frees up human time and energy to pursue other activities
  - Enhances human capital

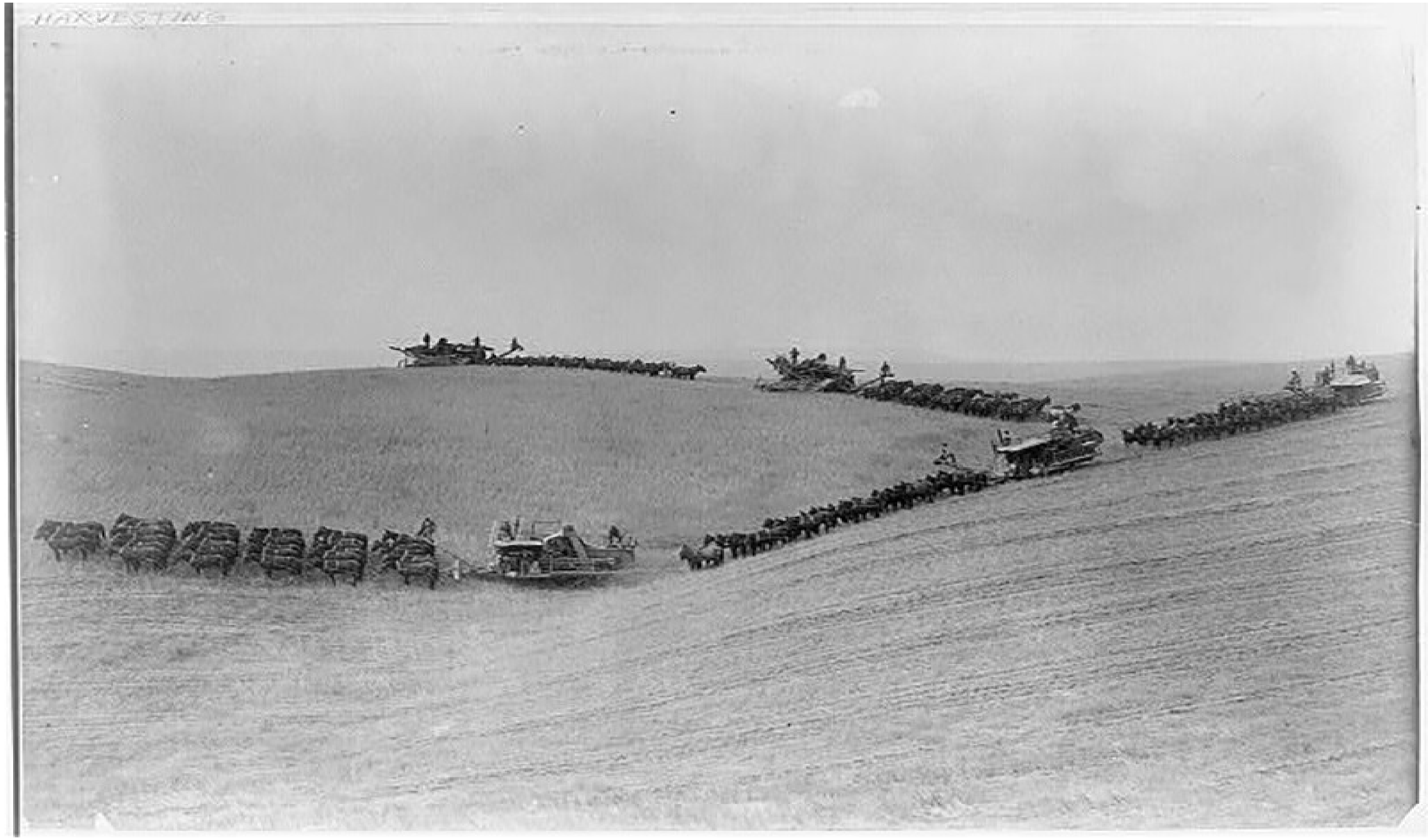
Contributions of FF to economic growth and human well-being

- Human capital
  - Electricity (67% worldwide from FF) “creates” more time at humanity’s disposal which allows individuals to accumulate human capital
- Bulk of new technology powered directly or indirectly by energy [81% of global energy from FF]

Agricultural Productivity, 1300–2000



Source: N. B. J. Koning, et al., “Long-term global availability of food: continued abundance or new scarcity?” NJAS Wageningen Journal of Life Sciences 55 (2008): 229–292.


HARVESTING