Brazilian Bioethanol Science and Technology Laboratory

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MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Food Security and Biofuels: Can Policy Flexibility Mitigate Food Price Crises for the Poor?

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Overview

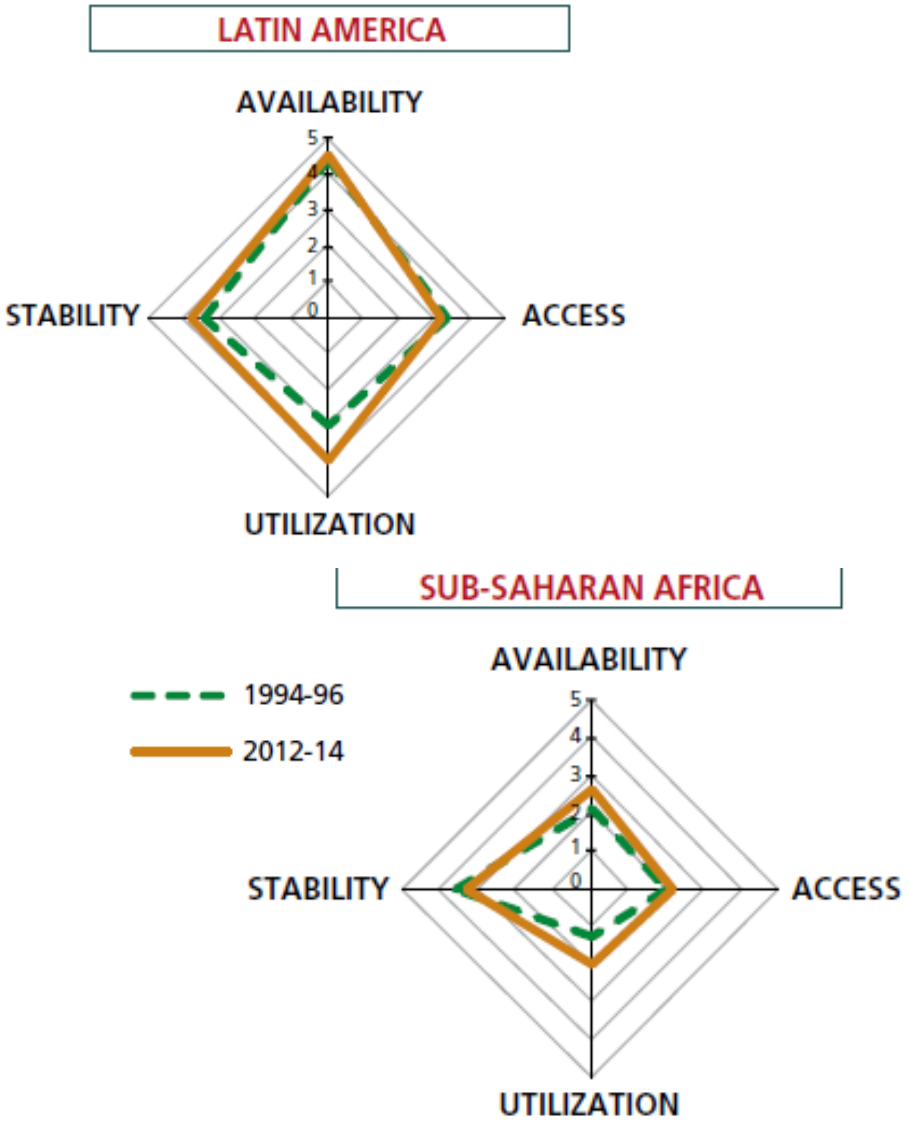
We consider current food security issues, review recent research with a focus on drivers, and consider the world's two largest biofuel production systems: Brazil sugarcane and US maize (corn) ethanol. These two systems represent nearly 90% of global ethanol production. We attempt to answer the following questions:

- How does feedstock use for biofuels interact with food security and global food prices?
- Can biofuel policy changes in these nations reduce the likelihood of food price crises for the poor?

We conclude with observations and recommendations for moving forward constructively.

Food Security is *only recently* being defined and measured in more consistent manners

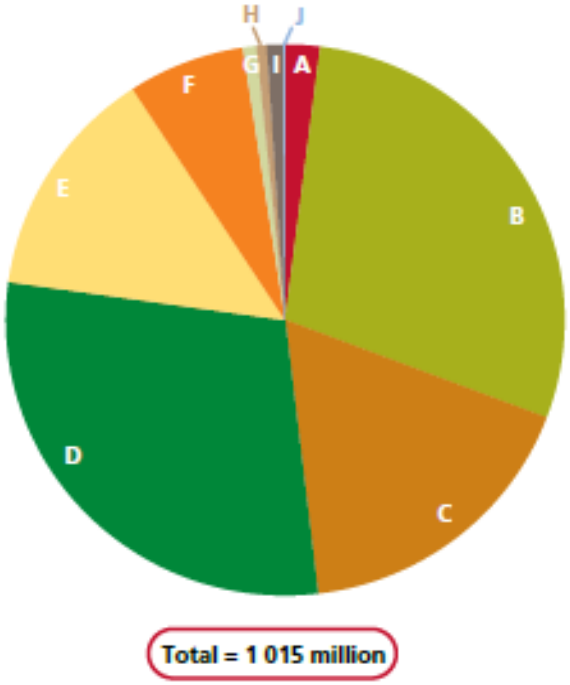
- Food security: when all people at all times have physical and economic access to sufficient, safe and nutritious food…for an active and healthy life (FAO 1996 World Food Summit). Four main dimensions:
  - ***Availability***
  - ***Access***
  - ***Utilization***
  - ***Stability***
- Food security is basic human right
- Key causes of hunger include poverty, lack of social safety net (weak governance), disasters (weather, political), and lack of local production capacity (FAO SOFI reports 2009-14).

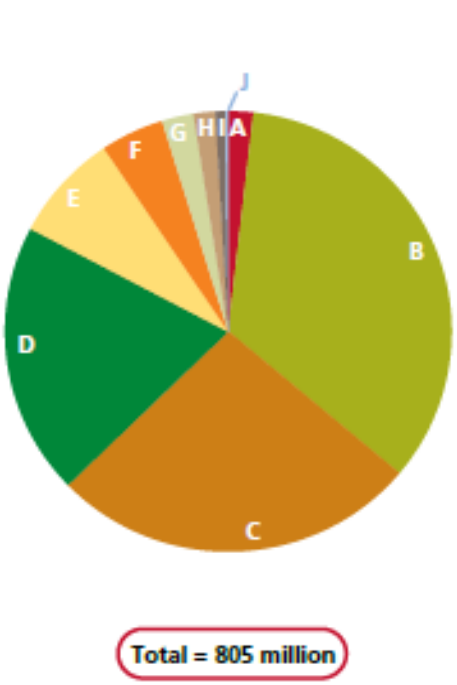


Source: FAO State of Food Insecurity in World (SOFI) 2014

World hunger is decreasing. Most under-nourished people (92%) are in Asia and Africa

The changing distribution of hunger in the world: numbers and shares of undernourished people by region, 1990–92 and 2012–14



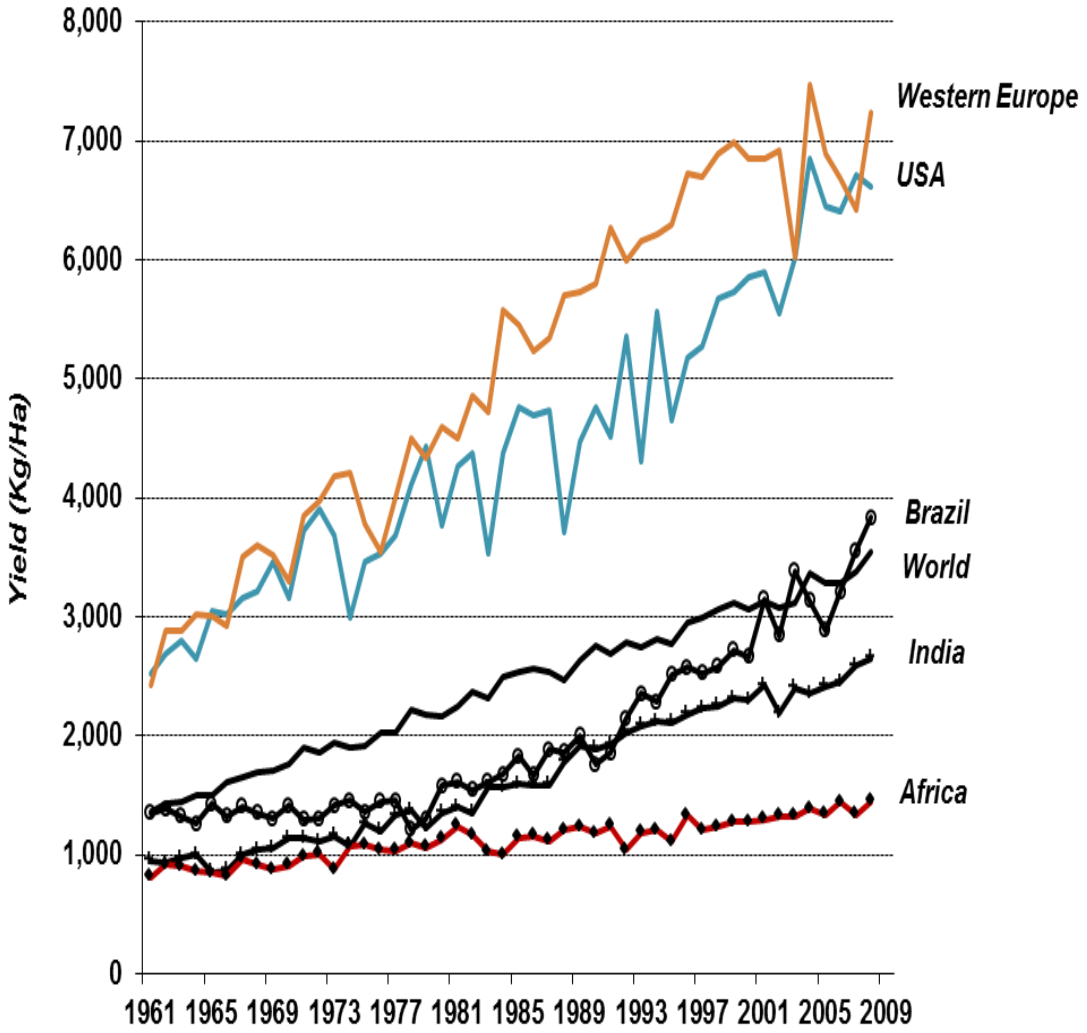


	Number (millions)		Regional share (%)	
	1990–92	2012–14	1990–92	2012–14
A Developed regions	20	15	2.0	1.8
B Southern Asia	292	276	28.8	34.3
C Sub-Saharan Africa	176	214	17.3	26.6
D Eastern Asia	295	161	29.1	20.0
E South-Eastern Asia	138	64	13.6	7.9
F Latin America and the Caribbean	69	37	6.8	4.6
G Western Asia	8	19	0.8	2.3
H Northern Africa	6	13	0.6	1.6
I Caucasus and Central Asia	10	6	0.9	0.7
J Oceania	1	1	0.1	0.2
Total	1015	805	100	100

Note: The areas of the pie charts are proportional to the total number of undernourished in each period. Data for 2012–14 refer to provisional estimates. All figures are rounded.
Source: FAO.

Source: FAO State of Food Insecurity in the World (SOFI) 2014

Experiences with food insecurity indicate that:



1. At global scale, there is plenty of land and food production; distribution and cost are key issues for poor.
2. Local investment in agriculture and effective social safety nets for the poor are essential to improve food security.
3. Additional factors contributing to food insecurity:

- 40+ years of food aid, over-production
- Lack of market incentives
- Lack of access to financial resources
- Price volatility
- Yield gaps

Sources: World Bank (Chart); and FAO Annual reports on State of Food Insecurity (SOFI) in the World

Experiences with food insecurity indicate that:

Key research question: How do biofuel policies actually interact with the conditions and processes that determine food insecurity?

1. At global scale, there is plenty of land and food production; distribution is an issue for the poor.
2. Local investment in agriculture and effective social safety nets for the poor are essential to improve food security.
3. Additional factors contributing to food insecurity:
   - 40+ years of food aid, over-production
   - Lack of market incentives
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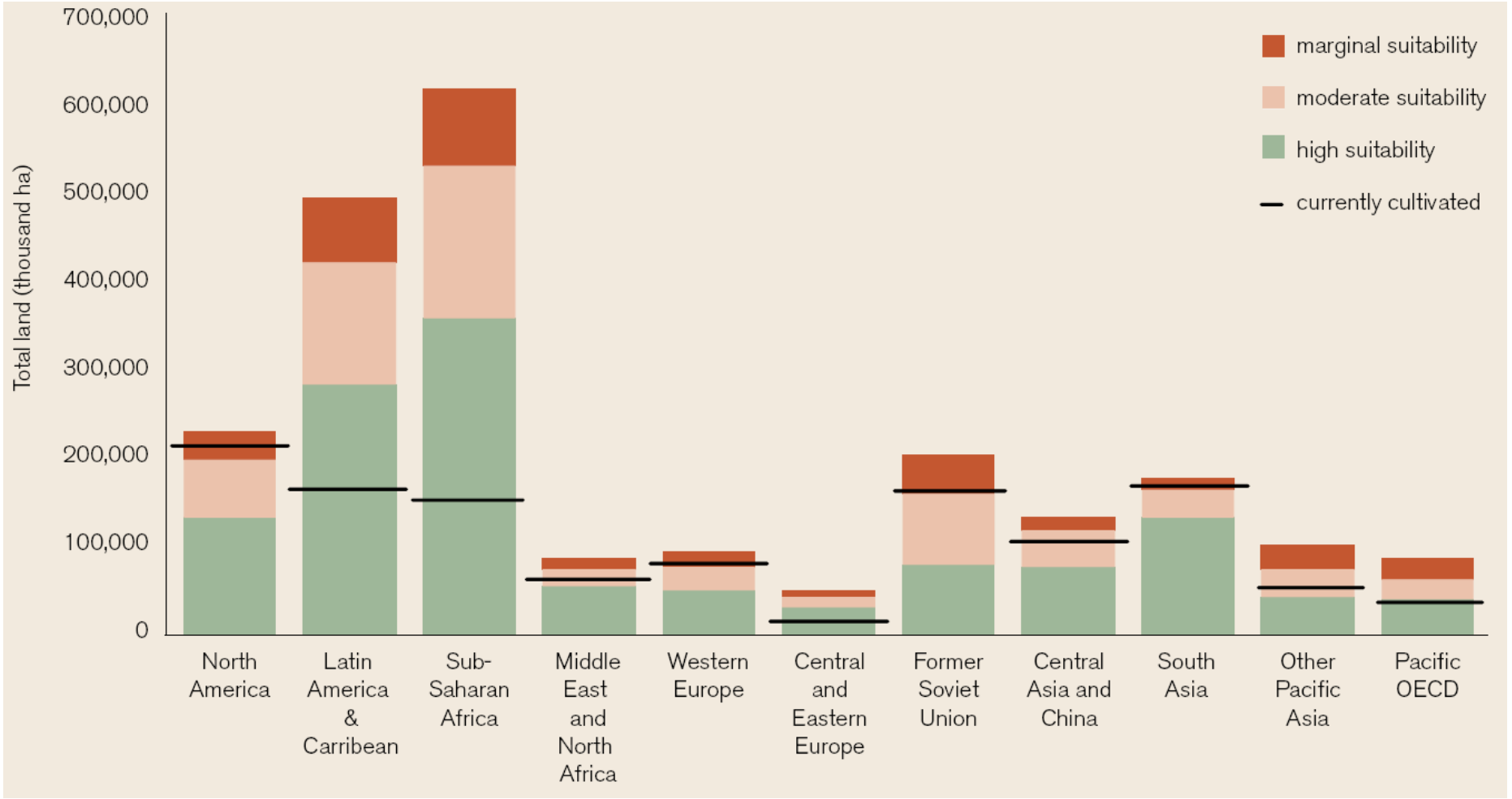
Sources: FAO Annual reports on State of Food Insecurity (SOFI) in the World

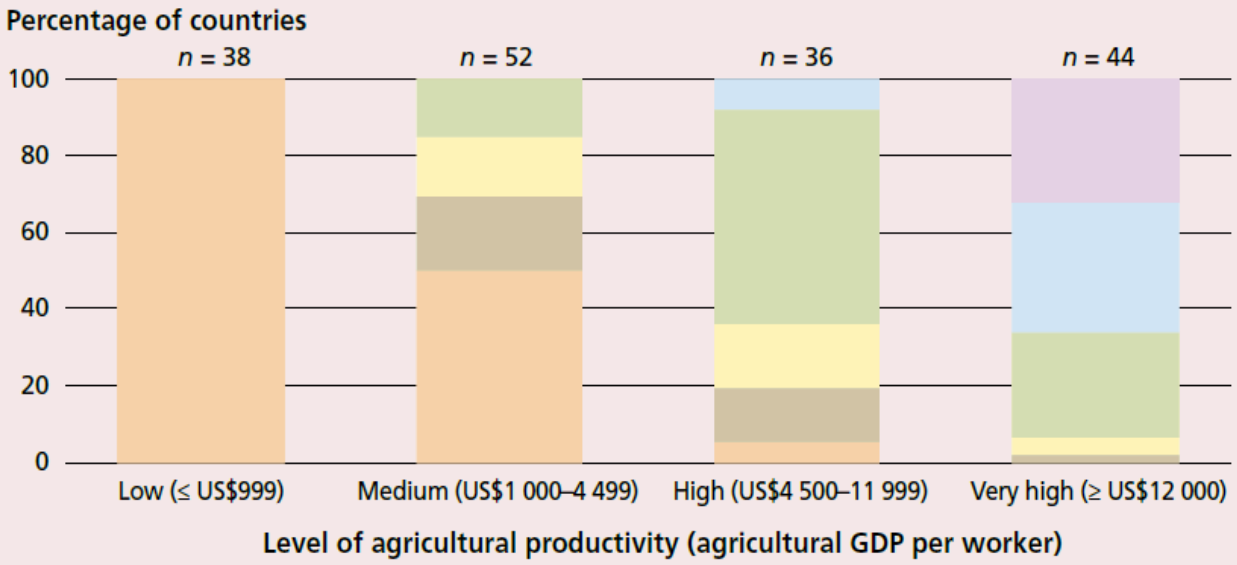
Land Availability – huge areas suited for rain-fed agriculture, especially Africa and Latin America



FAO 2007

Low Agricultural Productivity correlates with more severe Food Insecurity

FIGURE 6
Share of countries in each malnutrition category, by level of agricultural productivity



Notes: n is the number of countries characterized by each level of agricultural productivity. Agricultural productivity is derived by dividing agricultural GDP (in 2010 measured in current US dollars) by the population economically active in agriculture. Malnutrition categories are those illustrated in Figure 4.
Sources: Authors' calculations using agricultural GDP data from the United Nations (2012) and data on agricultural workers from FAO, 2013. Sources used to determine malnutrition categories are those used for Figure 4.

Source: FAO (2013 State of Food and Agriculture; SOFA)

Food security remains a problem for 800 million people. How can we reduce food crises?

Some proposed "solutions" have targeted biofuels:

1. **Simply forget biofuels**
   - Focus on solar, wind, conservation
2. **Only use "non-food" crops** for biofuels
   - Several NGOs and governments testing this idea
3. **Change policies so biofuel production adjusts** in response to food crises
   - Recommendation from the November 2013, 40th Meeting of the United Nations Committee on Global Food Security

Let's consider each…

Commonly proposed "Solutions" to mitigate food price crises

1. **Simply forget biofuels to focus on solar, wind and conservation**
   - Solar and wind can play important roles
     - But they cannot, in near to medium term, alleviate needs for liquid transport fuels
     - Aviation and long-haul shipping require dense liquid fuels
   - Conservation should always be first priority – but alone it is insufficient to provide energy security and meet societal development goals

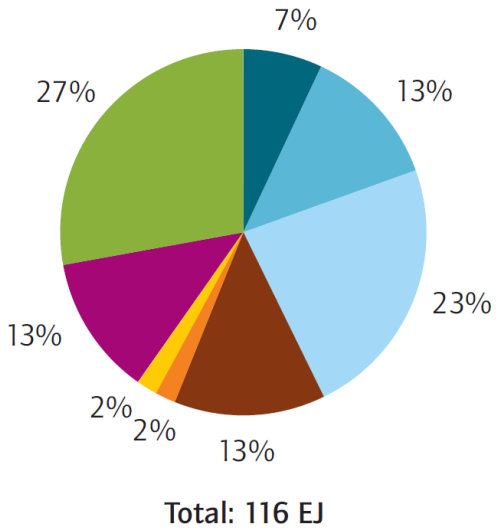
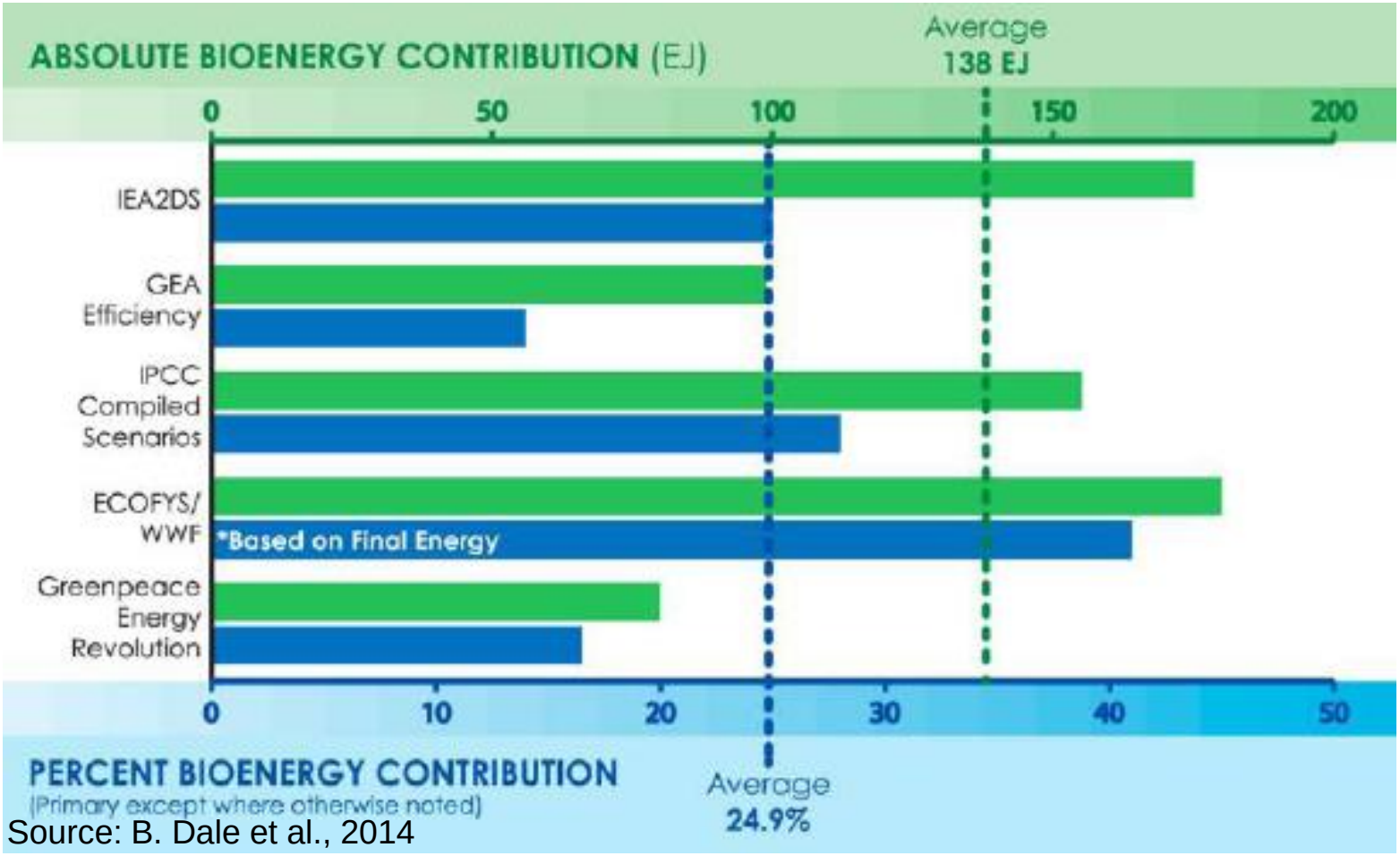


Chart: IEA 2011 Roadmap: Biofuels role in projected 2050 transport fuels

Studies that prioritize other renewables still rely on bioenergy for large, essential role to help society address climate concerns



Source: B. Dale et al., 2014

To address climate change, we need bioenergy and biofuels

Commonly proposed "Solutions" to mitigate food price crises

2. Only use "non-food" crops for biofuels

- Several NGOs and governments testing this idea

- Evidence to date…
  - Non-food crops lack investments to improve seeds, develop infrastructure and markets
  - Evaluations (e.g., NL Agency 2010 *Jatropha Assessments*) of multiple efforts to develop biofuels using non-food crops found consistent short-comings and failures
  - Costs and risks are high for new crops such as algae and other "next-generation" feedstocks

National Public Radio www.npr.org: "How A Biofuel Dream Called Jatropha Came Crashing Down" (August 21, 2012)

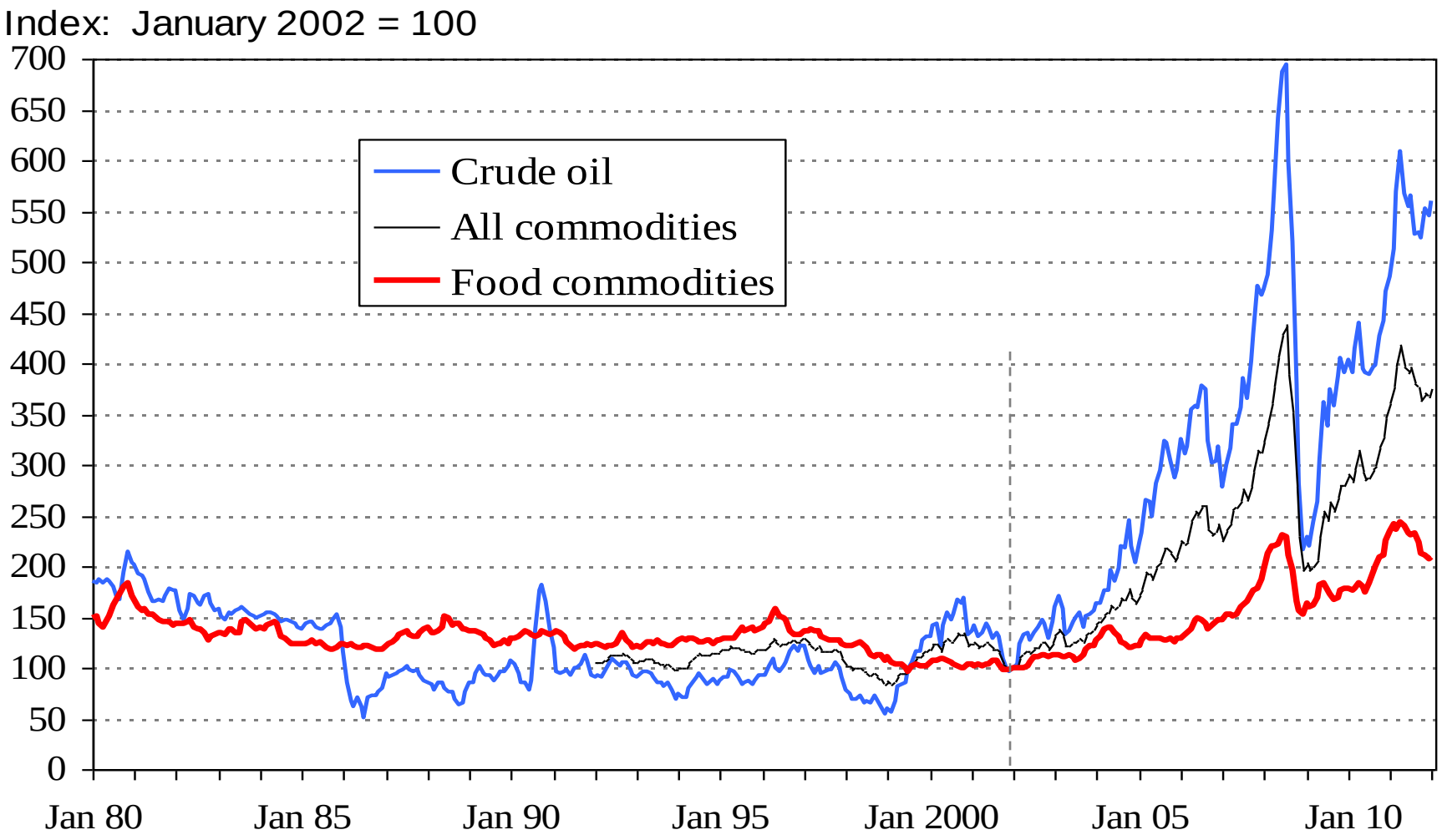
Commonly proposed "Solutions" to mitigate food price crises

2. Only use "non-food" crops for biofuels

Fact: You cannot eat "non-food crops"

- Therefore, using land, labor and water to produce inedible crops could have the ***opposite effect of that desired***
- Biofuel production with traditional crops builds a ***"production cushion" that can reduce local price volatility*** and allows markets to respond in times of crisis
- Non-food prices, products with limited markets, may be ***MORE volatile*** than food, creating added risk for producers of non-food products…

Non-food commodity prices rose more than those for food in the 2008 crisis



Source: Ron Trostle, ERS; based on International Monetary Fund: International Financial Statistics, Jan 2012p

Commonly proposed "Solutions" to mitigate food price crises

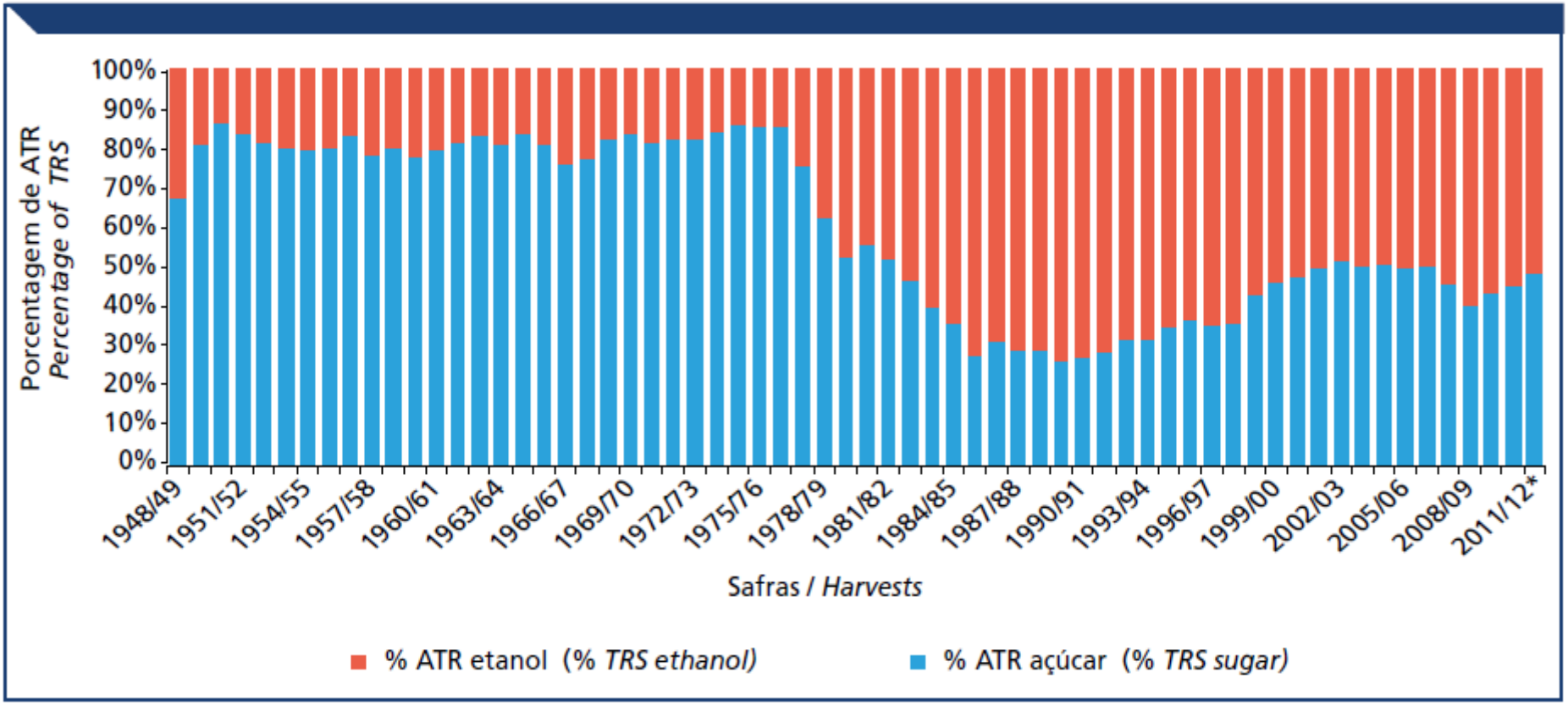
3. Change policies so that biofuel production adjusts in response to food crises

- This concept ***assumes*** that
  - Current policies do not allow such adjustment
  - Current conventional feedstock production systems can respond quickly to a food price crisis
  - Government interventions in markets (to change policies in "times of crisis") will not have detrimental side-effects on future production
  - Suspension of biofuel policies will "free-up" the food that's needed and/or reduce prices of required food stuffs
  - A biofuel policy response in US or Brazil that cuts biofuel production will help avert or mitigate food crises for poor populations in distant, affected nations

Available data raise doubts about each of these assumptions

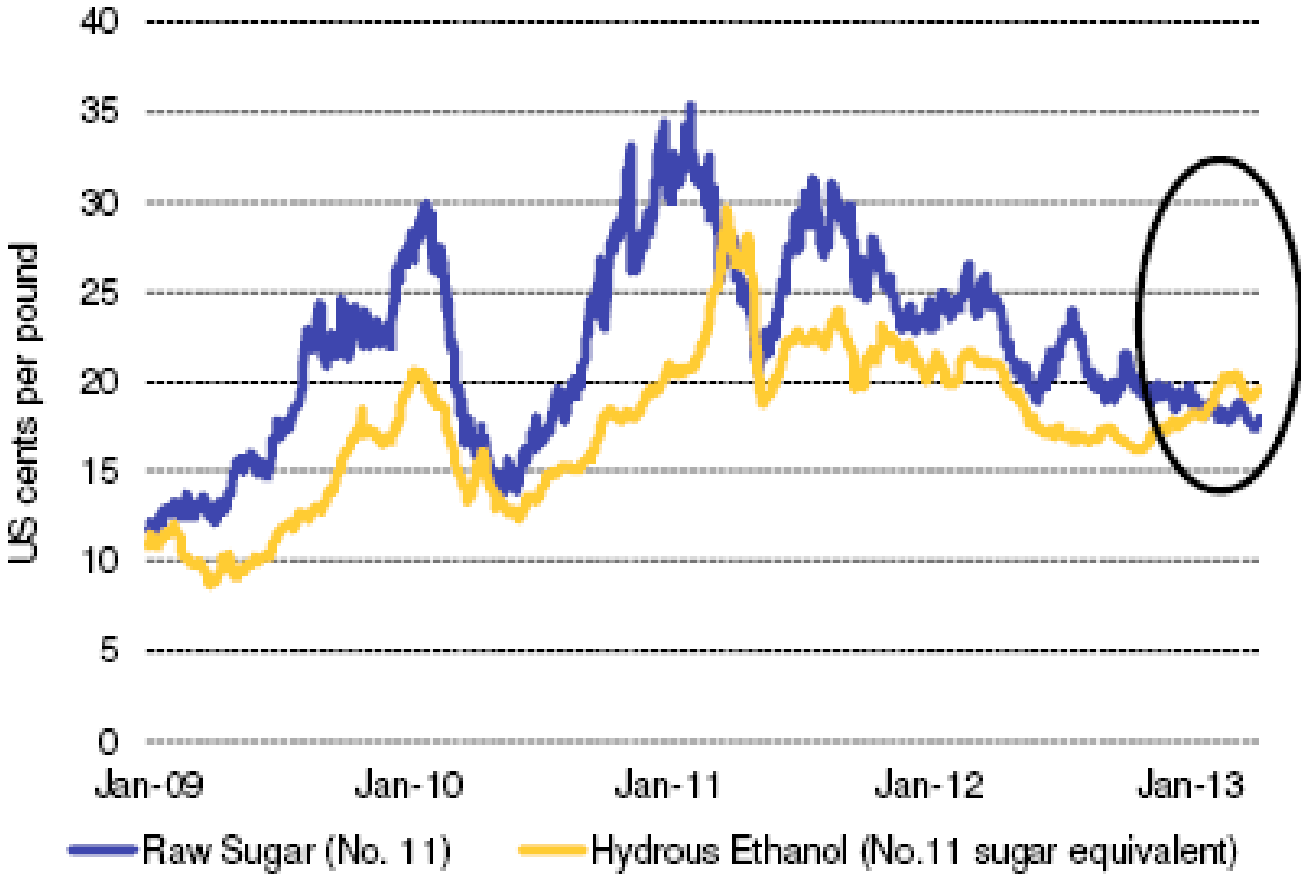
Sugar/Ethanol Production Mix

Brazil adjusts sugar-to-ethanol output ratio to respond to markets, but it takes time



Source: MAPA, 2013

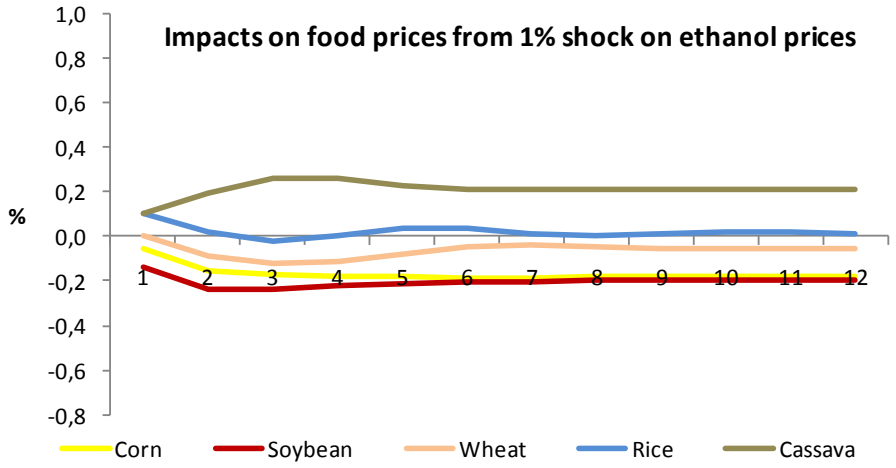
World Sugar Prices and Hydrous Ethanol Parity

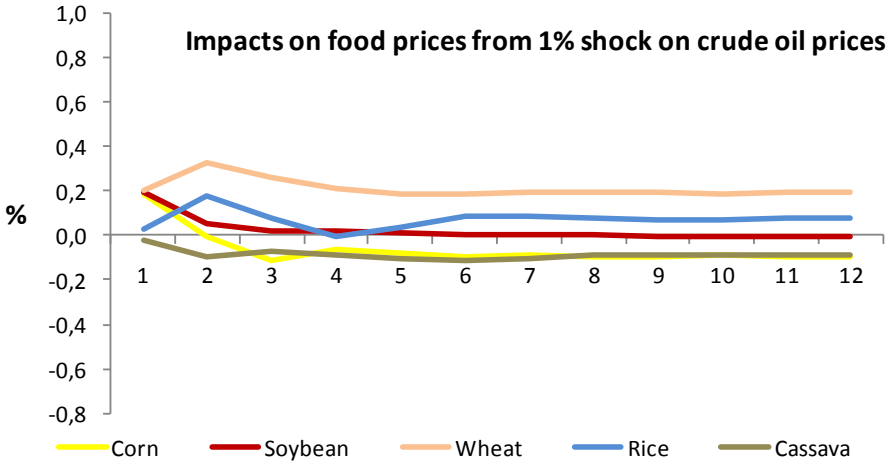


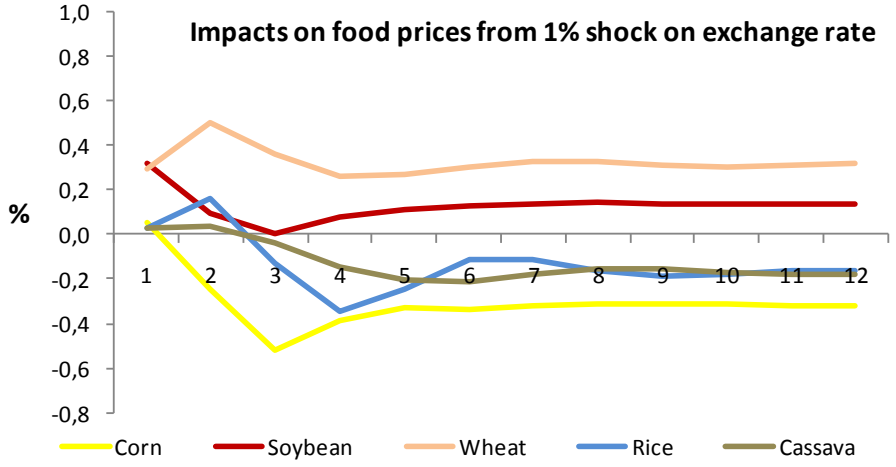
Sugar and ethanol prices respond to common external drivers. Sugar and hydrous ethanol parity prices tend to converge to a common value.

Source: LMC International, 2013

Is Ethanol Affecting Food Commodity Prices in Brazil? If not, how can ethanol impact food prices in other nations?







Preliminary results using time series "*Auto-regressive Vector with error correction model*" point out weak impacts from positive shocks on ethanol/sugarcane prices:

❑ There are no significant variations on domestic food commodities prices.

❑ Oil and exchange rate exhibit similar or greater impacts on food commodities prices

Source: Capitani et al., 2014

Flexibilities in Brazilian Sugar/Ethanol Sector

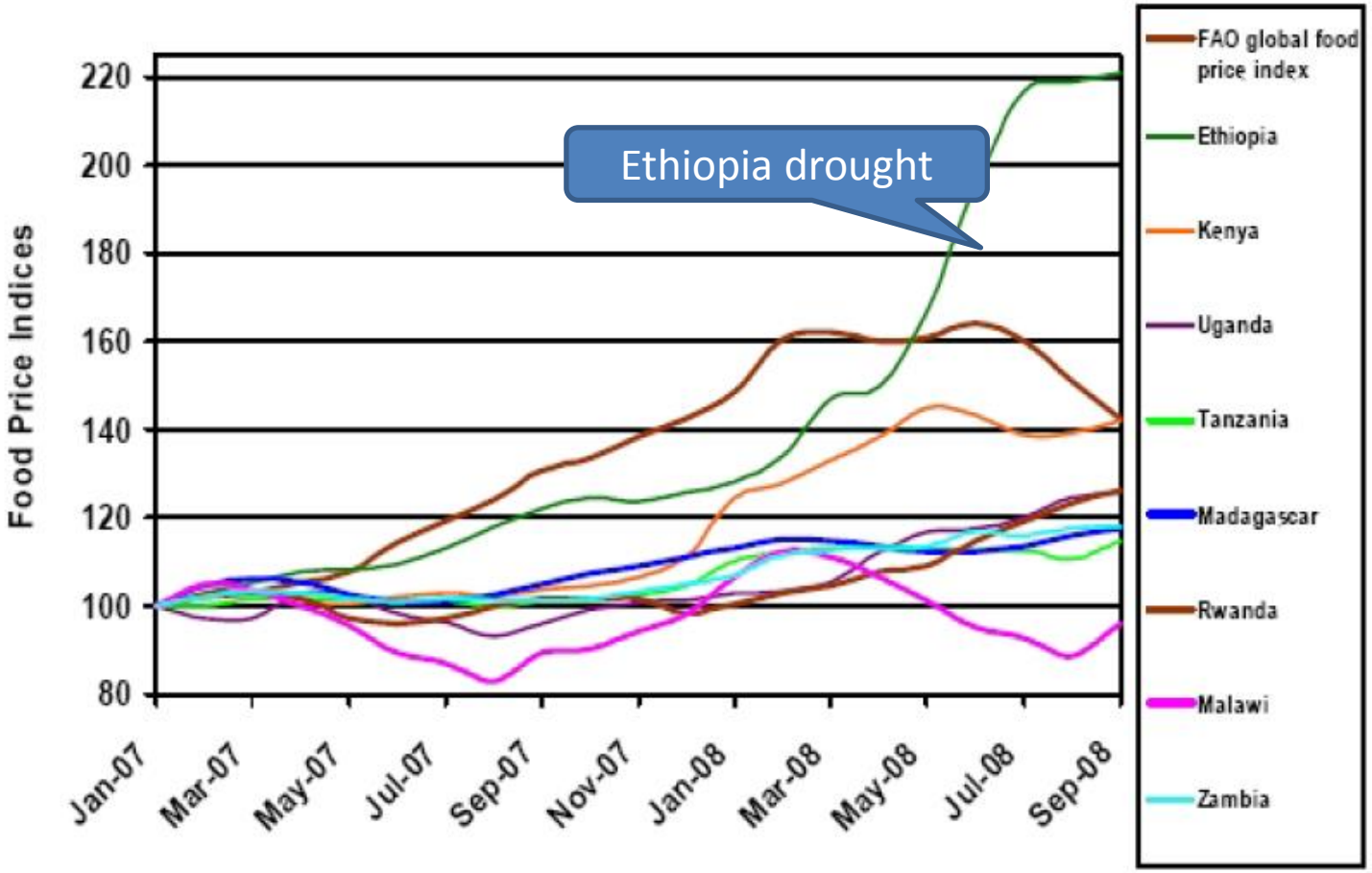
- **Feedstock production flexibility:** Although mills have some flexibility, annual cane production is relatively fixed, being a product of the areas previously planted and weather.
  - After fields are prepared for cane planting, it takes 18 months before first harvest begins and harvests continue seasonally for 5 or more years
  - Increases in planted area require foresight, large investments and about two years advance planning
- **Ability to adjust processing in response to markets:**
  - Decisions to produce sugar or ethanol are based on market analysis, risk and established long-term contracts.
  - Contracts are usually set before cane processing season begins.
  - Contracts limit ability for mills to make large changes in sugar-ethanol mix on short notice, making it difficult to respond quickly to sudden price crises.
- **USA** has similar limitations in terms of large, quick responses in corn production, but adjusts annually to market signals.
- In both Brazil and USA: **larger supplies** create market "**shock-absorbers**" and opportunities exist for a **second corn crop** if prices rise (as demonstrated by the historic US drought in 2012).

Source: Authors' analysis

Food Price Index of Selected African Countries

Figure 5: Evolution of global food price index and food price indices of selected ESA countri

Of note: Malawi, the least-impacted nation, is one of few in Africa with long-established biofuel programs



Source: Reproduced by kind permission of CGIAR. From 'Responding to Food Price Crisis in Eastern and Southern Africa: Policy Options for National Regional Action' (Karugia, et. al. 2009)

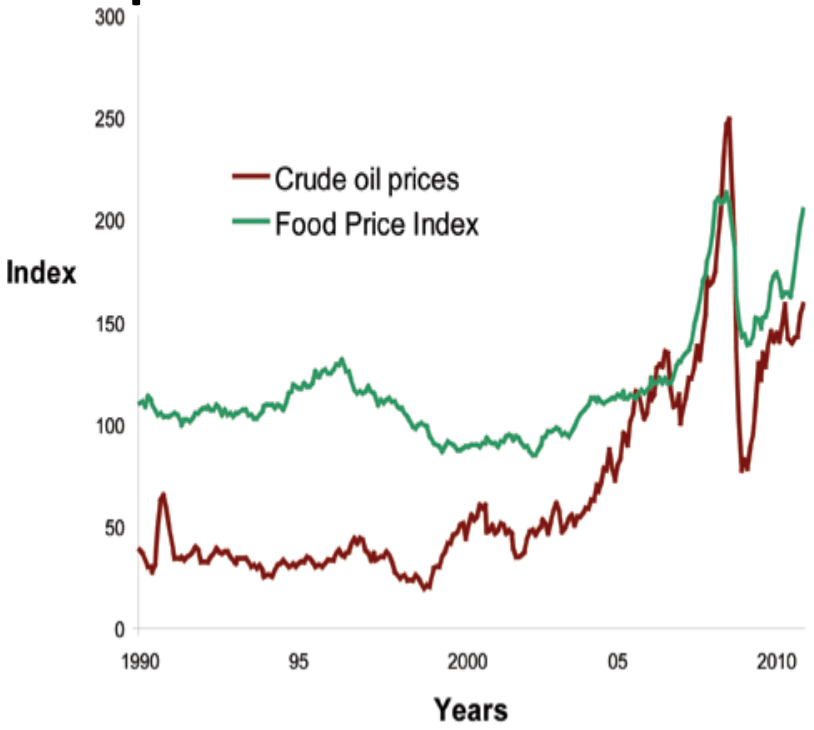
Source of chart: UK Defra 2010 – from CGIAR 2009

Commonly proposed "Solutions" to mitigate food price crises

3. Change policies so they adjust biofuel production in response to food crises

This was proposed in the November 2013, 40th Meeting of the United Nations Committee on Global Food Security. But…

- Food "crises" typically occur suddenly, exemplified by spikes in local staples in affected countries
- Food "crisis" have other causes – including ***significant role of crude oil prices****
- Shifts in corn and sugar use by US and Brazil are unlikely to have rapid influence on local food stuff prices in distant developing nations



*** If biofuel production helps moderate spikes in oil price, more biofuel production rather than less, may be best option to mitigate future food price crises.**

Grain commodity price volatility is far different from "food price" volatility (US Consumer Food Price Index, CPI) 1976-2012

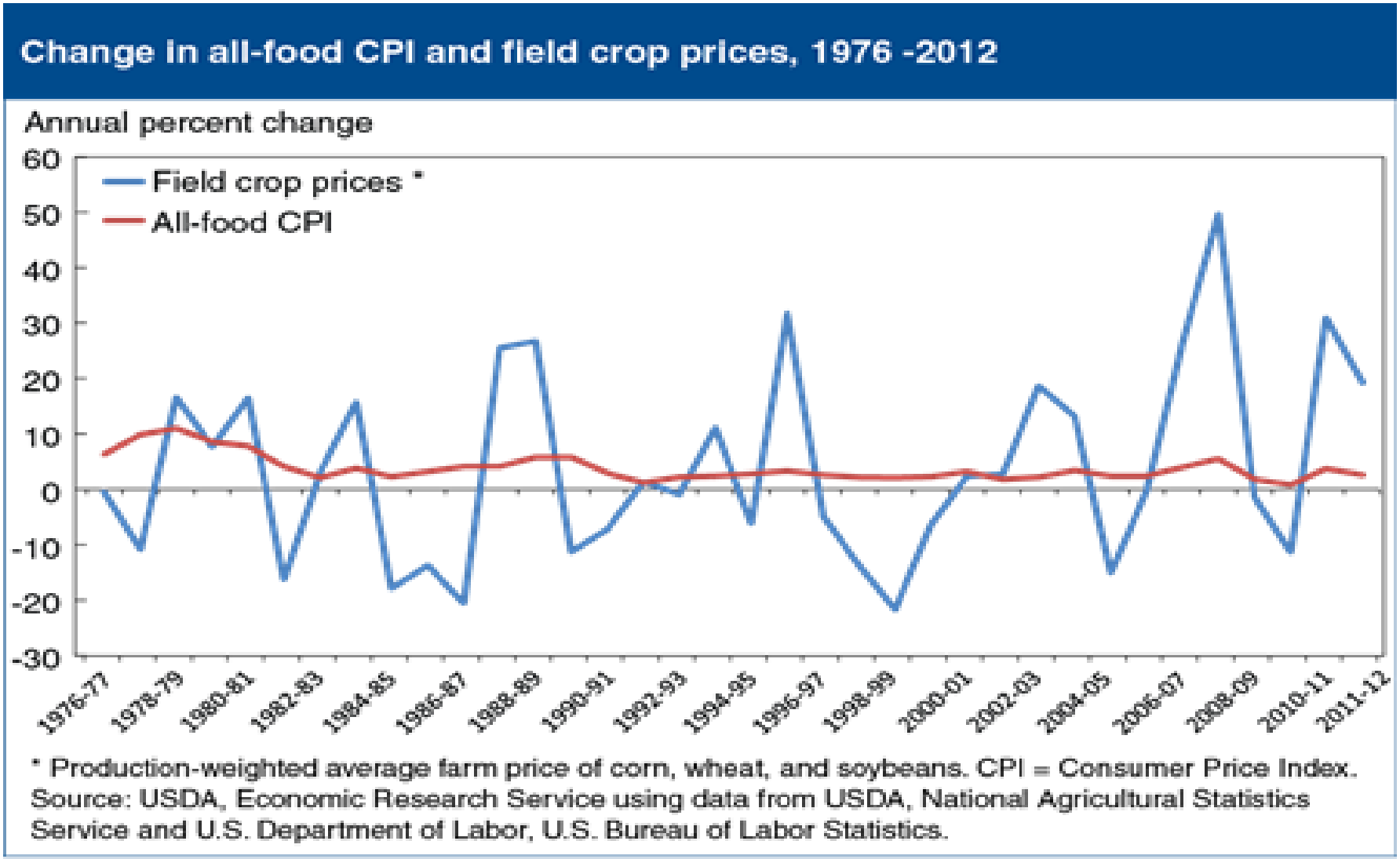
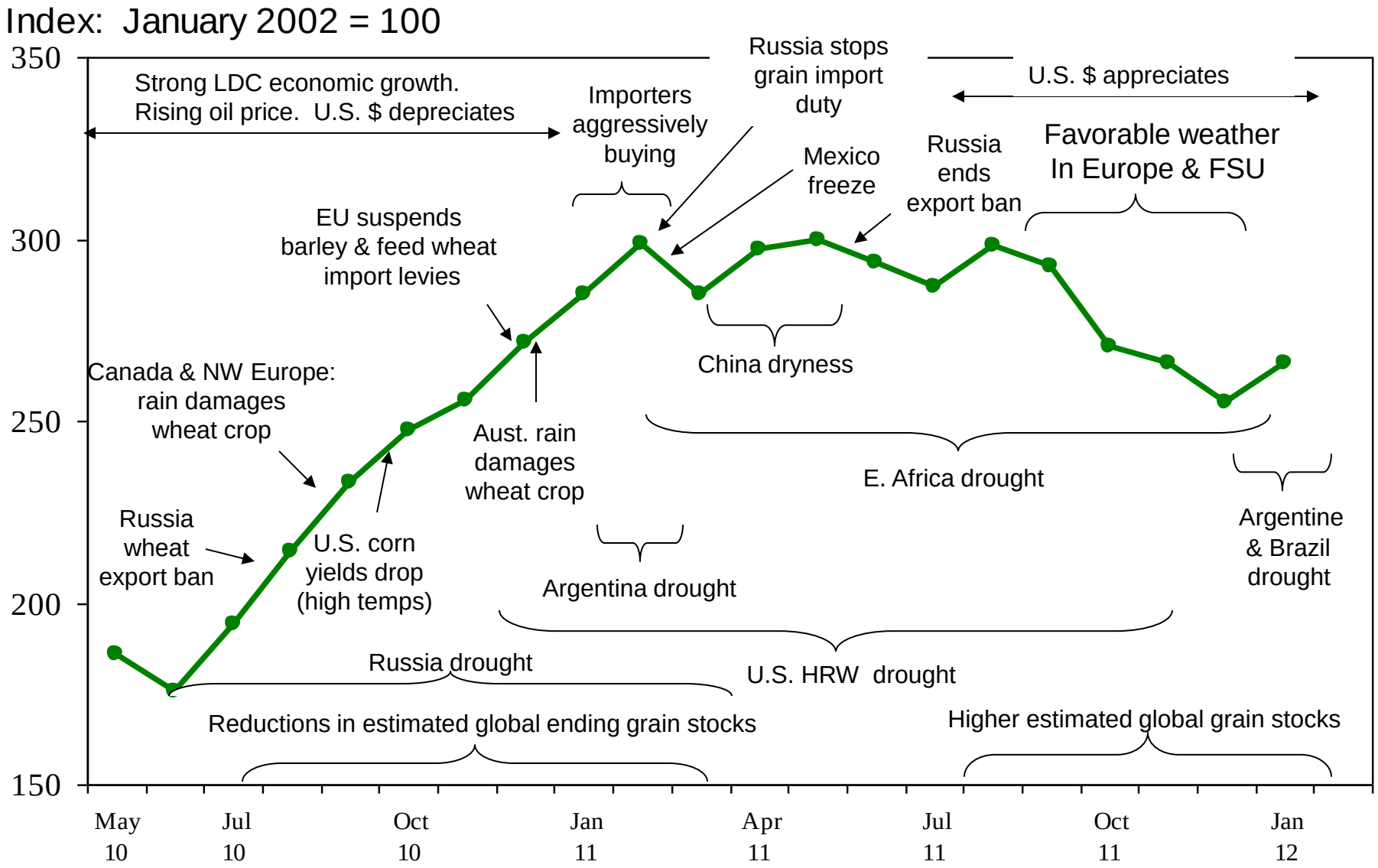


Chart: http://www.ers.usda.gov/data-products/chart-gallery/detail.aspx?chartId=41700&ref=collection&embed=True&widgetId=39734

Primary factors affecting global grain commodity prices[1] (2010–2012) – Weather events and import/export policies



[1]4-crop monthly price index: Wheat, rice, corn, & soybean prices; based on IMF price and trade share data.

Source: Ron Trostle, ERS

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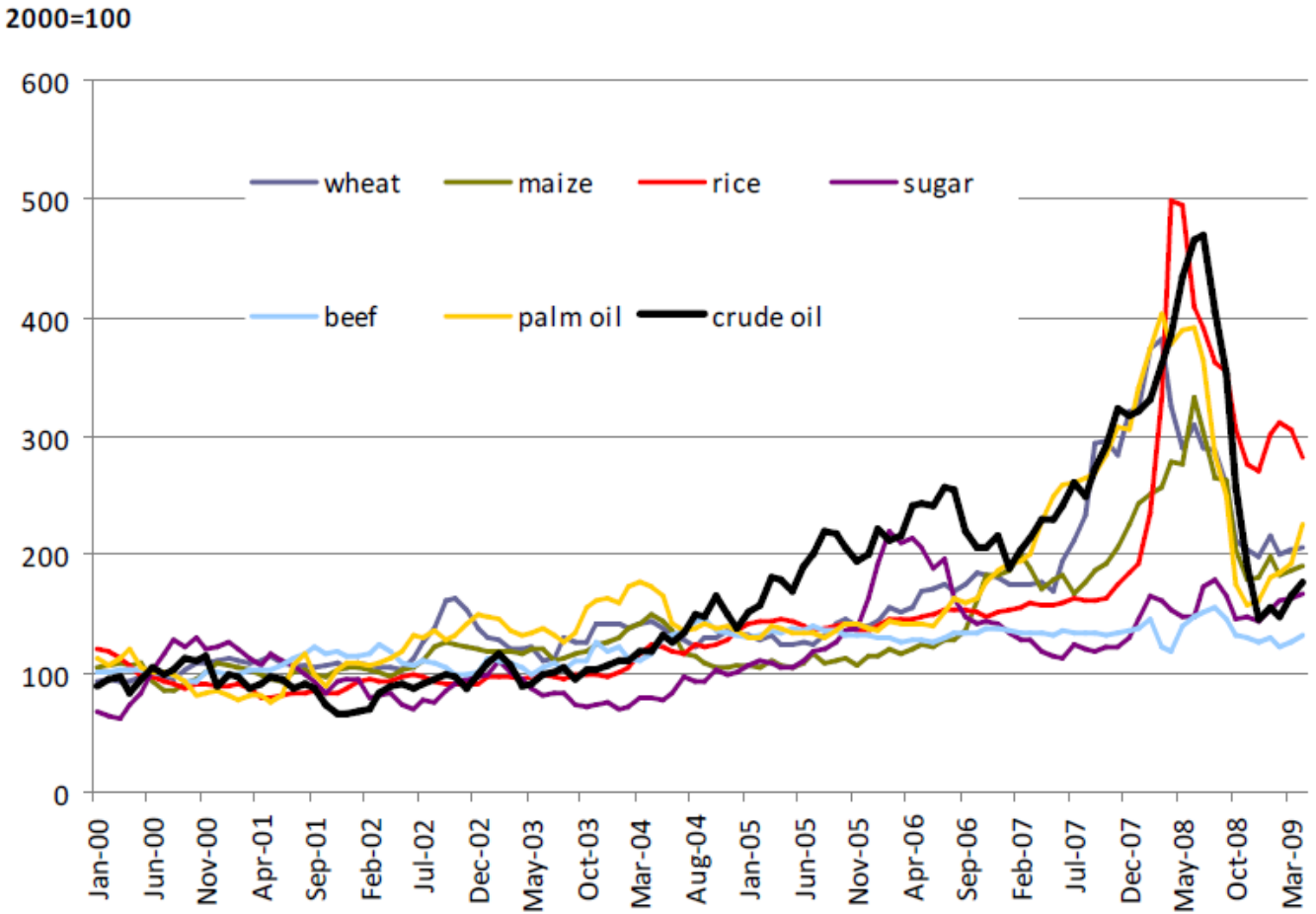
World Commodity Prices

Figure 1: Index of world commodity prices, January 2000 – April 2009

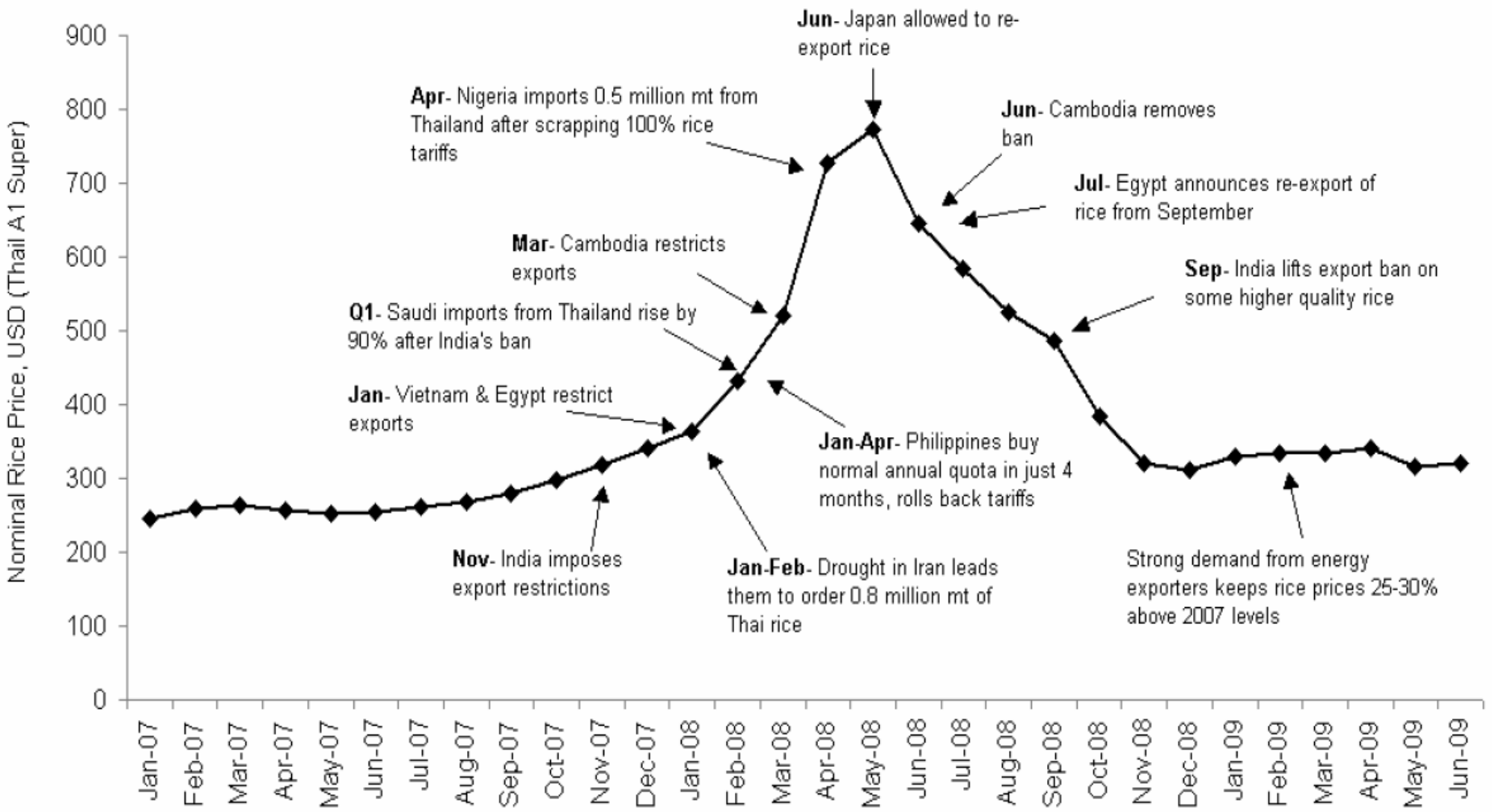


Source: Defra, based on UN indices

Note major influence of oil price (black) and largest peak: rice (red) not biofuel crop – but see next slide

Source of chart: UK Defra 2010 – based on UN

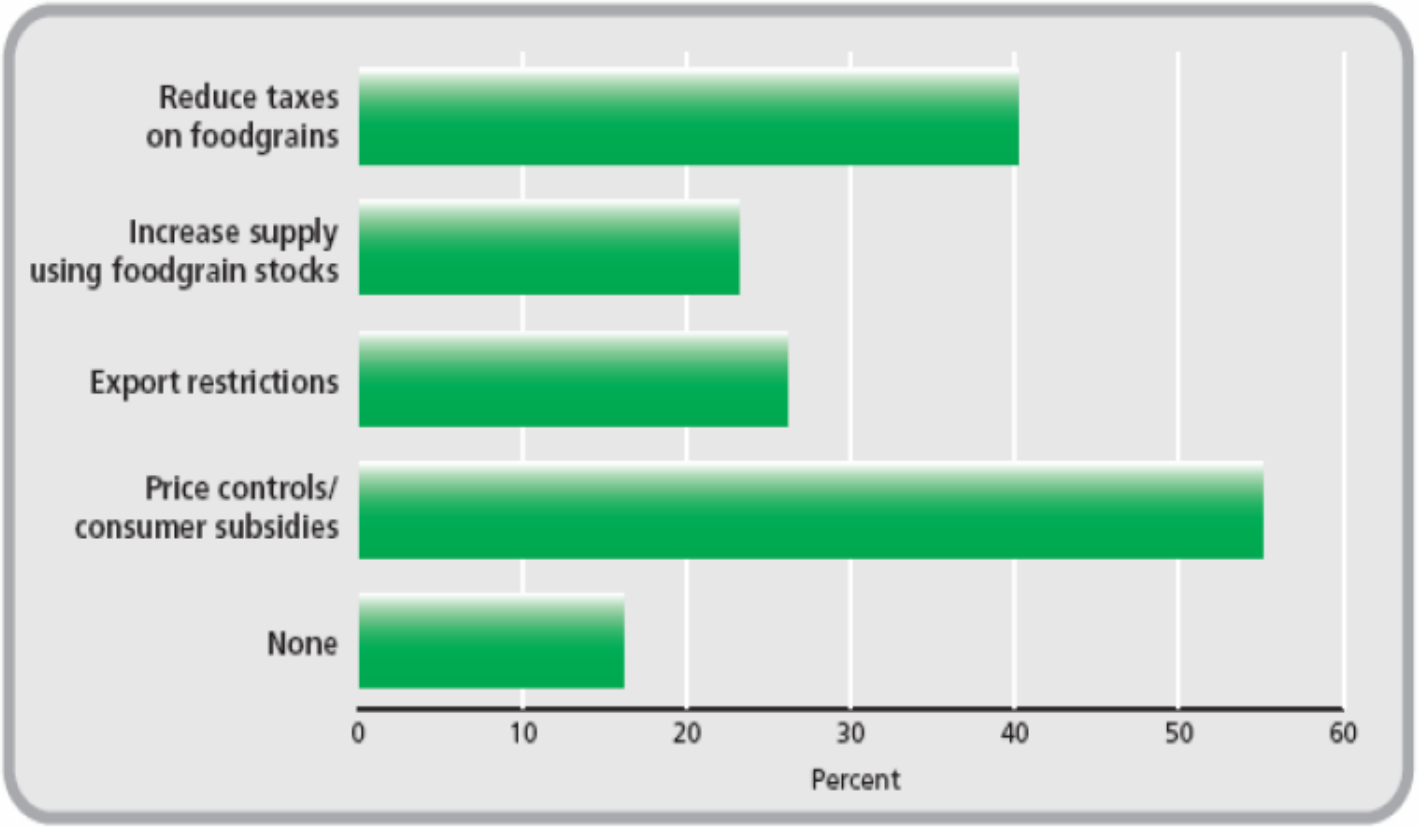
Common policies in response to food price crisis: Export restrictions drive prices even higher for rice, basic food staple in poor nations



Source of chart: UK Defra 2010, based on IFPRI 2009.

Common Policy Actions in Response to Food Price Spikes

Figure 7: Policy actions to address high food prices (sample of 77 countries by type of action)



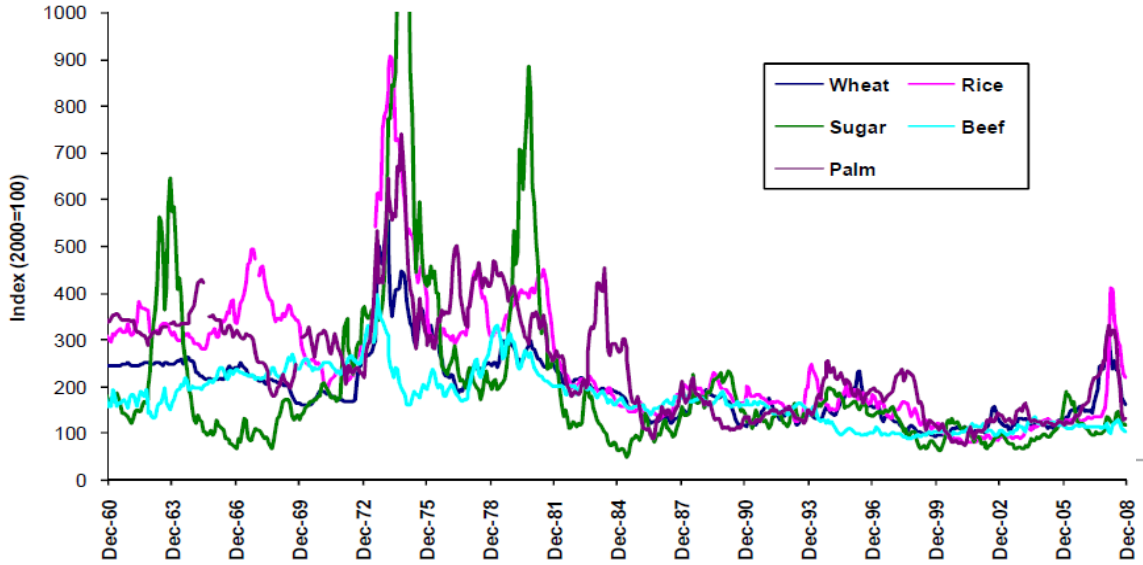
Source: FAO (2009)

These policies exacerbate food insecurity; they address symptoms, not causes.

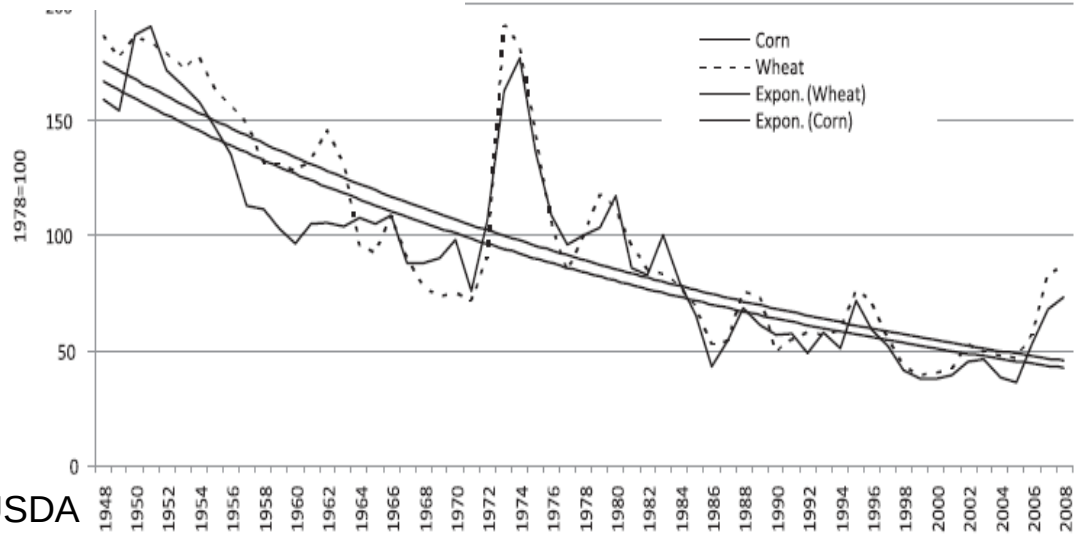
Source of chart: UK Defra 2010 – based on FAO 2009

Real Price Indices: long-term trend reflects periods of volatility but declining price over time

Figure 2: Real price indices January 1960 – December 2008



Source of chart: UK Defra 2010



Source: USDA

Sugar, Maize and Ethanol Markets in Brazil and USA

- "Futures markets" and speculation play important roles in price volatility, influenced by oil price volatility, economic growth swings, weather extremes, and unexpected policy changes.
- Current ethanol and feedstock markets are interconnected in ways that appear to dampen maize, sugar, and ethanol price volatility (note Brazil←ethanol→USA trade).
- The rate of growth in sugar and corn feed production (including exports) was not reduced by growth in ethanol production.
- Assuring demand for ethanol can support a "price floor" for producers (the "shock absorber" effect goes both ways)
- A policy opportunity often applied in Brazil is to adjust ethanol blend rate in gasoline.
- Policies that create incentives to maintain high levels of production and flexibility (multiple markets; ability to substitute), help dampen price volatility in linked markets.

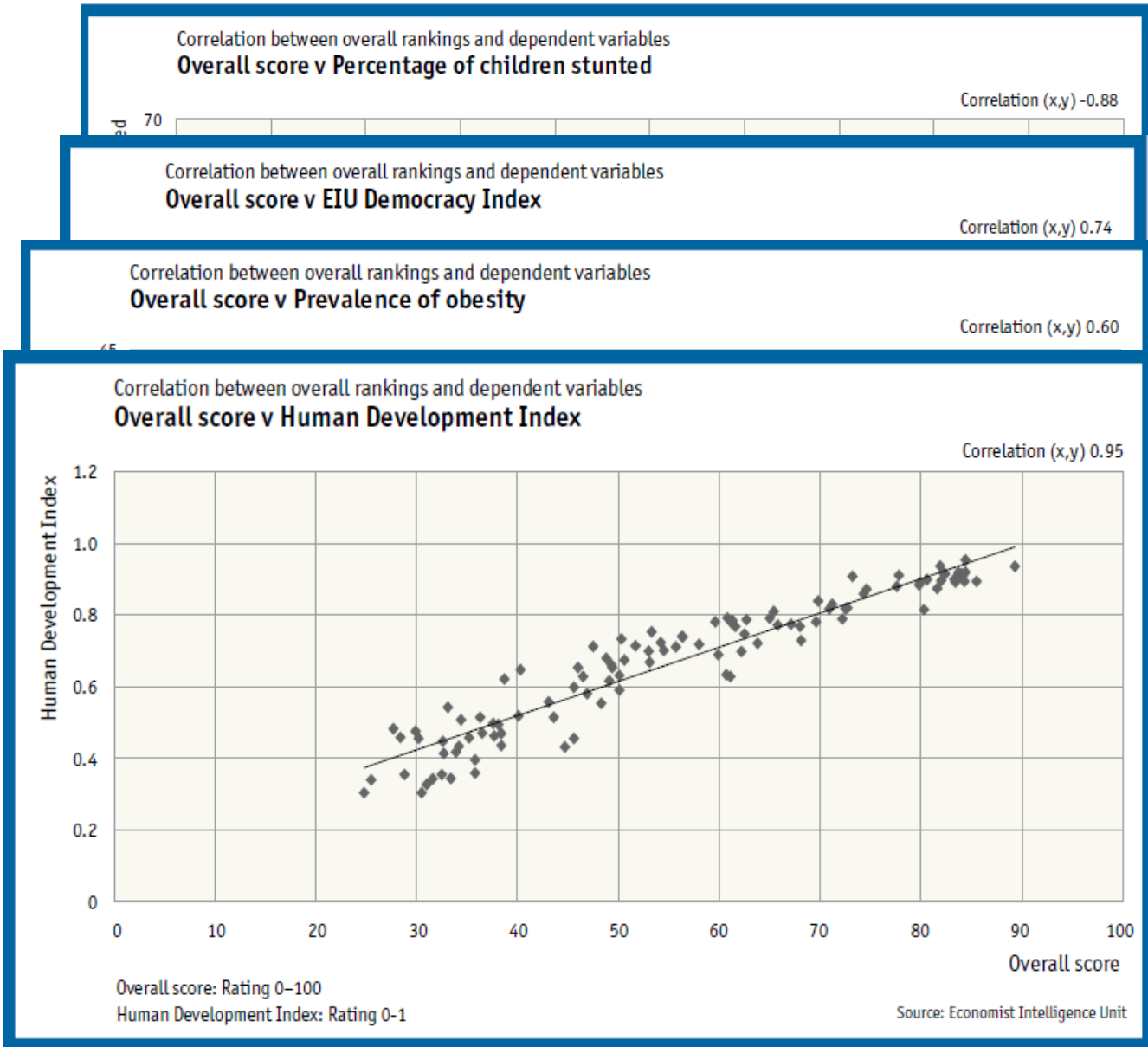
Source: Authors' analysis

Index of 4 Dimensions of Food Security

(The Economist Intelligence Unit, 2014)

- Analysis and ranking of 109 nations
- Increasing food security correlates well with democracy
- and less with obesity; more complex
- Food security correlates strongest with HDI

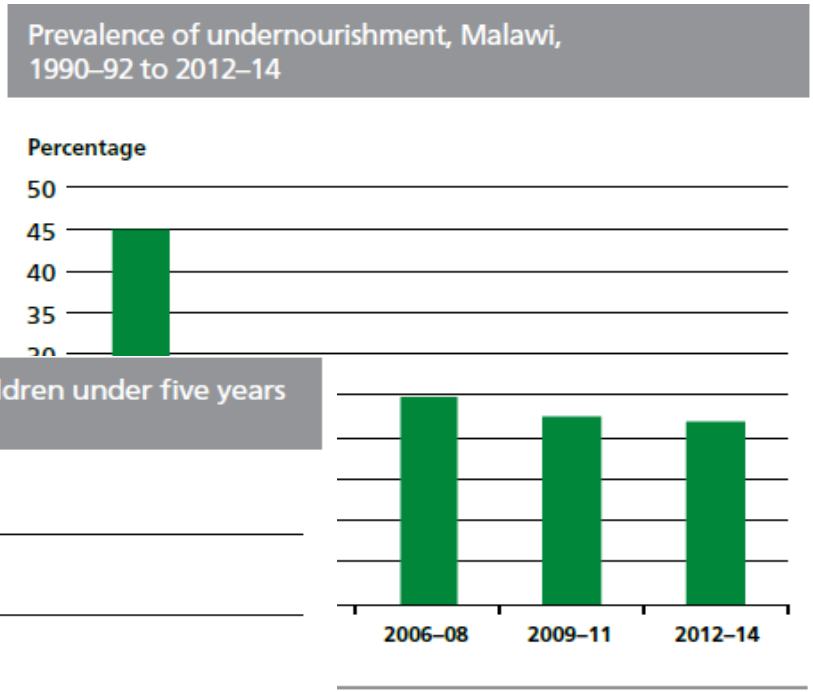
Source: The Economist Intelligence Unit Food Security Index 2014

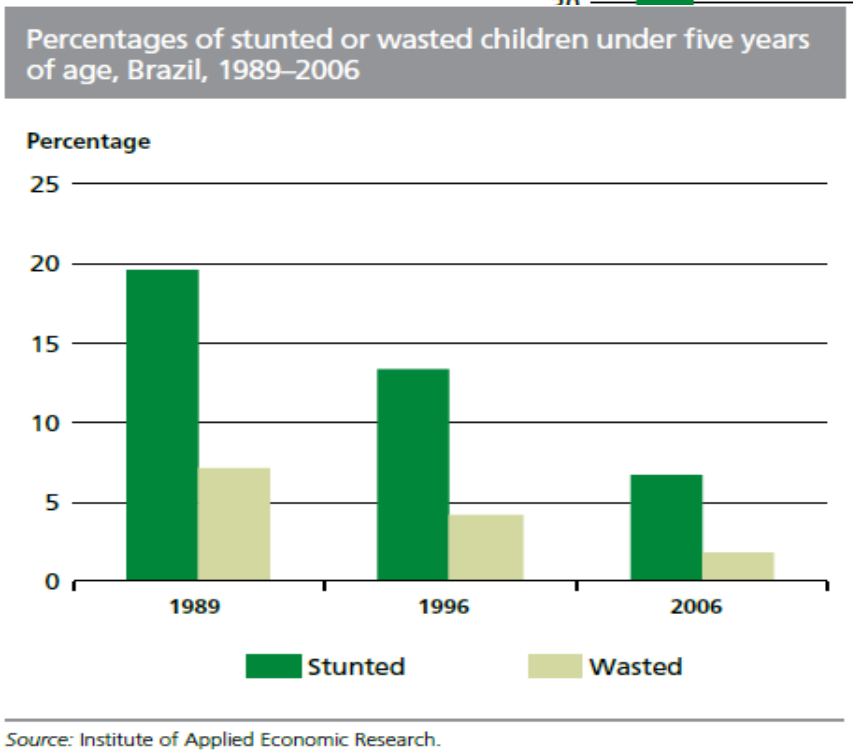


Food security has improved in some nations, surpassing MDG goals to cut malnutrition by 50%

- Malawi, an extremely poor land-locked African nation and
- Brazil

Both met the MDG goal for cutting hunger by at least 50% - ***while producing biofuels***





Source: FAO State of Food Insecurity in the World 2014

Wrapping up – Food Security, Biofuels and the Sustainable Development – what is needed to address food security concerns?

- Food security: Four main dimensions: ***Availability, Access, Utilization, Stability***
  - Causes of hunger include poverty and lack of social safety net (weak governance)
- Principles for sustainable development
  - Include stakeholders in process – define priorities
  - Sustainable employment
    - Reliable, sufficient household income provides food security
    - Improved rural livelihoods
  - Rural economies with more resilient production systems
    - Threats include climate change, extreme weather
    - Solutions include adaptive land management, land-use efficiency
    - Incentives to increase land-use efficiency and productivity
    - Systems that can minimize negative effects of extreme weather and disturbance
    - Fire and pests affect over 500 million Ha of biomass per year

Wrapping up: Food Security, Biofuels and the Sustainable Development needed to address food security concerns

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Biofuel policies, developed with care, can interact with these conditions and processes to improve food security.

Concluding remarks, food and biofuels (1)

- Research on potential effects often begins with assumption that land is the limiting factor. This assumption is misleading policy makers.
- Oil price spikes, commodity market speculation, US$ devaluation, export restrictions, social conflict, and weather, all had greater impact on food security for poor than biofuels (e.g. WB 2010, CBO 2009, Defra 2010).
  - Institutional/governance capacity is essential to improve food security
  - Needed: Incentives for investment in improved land management for agriculture and other services including waste reduction

Source: Kline presentation to "Pathways to Climate Solutions: Assessing Energy Technology and Policy Innovation" Workshop organized by the Aspen Global Change Institute; 24-28 February, 2014. Aspen CO.

Concluding remarks, food and biofuels (2)

- Food –vs- Biofuels has become emotionally charged, political issue
  - Media and popular discourse are predominantly negative, assuming:
    - Food is being used for biofuels
    - Biofuels contribute to global hunger and food insecurity
  - Lots of modeling of concerns , e.g. *"What might go wrong if…?"*
  - Little modeling of opportunities, e.g., *"What could be improved if…?"*
  - Very little analysis of decade of recent experience, e.g., *"What actually occurred?"*
- Negative opinions undermine public and political support and have direct effects on policies and investment
  - Example: EU RED revised to cap biofuels produced from conventional (food) feedstocks
  - Pressures to reduce or eliminate the USA ethanol requirements
- With more data, recent studies find diminishing role for biofuels in the 2007-2008 commodity price increase and, more important, the potential to mitigate food price volatility (e.g., lack of global food security crisis despite historically severe drought in USA 2012).

Source: Authors' analysis

Concluding remarks, food and biofuels (3)

- Research and analysis (FAO SOFI reports) indicate that food price crises are largely caused by sudden events affecting local access to food by poor in places where historic prices/incentives undermined local production.
- Food price crises are not caused by a lack of total food supply or lack of productive land at global scales.
- Commodity price changes for maize (US) and sugar (Brazil) represent tiny fractions of total food basket price, especially in less developed nations susceptible to food price crises.
- The potential for food crops for bioenergy to act as a buffer stock when unforeseen crises arise merits more study. This appears to occur in Brazil sugar and US corn where ethanol production is a partner rather than competitor for feedstock.
- Fossil fuel price is a major driver of global economy and food prices.
- There is no consensus about relative importance or direction of effects of US and Brazil biofuel policies on global food price indices.
- Biofuels 'done right' (Kline et al. 2009) can be a driver for agricultural sector investments that improve food security: technology, energy services, jobs, ports, railroads, communications, and more.

Source: Authors' analysis

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The views in this presentation are those of the author(s) who are responsible for any errors or omissions.

Thank you!

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Bibliography and references

- Arezki et al. 2014. Understanding international commodity price fluctuations. Journal of International Money and Finance 42 (2014) 1–8
- Babcock, B. A. (2011 June). The impact of US biofuel policies on agricultural price levels and volatility. . International Centre for Trade and Sustainable Development (35)
- Charles, C. (2012 April). Should we be concerned about competition between food and fuel? International Institute for Sustainable Development.
- Defra 2010 The 2007/08 Agricultural Price Spikes: Causes and Policy Implications. HM Government, United Kingdom.
- de Gorter, H., & Just, D. R. (2010). The social costs and benefits of biofuels: The intersection of environmental, energy and agricultural policy. Applied Economic Perspectives and Policy.
- Economic Research Service, Amber Waves, 10(2 (June)), 2012.
- Durham, C., Davies, G., & Bhattacharyya, T. (2012, June). Can biofuels policy work for food security? Department for Environment Food and Rural Affairs.
- FAO, IFAD, IMF, OECD, UNCTAD, WFP, the World Bank, the WTO, IFPRI, and the UN HLTF. (2011, June 2). Price volatility in food and agricultural markets: Policy responses. Policy Report for the G-20 .
- Fischer, G., van Velthuizen, H. & Nachtergaele, F. 2011. GAEZ v3.0 – Global Agro-ecological Zones Model documentation, (mimeo). IIASA, Luxemburg.
- King R (Oxfam), Kelbert A (IDS), Chisholm N (University College Cork), Hossain N (IDS). 2014. Help Yourself - Food Rights and Responsibilities: Year 2 findings from Life in a Time of Food Price Volatility. Joint Agency Research Report. www.ids.ac.uk and www.oxfam.org
- Langeveld, H., Dixon, J., and van Keulen, H. 2014. Biofuel cropping systems: carbon, land and food. Routledge Earthscan, Abingdon, UK. ISBN13: 978-0-415-53953-1
- Locke, A., Wiggins, S., Henley, G., & Keats, S. (2013 April). Diverting grain from animal feed and biofuels. London : Overseas Development Institute.
- McPhail, Lihong Lu, & Du, X. (2012). Ethanol Strengthens the Link Between Agriculture and Energy Markets.
- Peterka, A. (2012 31-July). Livestock groups urge EPA to waive ethanol mandate. Governors' Biofuels Coalition.
- Schafer, E. (2012 8-March). Proposed RFS changes spark food vs. fuel debate. Feed & Grain.
- Strassburg BBN, Latwiec AE, et al., 2014. When enough should be enough. Improving the use of current agricultural lands could spare natural habitats in Brazil. Glob.Env.Change 28 84-97.
- Tyner, W. E., Taheripour, F., & Hurt, C. (2012 16-August). Potential impacts of a partial waiver of the ethanol blending rules. Farm Foundation and Purdue University.
- Wright, B. (2011, February). Biofuels and food security: Time to consider safety valves? . IPC Policy Focus, International Food and Agricultural Trade Policy Council.

For more in formation:

- Alexandratos, N. and J. Bruinsma. 2012. *World agriculture towards 2030/2050: the 2012 revision.* ESA Working paper No. 12-03. Rome, FAO
- CBES. 2009. *Land-use change and bioenergy*. Report from the 2009 workshop, ORNL/CBES-001, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy and Oak Ridge National Laboratory. http://www.ornl.gov/sci/besd/cbes.shtml .
- Dale VH, KL Kline, LL Wright, RD Perlack, M Downing, RL Graham. 2011. Interactions among bioenergy feedstock choices, landscape dynamics and land use. *Ecological Applications* 21(4):1039-1054.
- Dale, VH, RA Efroymson, KL Kline, MH Langholtz, PN Leiby, GA Oladosu, MR Davis, ME Downing, MR Hilliard. 2013. Indicators for assessing socioeconomic sustainability of bioenergy systems: A short list of practical measures. Ecological Indicators 26: 87-102.
- Dornburg et al. 2010. Bioenergy revisited: Key factors in global potentials of bioenergy. Energy Environ. Sci., 2010,3, 258-267..
- Efroymson, R. A., V. H. Dale, K. L. Kline, A. C. McBride, J. M. Bielicki, R. L. Smith, E. S. Parish, P. E. Schweizer, D. M. Shaw. 2012. Environmental indicators of biofuel sustainability: What about context? Environmental Management DOI 10.1007/s00267-012-9907-5
- FAO and IIASA. 2007. Mapping biophysical factors that influence agricultural production and rural vulnerability. Food and Agriculture Organization and International Institute for Applied Systems Analysis, Rome, Italy.
- Giglio L., J. T. Randerson, G. R. van derWerf, P. S. Kasibhatla, G. J. Collatz, D. C. Morton, and R. S. DeFries. Assessing variability and long-term trends in burned area by merging multiple satellite fire products. Biogeosciences, 7, 1171–1186, 2010.
- IPCC 2012 Special Report on Renewables and Climate Change Mitigation.
- Kline KL, Dale VH, Lee R, Leiby P. 2009. In Defense of Biofuels, Done Right. Issues in Science and Technology 25(3): 75-84. http://www.issues.org/25.3/kline.html
- Langholtz M, Eaton L and Turhollow A. (in press). 2013 Feedstock Supply and Price Projections and Sensitivity Analysis. (BioFPR 2014).
- McBride A, VH Dale, L Baskaran, M Downing, L Eaton, RA Efroymson, C Garten, KL Kline, H Jager, P Mulholland, E Parish, P Schweizer, and J Storey. 2011. Indicators to support environmental sustainability of bioenergy systems. *Ecological Indicators* 11(5) 1277-1289.
- Oladosu D, KL Kline, P Leiby, R Martinez, M Davis, M Downing, L Eaton. 2012. Global economic effects of the US biofuel policy and the potential contribution from advanced biofuels. Biofuels 3(6):703-723. http://www.future-science.com/doi/pdfplus/10.4155/bfs.12.6
- Parish ES, M Hilliard, LM Baskaran, VH Dale, NA Griffiths, PJ Mulholland, A Sorokine, NA Thomas, ME Downing, R Middleton. 2012. Multimetric spatial optimization of switchgrass plantings across a watershed. *Biofuels, Bioprod. Bioref*. 6(1):58-72.
- USDOE 2011. U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. ORNL. http://www1.eere.energy.gov/bioenergy/pdfs/billion_ton_update.pdf
- USDoe State of Technology updates: http://www1.eere.energy.gov/bioenergy/key_publications.html

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