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A Safe Space For Humanity: The Nexus of Food, Water, Energy, and Climate*

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Key Points

- The world, and Asia, is currently passing through a difficult period of concern about the future sustainability of food supplies. The causes of this concern are based on many premises: the population is still growing fast; with increasing wealth, the diet is shifting to consumption of higher value products; the yield in major grains is leveling off; available land suitable for food production is limited; water for irrigation is lacking; and climate change is leading to increased temperatures with more variable rainfall.
- Reducing the inefficiencies in the food chain cannot be considered independent of energy policy and agricultural commodity trade policies. Caring for all of the intersectoral policies in the face of a very uncertain climate future is extremely difficult to articulate.
- The preliminary findings of case studies indicate the potential for vertical integration and modernization of food value chains to achieve food and nutrition security through drastically reducing their price structures and generating rural employment, while helping ease the competition over natural resources in the food-water-energy nexus. Aggregation of small farms, backed by equitable institutional arrangements, and mechanization and modernization of agriculture not only maximize efficiency in the use of land, water, and energy but also enable many smallholder farmers to access and benefit from emerging business opportunities in urban markets.

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Abstract

The 20th Century saw major human triggered transitions that cumulatively are threatening the safety of the habitat for humans on planet earth. Population, resources, and the rapid accumulation of wealth all are intertwined in the 5 major transitions from the past to our new global future. These major transitions are: first, the "urban population transition;" second, the" nutrition transition;" third, the "climate transition;" fourth, the "energy transition;"and, fifth, the "agricultural transition."

This policy brief focuses on the most salient problems arising from these global transitions that can be ameliorated by specific policy instruments in the short term. Some problems, like climate change, are very important but are not ready to be dealt with by short-term measures; others, like price reform, can and should be dealt with immediately but are inherently politically too difficult to resolve in the short run. Nevertheless, this pragmatic approach still leaves a range of policy changes that could be implemented in the short run. These range from policies encouraging "making agriculture a business not a means of subsistence," promoting "farmers and marketing cooperatives leading to more equitable and efficient food chains," encouraging "land aggregation to take advantage of new technologies," or promoting "commercialization of farming by encouraging Agribiz Parks," in addition to the usual policies of encouraging improving technical efficiencies for agriculture and food production.

Five Global Transitions

The world is undergoing major physical, social, and economic transitions from earlier periods when populations roughly matched then available resources and is now moving toward new global conditions which require new thinking about the nexus of food, water, energy, and climate. The transitions are happening so fast that the training and mindset of most senior planners and managers have long since been overtaken by these equilibrium shifts; and well-tried solutions to food, water, and energy management of the past are no longer viable. Moreover, since these transitions involve long-term commitments of land, water, and mineral resources, they are essentially irreversible.

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The global implications of these problems are explored and clearly articulated by the reports of the Commission on Sustainable Agriculture and Climate Change (Beddington et al. 2012) and the World Resources Institute's recent "Creating a Sustainable Food Future: A menu of solutions to sustainably feed more than 9 billion people by 2050" (Searchinger et al. 2013).

There are five major global transitions that make historically-based thinking obsolete. The first is the "urban population transition": the majority of the global population now residing in cities and having increased purchasing power; the second is the "nutrition transition": demands for a new basket of foodstuffs with greatly increased consumption of animal products and other high-value foods; the third is the "climate transition": increasing temperatures and increasing variability in water supplies and growing conditions for plants; the fourth is the "energy transition" from cheap fossil fuels to renewable energy resources; and the fifth is the "agricultural transition" from small-scale subsistence farming to large-scale commercial operations. All of these challenges are exacerbated by a growing world population and the deterioration of the quality of water and land. Coping with any one of these alone would be a major problem, but the transitions are actually happening simultaneously with differing rates of change in different countries and regions. New political leaders and resource managers need to be cognizant of what is going on globally and which flexible approaches will enable us to sustain our livelihoods during the transitions.

The Nexus of Food, Water, Energy, and Climate

Because of the nonlinear synergistic interactions among water, energy, climate, and other inputs into food production, it can be quite misleading if we treat them as separate inputs to the production process. Since almost all of the cultivable land is currently in use (Ausubel, Wernick, and Waggoner 2013), producing more food requires intensification in yields and/or crop patterns. This will require intensified use of chemical fertilizers, which would need huge additional energy inputs, or extensive multiple cropping, which would mean large additional quantities of irrigation water and energy. However, we are increasingly approaching limits to water available for conventional agriculture (Comprehensive Assessment of Water Management in Agriculture 2007). Furthermore, since 1962, the use of chemical fossil fuel-based fertilizers began to surpass the amount of globally available natural organic fertilizers. Today, they exceed organic fertilizer over 100% (Conway 2012). The production of chemical fertilizers, however, requires large amounts of fossil fuels, which exacerbate greenhouse gas production. Current estimates for the footprint of agriculture, including its fertilizer production and use, lies between 17% and 32% of total greenhouse gases (Bellarby et al. 2008). Additionally, the development of bioenergy from crops such as corn (about 20% of the corn crop in the United States is now diverted to biofuel production) also creates a conflict between food and energy supplies.

The United States Department of Agriculture (2013) estimated the current food-insecure (the number of people consuming less than a nutritional target of 2,100 calories per day) to number 707 million, and by 2023 to increase by 23%—faster than population growth of 16%—to 868 million.

Despite globally declining human fertility, by 2050, an additional 2 billion people will need to be fed; moreover, one half of the total 9 billion population (United Nations 2012) is expected to be urban, and wealthier, with demands for foods that require much more water and other inputs than the traditional grains, as well as demands for more grains to feed the bourgeoning livestock. An almost doubling (70%) of the global food production will be required to meet these additional needs.

One way of ameliorating water and energy scarcity is by increasing the efficiencies of land, water, and energy use in agriculture. The time-honored way of doing this is through the introduction of improved agricultural practices which include management, seeds, fertilizers, pesticides, and irrigation technologies. All of the agricultural practices need to be improved simultaneously for agriculture to really make major jumps in production. In order to achieve the doubling of output by 2050, however, the scale of all interventions must be greatly increased. Without increasing scale, access to markets and crop diversification into higher value crops, efficiency gains (sustainability), and food security gains would not be maximized. For instance, food chain and marketing improvements have to be expanded to make access for all easier. For mechanization of irrigation, the technologies, such as drip or pivot, may dictate much larger scales of operation than can be achieved by small farmers acting alone.

Food Consumption

Resource managers must cope with the resource constraints and global transitions in a way that is cost-effective and sustainable. Unfortunately, these global transitions are going to be experienced more harshly in some parts of the globe than in others. For example, Asia will be faced with a monumental increase in urban populations—more than double by 2050. When coupled with the large increases in demand for higher quality foods, this could lead to a more than doubling in the demanded levels of agricultural inputs of water, land, energy, and agricultural chemicals (Box 1).

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Population size by itself is not the whole problem. The current total world food production is capable of providing everyone with an adequate low quality diet. The real problems are the distribution of food and meeting the growing demands for higher quality diets. Moreover, in many countries, as much as 50% of the food production is lost in the post-harvest system from "farm to fork" (Lundqvist, Fraiture, and Molden 2008). Reducing these food losses and supply fluctuations are major problems requiring modern management of food chains relying on more efficient agricultural inputs, storage, transport, and marketing.

Sustainable Agriculture in Asia

The Nexus in Asia

The world, and Asia, is currently passing through a difficult period of concern about the future sustainability of food supplies. The causes of this concern are based

Box 1 On Megacities

Because of urbanization, the amounts of water required for food production could double due to the change in diets of the urban population and the newly urbanized groups caused by the urbanites' shift to less starchy foods toward more varied diets with more animal and dairy products, fats, and oils. The demand for these higher quality foods requires producing grains for animal feed and processing, storing, and refrigerating the foods. The processing and storage activities themselves require electricity, which has its own large water footprint. Rogers (2012) estimated that for each of the 10 projected megacities in Asia, the total water footprint by 2050 could be an order of magnitude greater than the water demands for conventional municipal water supply. Without careful planning, the megacities' shift in food preferences could lead to excessive demands being placed on the water and energy resources of a region.

Source: Rogers (2012).

on many premises: the population is still growing fast; with increasing wealth, the diet is shifting to consumption of higher value products; the yield in major grains is leveling off (Ray et al. 2013); available land suitable for food production is limited; water for irrigation is lacking; and climate change is leading to increased temperatures with more variable rainfall. These need to be explored and addressed as we move forward. The issues of greatest concern in South and Southeast Asia are the connections among the scarcity of land, water, and energy for producing food. Although demand for basic grains shifts early in the dietary income-elasticity transition, most of the rest of the transition appears to take place in oils, sugar, vegetables, fruits, etc. There will still be large demands for basic grains (Timmer 2011), but these "other" categories are vital to the overall development process since they potentially reinject huge employment and income into the rural areas, whereas the cereals create "food" but not much employment or income per hectare. What is needed is a look at the entire value chain in food production in agriculture from farm to consumers' tables. Such a systematic look will entail a broad view of climate, soils, and production technology, all the way to the global markets.

Production Technology and Scale

In Asia, most of the food production occurs on small farms. Unfortunately, irrigation for small plots is expensive and inherently inefficient in the use of

Box 2 Evaluation of Crop and Technology Choice Using the Nexus

Generating substantial business opportunities and employment in rural areas is critical in addressing persisting food insecurity. In the context of intensifying competitions over natural resources reflecting the food-water-energy nexus, food security related investments need to be designed in a manner that minimizes their resource requirements. In order to consider an approach to incorporate such requirements of both food security and the nexus concerns into the project appraisal process, a hypothetical project analysis was prepared and compared with a similar project that is being implemented.

The Asian Development Bank (ADB) loan for the Ningxia Irrigated Agriculture and Water Conservation Demonstration Project of $70 million aims to improve wine and date production in Ningxia Province in the People's Republic of China. The project expands the wine grape growing area at the expense of the currently grown grain crops and allows for inter-planting dates and grain by extending irrigation coverage. The project consists of 2,930 hectares of new and rehabilitated vineyard in Ningxia, and water savings of 3 million cubic meters from the current water use of 18.6 million cubic meters. ADB estimated the economic internal rate of return (EIRR) to be 19%.

We compare the project with a hypothetical project, where instead of growing wine grapes we substitute with table grapes, which have a much larger labor requirement over their food and value chain than do wine grapes. All other aspects of the ADB project remain the same except that the labor, energy, and transport for the winery part of the project are replaced with the corresponding numbers for the table grape food and value chain and incorporated into the cost of the hypothetical project. There will also be incremental costs associated with the storage, refrigerated transport, and marketing associated with the table grape project.

Comparing the wine project with the hypothetical table grape project in Ningxia based on data from various sources, we can highlight the significance of considering the factors other than EIRR, which are directly relevant to food security and food-water-energy nexus concerns:

- **Economic analysis:** The EIRR for both projects is similar indicating that either could be chosen.
- **Food security:** We assumed that the amount of food grains taken out of production to meet the production needs for grapes was identical for each project (75.9 million yuan per year or approximately 72,000 tons of corn).
- **Employment generation:** In the rural areas, the table grape project could provide up to an additional 250,000 person-days of employment per year (equivalent to 686 year-round jobs).
- **Water use:** We assumed that the new irrigation would be the same (drip) for each project; the water saved from irrigated corn would apply to each equally.
- **Energy use:** We calculated for the wine grapes an additional use of energy for reefer trucks that would amount to 1,033,400 liters of diesel fuel, which implies an additional 390 tons of carbon dioxide emissions per year.

water, energy, and land. What has happened in the developed countries of the world is that irrigation is now being provided through large plots of land irrigated by machinery that economizes on energy, land, and water. So far in Asia, these modern techniques have not become widespread, although the People's Republic of China (PRC) is now in the process of purchasing many such mechanized systems. The research questions for Asia deal with the effectiveness of the mechanized techniques on Asian crops and soils, and on the fragmented landholding patterns. If a center pivot covers 160 acres, how is it possible to irrigate land of many farmers each holding about 5 acres? What social and financial arrangements would have to be negotiated to realize the efficiency gains usually associated with such systems? More importantly, what is the potential for integrating high-value crops into the mechanized systems? Other questions arise from the issues of inclusive growth and household food insecurity. The important issue of rural employment is discussed next, but it is important to highlight that among the technology and model options to modernize and commercialize agriculture, we would select the ones that have a rural employment focus and that will maximize rural employment generation (Box 2).

Employment

A major problem facing developing countries today is the need to create employment, in particular rural employment to stem the tide of migration to cities. This can be done in part by modernizing agriculture and integrating high-value horticultural crops and by intensifying multi-season cropping in rural areas in response to new non-grain food demands (Collier 2013). For example, the number of days of labor needed for grain production in traditional agriculture in Asia is about 20 days per acre; these are in stark contrast with labor inputs of 4–5 hours per acre in modern mechanized grain farming in the United States. However, changing from grain to modern horticulture crops could generate more than 100–300 days of labor per acre in many developing countries. Thus, horticulture needs to be increased in the modern food production and value chains to provide rural employment and promote incentives for introducing modern methods in rural areas. In this way, contrary to popular belief, intensifying agriculture by increasing mechanization can increase rural farm and nonfarm employment. Essentially, this implies a reallocation of human resources from low-value, low labor requirements of traditional cropping patterns to high labor-intensive crops.

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Dealing with an Uncertain Future

Water supplies and food production are becoming increasingly uncertain due to climate change and changes in demographic patterns and economic growth. In the past, the assessment of climate variations and fluctuations of floods as well as droughts was largely predictable by steady state statistical models. However, due to the interaction of the four global transitions, the current approaches to risk assessment have become increasingly unreliable and we have to look elsewhere to find ways to deal with these uncertainties. The failure of predictive models of the future water demands and supplies leads to a return to earlier approaches to decision making under conditions of uncertainty, and to looking for simpler, more intuitively convincing models. This is when concepts such as "safety" and "surprise" need to be invoked (Shackle 1949). These essentially are based on the "negligible possibility of ruin"—a path into the future that will maximize the expected gain while minimizing the possibility of ruin to that point that it can be neglected (Boussard and Petit 1967). We do not want any nasty "surprises." We need a conservative and risk-adverse strategy to identify the boundaries of a "safe space" for humanity.

Climate change is one of the great unknowns in planning for future food supplies. Given the unreliability of general circulation models and their conflicting scenarios, it is preferable to rely upon short-term forecasts that allow for midcourse corrections as we move forward in time.

One such physically based approach suggested in the Brunei Darussalam–Indonesia–Malaysia–The Philippines East ASEAN Growth Area (BIMP–EAGA) corridor study (SRD 2014) is to utilize the basic science of the known temperature lapse rate with altitude and use a geographic information system to map all regions that have the right soils and sufficient area for cultivation and use these maps as a guide to adapt to climate change as it happens. Climatologists can project updated information on temperature and precipitation based upon the recent past. Adding these new estimates on the physically based maps, one can locate areas with better conditions for shifting cropping patterns, should they be necessary. Using this approach to look ahead 5–10 years could help avoid "nasty surprises."

Many of the publications on the future of global resource use are based upon consideration of the global transitions singly and separately, hence missing the interactions which either ameliorate or exacerbate the outcomes. The Club of Rome publications and Brown (2011; 2013) all have resource availability peaking out. Starting with King Hubbert's peak oil (1956) through Palaniappan and Gleick's (2011) peak water, and finally Ausubel, Wernick, and Waggoner's peak land (2013), no doubt there will soon be peak forests, peak fisheries, etc. until we have peak everything. To give Ausubel, Wernick, and Waggoner credit, however, they do indicate that agricultural land use had already peaked as the yields have increased and less land is needed to achieve the same food production. This is similar to the concept of virtual water: they call it "spared land." "Peakedness" is typically a pessimistic view of the actual size of the resource base. We refer to it as the "tyranny of the bell shaped curve." Using the normal distribution, or some close relative of it, commits us to have a particular expectation of the system behavior. Fitting a resource use rate to the rising limb of the curve guarantees that, sooner or later, a peak will be reached. We do not deny the existence of peaks—think of horse-drawn carriages in the 19th century—but there is great uncertainty about the shape of the curve and where exactly we are on it, and the possibility of substitutes in either production or consumption of the resource.

Achieving the Goals

Recent research (Collier 2013) indicates that the best way to achieve these goals is by integration of high-value products into efficient food-producing systems. In most cases, these would be based on large-scale commercial farming in the context of the value and marketing chains and integration with the global food system. This is particularly relevant given the widespread charges of "land grabbing" by multinational corporations in developing countries of Africa, Asia, and Latin America. The global nongovernment organization community is unanimous in calling for boycotting attempts by corporations or national entities to introduce large-scale mechanized agriculture because of the perceived effects of massive disruption of local farming systems and subsequent unemployment of many in the farm communities displaced by labor-saving mechanization. These are all acknowledged problems and the conundrum is how to make the shift to modern agriculture while avoiding the worst excesses. This does not have to be an irrevocable outcome of the shift to large-scale farming as indicated above, if new crops are introduced that are aimed at domestic and international markets for high-value crops. Aggregation of small farms (backed by equitable institutional arrangements) and mechanization and modernization of agriculture not only maximize efficiency in the use of land, water, and energy but also enable many smallholder farmers to access and benefit from emerging business opportunities in urban markets. Exploiting such opportunities is crucial for many poor farmers to improve their state of food security. Strong employment generation arising from the crop diversification into higher value crops would leave ample scope for rural economies, where the rural poor would not be left out from the transition. Policy and adoption of the "right" technology could build the basis and support such an inclusive growth pathway.

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Box 3 Corridor Studies

Case Study of the Brunei Darussalam–Indonesia–Malaysia–The Philippines East ASEAN Growth Area Corridor

Concern over availability of food and its conflict with water and energy resources is leading to new problems for regional planners. Autarchy in food production has been abandoned to take advantage of international trade in agricultural commodities. Most of the international aid and bilateral aid agencies have tended to focus on expanding agricultural production via infrastructure investments and less on food logistics management. This has been traditionally left to the governments and local entrepreneurs, and more recently to the global private sector. The ongoing study by Rogers, Azar, and Daines (2014) explores the feasibility of modeling food logistics within the framework of international and intra-national corridors, while taking into account the regional comparative advantage of spatial and temporal variation of water and energy resources.

The corridor focuses on part of the Brunei Darussalam–Indonesia–Malaysia–The Philippines East ASEAN Growth Area (BIMP–EAGA). This is an Association of Southeast Asian Nations (ASEAN) collaboration, created in 1994, among the four countries to increase trade, tourism, and investments within the region. BIMP–EAGA has a combined population of 57.5 million and a land area of 1.6 million square kilometers. BIMP–EAGA plans to develop a regional nautical highway via the expansion of roll-on roll-off (RoRo) ferry networks at priority ports, including the development of RoRo shipping and port services in selected BIMP–EAGA ports.

The study concludes that viable opportunities exist for reducing the cost of food production and distribution by 80% by combining the latest energy- and water-saving technologies in a verticality integrated food value chain in an autarchy infrastructure throughout the four stages of the chain from "farm to fork."

At the production stage, harnessing efficiency gains from large-scale production in most climate-efficient and climate change-resilient zones with optimal soils, low-cost and water-saving irrigation, and geographically concentrated production in build–operate–transfer lease, train–transfer cooperative agro-parks on unutilized reclamation areas allows up to 5%–25% cost reductions.

At the packing–processing stage, eliminating supermarket-type packaging , harnessing renewable energy, and using efficient large-scale processing technologies together can reduce the cost by another 5%–25%.

At the transport stage, an operating cost reduction of 90%–98% can be achieved by shifting from energy-inefficient and high-cost road transport to energy-efficient new shallow-draft waterways and light railways.

And at the marketing stage, the high wholesale and retail marketing margin can be reduced through direct sales from farmer cooperatives to consumer wholesale cooperatives, and the marketing stage spoilage can be reduced by using the same 40-foot refrigerated container packed in the field as the consumer coop shops in the street.

This food–water–energy nexus-responsive food value chain infrastructure innovation shows that it is feasible to reduce the price of the key food varieties for the urban poor, allowing them to access a middle-income diet on a lower income budget. The case presents an alternative approach to accelerate the pace in providing a more secure and better nutrition supply to the poor.

Source: SRD (2014).

In order to achieve this, we need to look beyond conventional participatory agricultural management skill transfer recipes (Box 3). Expanding capacity and knowledge are always good, but the emphasis should be to bring in, where possible, modern commercial and corporate actors who can best transfer these skills. Finally, investments in transportation and marketing have the potential to greatly facilitate the agricultural transition to modern practices and production efficiencies and at the same time reduce the costs of improved diets of the poor. We are not searching for optimal strategies which may be risky, but looking for strategies for a safe transition to a sustainable food supply. In other words, can we identify a "safe place for humanity?" Food, energy, and water are at the top of Maslow's needs hierarchy (1943). Meeting those needs does not mean that conflicts, wars, and disease will be resolved, but that humanity will be more resilient to deal with these issues in a safer space than where it is currently located.

Conclusions

The stakes involved in not adapting to the great global transitions are enormous. A misguided choice of technology or policy in the near future could set in train a whole set of circumstances that may be difficult to change later. For example, relying on small farm agriculture to provide for the future food supply of many heavily populated developing countries may lead to exhaustion of water and land resources due to inefficiencies in the production process and food chains under traditional agriculture, to increasing the already huge rural to urban migration, and to food importation strategies to sustain the feeding of large cities which would further impoverish the rural populations. Reducing the inefficiencies in the food chain cannot be considered independent of energy policy and agricultural commodity trade policies. Caring for all of the inter-sectoral policies in the face of a very uncertain climate future is extremely difficult to articulate and makes it harder yet to make future plans. Governments need to establish mechanisms for society to address the nature of uncertainties faced under current and future conditions. Obvious ones are drought and flood insurance for rural areas and a combination of land use zoning for coastal and urban regions. Others are agronomy and crop research looking toward more sustainable food production systems that will hedge against the uncertainties from natural and human-made disasters.

Pretty and 31 collaborators (Pretty et al. 2010) listed the top 100 questions of importance to the future of global agriculture under four subheadings: (i) natural resource inputs (climate, watersheds, water resources, and aquatic ecosystems); (ii) agronomic practice (crop production systems and technology); (iii) agricultural development (social capital, gender, and extension); and (iv) markets and consumption (food supply chains, prices, markets, and trade). Many of the top issues according to these global experts are significantly affected by the five great global transitions mentioned earlier. However, by dicing and slicing the question of importance, the experts have ended with a set of seemingly independent issues, all of which should be interacting and not independent of each other. For example, when the food value chain margins are examined, we noticed a great asymmetry between the values and the actual production cost on the farms. In the PRC, an estimated value chain for table grapes costing 4.2 yuan per kilogram at the farm gate would be selling for 17.4 yuan per kilogram at the urban markets (Rogers and Azar 2014). Taking an integrated view of the value chain would allow individuals and companies assess which links in the chain would do most to promote efficiency throughout the chain. It also allows estimation of the various labor requirements, energy inputs, and legal and social adjustments that would have to be

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made. Depending on how this is viewed, it could reduce the costs of higher value diets to the urban poor, or it could improve the margins of rent-seeking individuals higher up the chain.

From our perspective, the gains from the cost reduction due to efficiency gains in the food corridor should be passed on to consumers so that poor consumers can access diversified food baskets. It is not clear that this can be done by an unregulated competitive market. By assuring access to storage and marketing as well as improving roads from farm to market, governments can influence the outcomes in favor of inclusive growth. The redistribution of margins to smallholder farmers, however, has to ensure that marketing margins will have to be substantially decreased. This can be achieved by ingenious methods of bifurcating the urban markets between wealthy consumers who shop in the regular markets and the urban poor via marketing cooperatives located in the parts of the city where most of the urban poor live. SRD (2014) reports on one such successful similar development for table grapes in Maharastra, India.

None of these concepts are especially new and innovative, but they are hard to implement, such as the Asian Development Bank's Operational Plan for Sustainable Food Security in Asia and the Pacific (ADB 2010). This emphasized the nexus among declining land and water resources and stagnating crop yields; lack of access to markets, services, resources, and nonfarm income; and climate change impacts and price fluctuations, but has encountered difficulty in integrating these

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concerns which cross many disciplinary and institutional boundaries. The nexus awaits clearer methodological and institutional frameworks.

The Way Forward

We can summarize our findings under the following three headings:

Social Goals

The overall goal of studying the food–water–energy nexus and integrating the results into food policy should be to provide ways in which the urban and rural poor may be able to afford nutritious diets usually associated with urban middle classes. The importance of grains in the food supply of the poor should not be ignored, however, because of their dominant role in current diets, and will remain so for a considerable time. For example, in the PRC, 45% of calories in the diet for middle-class families come from non-grain sources; for poor families, it is less than 25%, with 75% coming from starchy staples (FAO 2009). Another example of the relative role food plays in household expenditures: the United States consumes almost twice as much food (in terms of kilocalories) per capita as India but spends only 6.2% of its household expenditure on food compared with 35.4% for India (USDA 2012). Nevertheless, the technology is now available to use the same resource base to provide needed amounts of food grains as well as low-cost, high-quality non-starchy foods such as dairy products, fruits and nuts, and animal fats and oils to the urban and rural poor (SRD 2014).

Economic Goals

The overarching economic goal is to stress the importance of generating rural employment, and effecting a redistribution of income by developing producers and marketing cooperatives to garner a larger portion of the margins between "farm and fork." The greatest efficiency improvements in meeting adequate food supply may not lie in the production part of the food chain. Creative bifurcation of the market into middle class and poor could be achieved by organizing the food chain to exploit these differences in the margins at various points along the chain.

The increased size of landholdings needed could be facilitated by using land concessions with long term leases, or producers' cooperatives, expanding the role of domestic and international commercial enterprises, and stressing the role of "agribiz" in the development of "agricultural business parks." The modality to aggregate small landholdings and modernize agriculture has already been tested in Kenya and other parts of Africa (Meaney 2012) and is yielding positive development on the access of smallholders, in the Kenyan case, to international markets. We have not stressed classical economic recommendations for efficient production, such as correct pricing of inputs and reduction of subsidies, removal of trade barriers, etc., because most agricultural settings worldwide are plagued by subsidies and other impediments—often very large—which distort the pricing signals leading to many suboptimal results. These problems should be addressed, but should not be allowed to interfere with action on pressing current food problems.

Physical and Environmental Implications

Classical comparative advantage due to geography, climate, location, and trade and transit networks can lead to a balanced and resilient food system. The fact that temperature varies with elevation is a good way of dealing with adjusting to potential climate change. It is important that countries and regional international agencies document the land availabilities by elevation as well as soil type, so that if the climate changes more rapidly than currently expected, an available strategy for adjustment to the change would be readily apparent. Also, by relying on modern farming methods, the amounts of agricultural chemicals used may be better matched to actual plant needs (Davis et al. 2012). The use of drip or center pivot irrigation techniques not only saves large amounts of water, but also drastically reduces the amounts of agricultural chemicals used per hectare (Meaney 2012). Correctly enacted, a policy based upon the nexus would be very helpful in maintaining environmental quality. Increasing the size of landholdings needed by using land concessions with long-term leases or producers' cooperatives, expanding the role of domestic and international commercial enterprises, and stressing the role of "agribiz" and "agricultural business parks" all lead to a more sustainable food regime.

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