Sustainable Consumption of Food

A Framework for Analyzing Scenarios about Changes in Diets

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Keywords

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Summary

This article describes the integration of life-cycle assessment methods with a new input-output model of the world economy to analyze the environmental and economic implications of alternative future diets. The article reviews findings by industrial ecologists about the energy and land required for the production and consumption of alternative foods and diets in several European countries. It also reviews attributes of foods and diets identified by nutritionists as reducing the risks of obesity and major chronic diseases related to the diets of the affluent. The predominantly plant-based Mediterranean-type diet emerges as a dietary scenario that could satisfy both sets of concerns. The likely implications for agriculture and for farm policies of a shift toward this diet from the current average diet in the United States are discussed and shown to be substantial. The one-country studies reviewed in the article provide substantial insights into the potential ramifications of dietary change. Many of the limitations of these studies could be overcome by conducting the analysis in a global framework that represented the relationships among consumption, production, and trade and the physical constraints within which they operate. Analysis of the environmental and economic implications of alternative scenarios describing healthy diets can help stimulate more intensive dialogue, debate, and action among the interested parties; such analysis can both benefit from and contribute to initiatives such as the World Health Organization's global strategy on diet and health, which intends to enlist the support of governments, corporations, and civil society.

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Introduction

Every day, vast quantities of food are produced, processed, distributed, and consumed, and these activities have direct impacts on human health and on the environment. The complex links from specific lifestyles and diets in affluent societies to environmental degradation have begun to be described and analyzed in substantial quantitative detail by industrial ecologists, whereas links between the choice of diet and chronic illnesses are now subjected to systematic investigation in the nutrition and public health communities. In both cases, certain relationships appear to be consistent and strong despite the fact that knowledge of underlying mechanisms is still preliminary. A substantial body of research shows that certain diets are protective of health and have relatively low environmental impact, and in this article I define a sustainable diet to have these two characteristics. The Mediterranean-type diet characteristic of Greece in the 1960s (described below) is widely taken to be a model diet by nutritionists. Actual diets in the wealthy countries differ strikingly from the Mediterranean-type diet in both quantity of food intake and mix of foods, and the differences have grown greater with the passage of time, notably in the Mediterranean countries themselves. Unfortunately, these diets of the affluent countries set the model being emulated in the developing world as well. Although improvement in dietary undernutrition and malnutrition in the developing countries must be part of a global strategy for the sustainable consumption of food, the focus in this article is on prospects for changes in the diets of the affluent.

Two compelling reasons exist to believe that current food-choice trends associated with affluence can be reversed: people are concerned about the environment and, even more, about their personal health. Moving toward a Mediterranean-type diet on a global scale, though, would require substantial changes not only in consumers' food choices but also in farm policies and in agricultural and food-industry practices. The objective of this article is to describe a framework, based on life-cycle assessment (LCA) and input-output economic models, for analyzing alternative scenarios for the future adoption of healthier diets in order to better understand their environmental and economic impacts and the opportunities, obstacles, and bottlenecks associated with implementing them. Such an analysis requires a method for constructing scenarios in terms of changes in the values of variables and parameters (i.e., technical coefficients). It also requires a mathematical model that allows for changes in the values of variables subject to the relationships constraining them.

The article is organized as follows: The next section reviews the recent literature using life-cycle and input-output methods to characterize individual foods, menus, and diets by their use of land or energy and their greenhouse gas emissions at different stages of production, processing, and consumption. These studies have been carried out in Europe using data mainly from the Netherlands, Sweden, and Switzerland, but the main results provide insights into the relationships between diets and environmental impact more generally. This section also summarizes results of observational and intervention studies of the implications of individual nutrients, foods, and diets on the incidence of major chronic diseases. The so-called Seven Countries Study (the United States, Japan, and five European countries), begun in the 1950s and continuing to this day, was a pioneer in postulating a relationship between diet and chronic illness and introduced the concept of the "Mediterranean diet" in the course of its analysis of this relationship. Characteristic features of a Mediterranean-type diet appear both to promote health and to reduce environmental impacts.

In the second half of the 1990s, two studies by economists at the U.S. Department of Agriculture (USDA) analyzed the implications for American agriculture of a scenario in which domestic consumers complied with official dietary recommendations expressly described in the 1995 study as being based on a Mediterranean diet. Results of these studies are described and indicate that, if consumers changed their diets, there would be substantial changes in land use as well as a marked impact on relative prices, imports, and exports of foods. The authors concluded that the adjustments required of U.S. agriculture would run counter to the objectives of current national farm policy. Although the diet analyzed in these studies is healthier than the actual American diet,

it still is far from what a nutritionist would call a Mediterranean diet. The fact that facilitating even this modest redirection of eating patterns would require a reorientation of farm policies that have prevailed for decades suggests the magnitude of the impact that needs to be envisaged in the event of even more substantial changes in diet.

The following section describes an analytic framework based on an input-output model of production, consumption, and trade for examining the implications of scenarios about dietary changes more systematically and in the context of the global economy. Using concepts and methods of LCA and input-output economics, the model can identify patterns of production and trade and quantify physical inputs such as land, water, and energy as well as costs and prices associated with different assumptions about diets, production techniques, and policies. In this framework the feasibility and environmental and economic implications of alternative scenarios for both consumption and production practices can be evaluated and compared.

Economists and industrial ecologists can provide models and technical data but need to rely on other disciplines for content expertise, in particular regarding diets and agricultural technologies. The public health community is in a position to assess the health implications of different diets and, equally importantly, has long experience in promoting dietary changes. The newly approved global strategy of the World Health Organization (WHO) is described as it relates to diet and health, as are its attempts to engage government, corporate, and civil society stakeholders in anticipating and shaping future diets and relevant policies. The final section of the article provides some conclusions and recommendations regarding the use of scenario analysis to advance that kind of social and political agenda.

Environmental and Health Consequences of Dietary Choices

The choice of diet has far-reaching, interconnected ramifications, and different research communities have emphasized and examined some more than others. A number of authors have described the inefficiency of resource use involved in converting grain to livestock when the grain could instead be eaten directly (Cohen 1995, Kendall and Pimentel 1994, Smil 2000). Drawing in part on this work, Goodland concluded that "... one under-recognized area for major gains [in increasing the supply of food and reducing the environmental impact] is eating lower down the food chain" (1997). Nutritionists are interested less in individual agricultural products than in the mixes of foods that compose different actual diets and in recommending dietary changes in the interest of improved health. They typically have ignored the environmental consequences of recommended diets, with the early and notable exception of Gussow and Clancy (1986).

In the last few years, industrial ecologists have created a body of analysis of agricultural systems, in relation to diets on the one hand and the environment on the other, that, for the first time, can support a framework for evaluating alternative diets from several points of view simultaneously. One direction this work has taken is the detailed survey of the biomass required to satisfy the plant and animal portions of specific regional diets (Wirsenius 2001). The other direction, the direct antecedent for the approach proposed in this article, has focused instead on quantifying the fossil fuel energy and other inputs required for alternative practices both in agricultural production and in the processing, storage, transportation, and preparation of food needed to bring grain, livestock, and other agricultural products to the dinner plate.

In what follows I review the questions posed in the latter set of studies, the methods utilized, and the main variables included in order to lay the foundation for a more comprehensive and integrated framework. This discussion is followed by a brief review of scientific studies about what composes a healthy diet. The section concludes with the observation that a Mediterranean-type diet appears able to address both environmental and health concerns.

Environmentally Preferred Diet

Carlsson-Kanyama and Lindén described recent trends in food production and consumption in a case study for Sweden and identified

prospects for future changes that could lead to more efficient use of resources (2001). They examined the future potential for organic food, less meat, more convenience foods that are fast and easy to prepare, and new food technologies, through interviews with representatives of the food industry interested in prospects for new markets. In another case study Shanahan and colleagues (2003) analyzed typical meals of one household in each of three countries: Ghana, Russia, and Sweden. They found that the Swedish household, unlike the other two, was substantially and increasingly dependent on global sources for its food, one reason for the much higher per capita energy use and carbon emissions in Sweden. Carlsson-Kanyama and colleagues (2003) provided estimates of life-cycle energy inputs for foods, meals, and diets for Sweden as a basis for planning household menus and pointed out that meals with similar nutritional characteristics may have different energy impacts.

One of the earliest life-cycle studies of food was carried out by Carlsson-Kanyama and Faist (2000), who observed that by mid-1999 "a new scientific research area was being established: that of household consumption and its related environmental impacts" (p. 5). They developed a database quantifying the energy used in Sweden during the full life cycles of various foods and illustrated the effective use of these data with the example of a hamburger with its various accompaniments. They called the data collection effort a "simplified" LCA, because it was not system-specific and lacked detail on certain stages. Using this database, they demonstrated a substantially higher use of energy in the production of animal relative to plant foods, greenhouses relative to open-air cultivation of a given crop, and canned or frozen relative to fresh produce.

Jungbluth and colleagues (2000) also carried out a simplified LCA, this time for a region of Switzerland. They focused on two groups of products, meat and vegetables, selected because they represented as much as 40% of all energy associated with foods and provided a more useful basis for consumer decisions than comparisons of individual products. The greatest environmental impacts were associated with fresh food flown in from another country and also with greenhouse production and meat consumption, with less importance for food packaging and an unclear result for organic foods.

A recent study of Dutch food consumption focused on land requirements for different "food packages," or stylized diets, including an "optimal diet," based on official Dutch dietary guidelines, and several versions of an "affluent diet," based on actual diets in several European countries and the United States (Gerbens-Leenes and Nonhebel 2002). The authors also reported changing land requirements over a several-decade period and actual changes in the Dutch diet. Both regional and intergenerational differences were attributed to greater consumption not only of meat but also of added fats and a category that is usually ignored: beverages, such as beer, wine, coffee, and tea. Relative to the European diets, the U.S. diet (even standardized to a common energy intake) required more land, due to its greater weight of meat, despite a partial offset from lower consumption of dairy products. The authors expressed concern about future demand pressures on land if Europeans continue to shift toward U.S. patterns of meat consumption and developing countries move increasingly toward affluent European diets. In another LCA study of Dutch diets, Dutilh and Kramer (2000) found that restaurants used substantially more energy per kilogram (kg) of food in the cooking process[1] but that there was no systematic difference in energy use for homemade relative to industrially produced foods, a result that merits closer examination.

Whereas LCA studies typically examine the environmental impacts of individual products or groups of products, Faist and colleagues (2001) undertook to describe a complete, sustainable food-production and consumption system that was achievable through specific behaviors of private households and other actors. The authors used a material flow approach to quantify energy requirements for Swiss food production and consumption and to evaluate the impact of potential changes in behavior. They found that most energy was used during the stages of agricultural production and in household storage, preparation, and waste rather than in the intermediate processing stages. They also found that adoption of more efficient cooling devices

(i.e., refrigerators and freezers) by households had more potential to reduce energy requirements than a shift to only organically produced foods.

The integration of life-cycle methods within an input-output model of an economy has made it possible to extend analysis from individual products to the entire economic system. Using such a "hybrid" method to quantify energy requirements associated with several categories of foods in the Netherlands, Kramer and colleagues (1999) found that transportation of imported and exported foods substantially increased the carbon emissions from the production and consumption of foods. They also identified opportunities to reduce energy use by substituting other sources of protein for meat and foods grown in open air for those cultivated in greenhouses.

A substantial body of research uses life-cycle methods within an input-output framework, but it has been almost exclusively limited to the use of the simplest open, static input-output models.[2] Kytzia and Faist (2004) developed this basic input-output model in both its physical version (i.e., with variables measured in physical units) and its dual price version (i.e., with variables measured in money prices per physical unit of output) to analyze alternative scenarios for the food system in a region of Switzerland. They found that a vegetarian diet would reduce land use and energy requirements, but that it would also depress the regional agricultural economy. They failed to replicate the importance for energy use of food cooling that had been identified by Faist and colleagues (2001). Although the price model could have been used to calculate changes in relative prices of foods, this direction was not pursued by the authors.

Fuchs and Lorek (2000) reviewed the literature on household consumption of food for their analysis of globalization and sustainable consumption. Whereas many sources affirm that food has a major impact on the environment, Fuchs and Lorek pointed out the preliminary and highly contingent nature of the conclusions that have so far been drawn even from quantitative studies because of differences in industrial organization and choice of technology in different places and at different times. For these studies to build cumulatively upon each other more effectively, these supply-side conditions and the linkages from micro to macro level variables (such as crops to diets) need to be made explicit. This is one of the features of the modeling approach proposed in this article.

Fuchs and Lorek argued for situating the analysis of alternative diets within a worldwide framework, because effective strategies for achieving sustainable food consumption need to take on the challenges and take advantage of the opportunities of globalization. Because the international diffusion of the U.S. diet is leading to the establishment of "a common popular taste worldwide" (p. 25), strategies for dietary change also need to be global in scope. They might have added an additional motivation: although changes in diet in the rich countries might reduce resource use and environmental problems, these improvements could be more than offset by the upgrading of developing country diets, especially if they are upgraded toward today's typical affluent diet. Such scenarios can be evaluated using the modeling approach proposed in this article.

Although acknowledging the costs of transporting foods, Fuchs and Lorek argued that it can in some circumstances be more efficient, economically and environmentally, to import food than to produce it locally. They recognized that government intervention in agriculture is the source of protectionism and agricultural overproduction in the U.S. and many European countries and that trade liberalization can be a beneficial counterbalance. They observed that trade is likely to reduce food prices but has a potential impact on incomes and income distribution that is less evident. Because there are so many influences on food and agricultural practices, they emphasized the need to select only the most important considerations and only the most promising options for deeper analysis.

The global framework for scenario formulation and analysis to be described below is well suited to addressing the concerns of Fuchs and Lorek. The most important dietary distinctions are between meat-based and plant-based diets and the different ways foods are grown, processed, and transported. The trade-off for particular foods between resource intensity in

production in particular regions and in transport between specific pairs of regions, can be investigated only in the context of a global model.

Healthy Diet

The term "Mediterranean diet" was coined by Ancel Keys, who in the 1950s initiated what became known as the Seven Countries Study, a pioneering epidemiological investigation of the relations among lifestyle, diet, and heart attack and stroke in Finland, Greece, Italy, Japan, the Netherlands, the United States, and the former Yugoslavia (Keys 1980, Menotti et al. 1999). Keys set out to understand why there were great differences in the incidence of chronic diseases even among the genetically relatively homogeneous populations of different European countries. He observed a systematic relationship between good health and longevity and the dietary characteristics common to the countries located around the Mediterranean Sea.

The predominantly plant-based Mediterranean diet subsequently provided the original prototype for official dietary guidelines in the United States and many other countries (Nestle 1995). It is low in meat, rich in fresh fruits and vegetables, low in added sugar and salty snacks, and low in saturated fatty acids; the principal source of fat in the traditional Mediterranean diet is olive oil, rich in monounsaturated fat. Nutritional guidelines in other parts of the world that are considered Mediterranean-type diets often replace olive oil with plant-based oils that can be grown in other climates. Locally or regionally grown foods are recommended by nutritionists over imported ones because the former are more likely to be available fresh and tend to be less expensive and therefore more widely accessible, a clear advantage for promoting public health. The term "Mediterranean-type diet" refers to one with these properties, although they may be realized through alternative choices for individual foods.

It has rightly been observed that the Mediterranean diet does not have a monopoly on eating well (Healthy Eating Club 2001a). The Seven Countries Study also revealed health-promoting characteristics for the rice-based Japanese diet, which, unlike the Mediterranean diet, is high in carbohydrates and low in fat; both diets are low in meat and saturated fats and high in legumes and vegetables. Unfortunately, no other Asian country—such as China, India, Indonesia, or Thailand—was included in the study, and there are no comparable historical data for them from other sources. The "Asian diet" has also been called a healthy one and may be preferred for a variety of reasons; but as a nutritional model for good health, the available evidence appears to favor the Mediterranean-style diet (Willett 1994, Healthy Eating Club 2001a).

A growing body of evidence about the protective effects of a Mediterranean-type diet has been obtained from observational and intervention studies, some involving tens of thousands of subjects. In a review of several hundred studies, Tavani and LaVecchia (1995) found that fruits and vegetables, notably fresh and raw vegetables, are associated with lower incidence of cancers especially of the digestive and respiratory tracts. Bosetti and colleagues (2003) concluded that several features of the Mediterranean diet reduce the risk of cancers of the upper digestive tract. In a review of epidemiological, case-control, and prospective studies Kushi and colleagues (1995a) found that high consumption of plant foods and whole grains and low to moderate intake of dairy products probably account for the low rates of numerous chronic diseases, including coronary heart disease, in Mediterranean populations; the inverse relation of vegetable and fruit intake to lung cancer is strong and consistent; and for cancers of the esophagus, stomach, and pancreas, evidence of a protective effect is "overwhelming." Rimm and colleagues (1996) found an inverse association between fiber intake from vegetables, fruits, and cereals and risk of coronary heart disease. Martinez-Gonzalez and colleagues (2002) attributed the benefit of a Mediterranean diet for reducing coronary risk among subjects in Spain mainly to a high intake of fiber and fruit. Hu (2003) associated the benefits of plant-based foods with unsaturated fats as the predominant form of dietary fat and whole grains as the main form of carbohydrate. Many cancers have been associated with total fat intake, especially saturated and animal fats, but Kushi and colleagues

(1995b) claimed stronger evidence for red meat rather than total fat intake as the causal agent, concluding that even relatively high-fat diets may be healthful provided that the main source of fat is olive oil or possibly other fats of plant origin. Ness and Powles (1997) reported a strong protective effect of fruits and vegetables for stroke and a weaker effect for coronary heart disease, whereas Liu and colleagues (2000) found that a higher intake of fruits and vegetables in women may be protective against cardiovascular disease. Kushi and colleagues (1999) concluded that dietary fibers and whole grains are associated with decreased risk of coronary artery disease and some cancers even when controlling for the confounding factor of total energy intake.

Obesity, associated with high total energy intake, especially from added fats and sweeteners, is a factor contributing to cardiovascular diseases, some cancers, and diabetes and has now reached epidemic proportions that are truly global (Chopra, Galbraith, and Darnton-Hill 2002). Recent research shows that a diet of low energy density (kilojoules/gram) is more likely than a diet of low fat content (% fat in total energy) to be associated with lower total energy intake (de Castro 2004, Bell and Rolls 2001, Rolls and Bell 1999). A Mediterranean-type diet is lower in calories than the typical U.S. or northern European diet, despite the substantial quantity of olive oil it includes, because of the great bulk of its plant-food content: 2 kg of plant food per day versus only 1 kg per day in the typical modern western diet (Healthy Eating Club 2001b).

Overlap

According to the studies reviewed above, the production of fruits and vegetables and other plant-based foods under prevailing circumstances is less resource-intensive than the production of meat, and the former offer protection from the risk of cardiovascular disease and some cancers. Production and consumption of fruits and vegetables that are fresh and unprocessed requires less energy than production and consumption of processed foods and confers additional health benefits. Under many circumstances, a diet composed of locally and regionally produced foods is to be preferred because it reduces the energy costs and pollution associated with transportation and will, in part for this reason, be less expensive and therefore more affordable to a large public. Avoiding excess energy intake (provided the diet is nutritionally adequate) is healthier, and less food requires fewer resources. Although there is a great deal of latitude, and therefore ambiguity, in defining a Mediterranean-type diet, nutritionists and public health professionals have found it a useful analytic construct for studying the association of food intake patterns with health. It can likewise serve as a useful construct for describing future diets that may be desirable from an environmental point of view and analyzing their feasibility and their implications.

Implications of a Dietary Scenario

In a special issue of the *American Journal of Clinical Nutrition* devoted to the Mediterranean diet, O'Brien (1995) identified the major categories of change in food intake that would be needed under a scenario where Americans shifted from the prevailing average diet to one broadly consistent with a Mediterranean-type diet. He took the 1990 dietary guidelines of the USDA to approximate the latter and constructed a hypothetical diet that complied with its basic recommendations. (A more accurate description would be that these dietary guidelines are less distant from the Mediterranean-type diet than is the actual American diet.) Then he estimated the demands that this dietary transition would place on agricultural production. By framing the question in this way, O'Brien was able to focus on identifying the obstacles that would be encountered if American farmers were called on to provide a diet more reliant on plant-based foods.[3] The study was followed by a more detailed investigation, including quantitative estimates of land use in agriculture, by other economists at the USDA (Young and Kantor 1999) and an assessment of the policy implications by the agency's chief economist (Collins 1999).

Based on a detailed comparison of actual and recommended U.S. diets (Kantor 1998), Young and Kantor (1999) showed that compliance with the official dietary guidelines would require:

Table 1 Major Changes in Consumption Needed to Meet Dietary Guidelines in the US

Food Group	*% increase*	*% decrease*
Vegetables	8	
Dark green leafy and deep yellow	333	
Dry beans, peas, and lentils	200	
White potatoes and other starchy vegetables		38
Other vegetables		32
Fruit	131	
Citrus, melons, and berries	150	
Other fruit	114	
Milk, yogurt and cheese	22	
Meat, poultry, fish, eggs and nuts	5	
Added fats and oils		36
Added sugars		63

Source: Based on Young and Kantor (1999, table 2).

- Significant increases in fruit and vegetable consumption, especially dark green leafy vegetables and deep yellow vegetables.
- A moderate increase in dairy product consumption, with marked shifts from full-fat to low-fat items.
- A small increase in the consumption of the meat product group,[4] with continued shifts from the "red meats" (beef, pork, lamb, and veal) toward poultry and fish and marked changes in meat characteristics, notably reduced fat.
- Substantial reduction in intake of added fats and in sweetener consumption.

These changes are quantified in table 1.

Young and Kantor estimated that about 5.6 million additional acres (15.3 − 9.7, third row from bottom in the table) would need to be planted to food crops in the United States if all adjustments to meet the dietary requirements were made in the domestic supply.[5] The adjustments in acreage are shown in total and by food group in table 2. The additional land requirements amount to about 2% of the 1990–1995 average acreage planted and could be readily accommodated by the 22 million acres of cropland idled under U.S. federal planting constraints. Nonetheless, substantial disruptions would be experienced on individual farms and in specific regions of the country.

Given the climatic and water constraints on fruit production, especially citrus fruits, and the size of the projected increase in demand, there would be a significant increase in net imports of fruits. Increased imports of fresh winter vegetables would also be anticipated, with obvious implications not only for Mexico, the major source, but also for Canada, which relies on the United States for most of its vegetable imports.

Soybean oil composes over 80% of added fat and oil supplies in the United States (Young and Kantor 1999, table 7), and if the entire fall in this demand translated into reduced production of soybeans, 12 million acres of land would be idled. But Young and Kantor assumed a partially offsetting increase in the demand for soybean meal as feed to satisfy the increased demand for meats, especially poultry, and dairy products, and a fall in the price of soybean oil that would stimulate its use in nonfood industrial applications and possibly as a fuel. For these reasons they restricted the potential decrease of 12 million acres to only 3 million (see table 2).

With continued preference for lower-fat meats, more animal is required to deliver a kilogram of meat. A larger number of animals would increase the supply of fatty meat parts, and there would be pressures to export them as well as the fat removed in the production of low-fat dairy products. The shift from red meats to poultry, a far more efficient

Table 2 Acreage Adjustments for Compliance with Dietary Recommendations (millions of acres)

Crop	Average Planted Area, 1991–1995	Change in Acreage	
		Increase	Decrease
Fruits			
Citrus	0.9	1.4	
Melons, berries	0.6	0.7	
Other	1.9	2.1	
Vegetables			
Dark-green and deep-yellow	0.4	1.4	
Starchy	2.4		0.9
Other	1.6		0.5
Dry beans, etc.	2.1	2.7	
Peanuts	1.7		
Tree nuts	0.7		
Wheat	70.7		
Rice	3.1		
Feed grains			
From sweeteners	5.6		3.5
From oilseed[a]	0.0	2.0	
From meat, dairy	55.7	5.0	
Other	36.9		
Soybeans	60.5		3.0
Sugar			
Beet	1.4		1.1
Cane	0.9		0.7
Land in food crops (total of above)	247.1	15.3	9.7
Other cropland	108.7		
Total cropland	355.8		

Source: Young and Kantor (1999, table 3).
One acre ≈ .405 hectares (ha) ≈ .004 square kilometers (km^2)
[a] Offsets loss of soybean meal.

converter of feed grain, would continue under this scenario.

The feed grain sector would be indirectly but strongly impacted by the changing demand for red meat, poultry, sweeteners, and oilseed. Some corn diverted from use as a sweetener would be used to satisfy demands from expanded meat and dairy production, and pressures for increasing corn exports to limit the decrease in acreage planted to corn would also emerge. Young and Kantor made optimistically high assumptions about gross increases in acreage planted to other feed grains to offset the reduction in corn acreage. Reduced production of soybeans and corn would each have a disproportionately high impact on agriculture in the midwestern corn belt states.

The authors concluded that this scenario would require the profound rethinking of the overall rationale for American farm programs, which dates back to the 1930s in its objective of promoting U.S. agriculture mainly through price and income supports for feed grain and livestock producers. (This history helps to explain why the USDA interpretation of a Mediterranean-type diet is so heavy in meat.) Fruits and vegetables, in contrast, have not been favored crops; in fact, a statute actually limits their production (by subsidized grain and cotton farmers), with the rationale of maintaining prices in the fruit and vegetable markets (Collins 1999). This legislative package both reflects and reinforces the fact that the American culinary tradition is

focused on meat and potatoes. Some of Young and Kantor's assumptions regarding acreage in soybeans and feed grains also mainly reflect concerns with minimizing disruption of these sectors. Under assumptions other than those made by Young and Kantor, demand for cropland might decrease instead of increasing with the adoption of a Mediterranean-type diet.

The results of these studies have been described in detail to illustrate the range and magnitude of impacts that might be associated with a change in diets. These studies indicate the substantial implications for agriculture in the United States of a moderately more healthful diet and the role that farm policies can and do play in facilitating or obstructing such changes. Clearly, if the USDA researchers had analyzed a scenario about a Mediterranean type diet and not the USDA guidelines, the need for changes in practices and policies would be even greater. The next step is to move from estimates of isolated impacts, as provided by Young and Kantor, to a modeling approach that consistently takes all assumptions simultaneously into account and is embedded in a global framework where trade is endogenous. This framework requires life-cycle inventories quantifying inputs, outputs, and environmental impacts for individual crops and foods, input-output matrices quantifying inputs per unit of output for all sectors of the economy, and an input-output model of the world economy to capture impacts of simultaneous changes in demand patterns and production technologies as well as policies on resource use, the international division of labor, trade flows, and incomes and prices.

Global Framework for Scenario Analysis

Scenarios

A scenario serves as a hypothesis to be tested with a model. The implicit hypothesis lying behind the scenarios discussed in this article is the following: If the meat-based diets favored by today's affluent populations were replaced by a palatable, nutritious, plant-based diet, and if the latter rather than the former were emulated in the developing countries, it would be possible to feed a growing global population without substantial increases in either the cost of food or pressures on the environment.

One example of these hypothetical dietary assumptions is the Mediterranean-type diet, and the simplest scenario would have all diets converging to a common one. This could be a good choice for an initial analysis at a relatively aggregated level of representation of crops and foods. One could also define distinct regional versions of plant-based diets that make the most intensive use of customary, locally available items and further disaggregate to distinguish the current and possible future diets of different categories of households in each region.

By contrast, a business-as-usual scenario would assume that regional average diets will remain basically unchanged from current patterns. It is unclear whether this scenario is feasible because the world population is growing and changes in the climate system increasingly affect the mixes and yields of crops in different regions. Julia (2004) used the modeling framework described below to analyze the impact of climate change on agriculture and its ability to satisfy the demand for food. Another plausible scenario is that diets of growing segments of the populations of developing countries will shift toward the current diets of the affluent: more calories per capita and a larger share of calories from animal products and added fats and sweeteners. The physical feasibility of such scenarios for the future and their environmental and economic consequences have barely begun to be explored.

Model

The author's recently constructed model of the world economy, the World Trade Model, maintains the features that make input-output models attractive to many industrial ecologists working with life-cycle or material flow data. Furthermore, it extends these properties to a global scale by making operational a theory of trade based on comparative advantage in the case of many regions, many goods, and many factors

(Duchin 2003). The basic attractions of an input-output model include a physical model based on the representation of technological requirements in physical units, compatible with the units of an LCA; the ability to capture and quantify not only the direct physical requirements for producing a product or set of products but also the indirect requirements that an LCA would otherwise ignore; and a dual price model that can trace both direct and indirect factor costs (i.e., profits and other components of value added) associated with the physical flows. Additional features of the World Trade Model ensure a realistic representation of the physical relationships underlying trade. In particular, production in each region is constrained by the availability of each factor of production, and these factors can include not only labor and capital but also land and specific natural resources, as well as unpriced resources such as fresh water.

The World Trade Model is a linear program with a primal that corresponds to the one-region physical input-output model and a dual that corresponds to the one-region price model.[6] The new model provides closure for the input-output model of the world economy developed by Leontief (1974) and implemented by Leontief and colleagues (1977) by making imports and exports and their prices fully endogenous. The solution to the primal determines where production takes place, on the basis of the lowest relative production costs, and the volumes of trade. It also solves for the amounts of factors used in each region. The dual determines world prices for all products and regional rents on scarce factors, such as cropland or water.

Model results for a particular scenario include near-optimal solutions, which may be as interesting as the one identified as optimal. The model could be modified to minimize environmental problems, such as carbon emissions, instead of economic costs. The model has recently been extended to take transportation requirements into account in determining an optimal solution (Strømman and Duchin 2004), a feature that will be particularly valuable for examining the trade-off between locally grown and imported foods for pairs of trading partners under various different assumptions about agricultural production and food-processing technologies.

The model requirements provide structure for the database needed to analyze scenarios of dietary changes. The data requirements for the computation of a scenario for each country or region are an interindustry matrix, final demand columns including one representing the average regional diet, a matrix of resource and other factor inputs and pollutant emissions per unit of output, a vector of factor endowments, and base-year factor prices for priced factors. The interindustry matrix is an input-output matrix extended to include greater detail on agriculture and food production coming from life-cycle inventories.

Concepts and Methods for the Representation of Scenarios

Describing a scenario in a modeling framework requires a decision about the level of detail. In the case of a diet scenario, should there be 30 food categories, 300, or 3,000? Thirty categories is probably an adequate order of magnitude to distinguish, say, the average U.S. diet, a northern European one, a Mediterranean-type diet, an Asian-type diet, and several regionally specific diets of malnutrition. This level of detail would also be adequate to make many of the distinctions that appear to be important from resource utilization and public health points of view, namely to distinguish animal from plant products, red meat from poultry or fish, and fresh from preserved fruits and vegetables. The production and consumption of prepared foods and meals, of evident interest to the food-processing and food-service industries and also many consumers, needs to be represented in a manageable number of categories. Assessing the physical feasibility of supplying a particular diet requires assumptions about endowments of resources in different regions, namely of cropland, pastureland, and fresh water. Alternative technologies for producing a given crop or food could be described using a handful of alternative templates, along the lines of a simplified LCA analysis.

Creating templates to describe alternative diets or production technologies involves a degree

of abstraction not generally required for representations based only on direct measurement, the latter being the case for LCA studies. An individual's actual food intake on a particular day can in principle be measured in full detail and with great precision. But the concept of an average diet for a country or household, or even the average daily food intake for an individual over the course of a year, already represents an abstraction because of the likelihood of great variations from person to person and from day to day. Future diets can obviously not be measured. The quantitative description of an average diet—even more than in the case of an average technology for producing a particular good because of greater variability—is a stylized representation that succeeds when it captures the characteristics most important for the analysis. A simplified LCA is more stylized than a full LCA, and an input-output representation is generally more stylized yet. Greater abstraction, or sacrifice of detail, is necessary to describe the workings of much larger and more complex systems. To investigate future prospects for such systems requires projecting alternative values for technical coefficients and cannot rely on direct measurements. The corresponding challenge in scenario construction is to pose questions for which order-of-magnitude answers are suitable and informative.

Compared to detailed life-cycle inventories, many models of entire economies, not to mention the world economy, employ a much smaller number of categories for representing production and consumption activities and, if they do utilize many variables, manipulate them in a formal way rather than attending to the distinctive properties of different variables. One consequence is that they may fail to ensure that important physical constraints are satisfied. The collaboration of input-output economists with life-cycle analysts makes it possible to handle a moderate level of detail systematically and to represent the interdependency among variables while also paying attention to the physical constraints of the system. Some of the studies described earlier, namely those by Kramer and colleagues (1999) and Kytzia and Faist (2004), demonstrate the feasibility of this approach in one-region settings and suggest its potential in a global framework.

Diet Change and Public Health

People in their everyday lives choose what they eat, subject to budget constraints and the availability of foods, and have a personal interest in avoiding chronic diseases and premature death. The public health community and professional nutritionists have a long history of designing and implementing media-based educational campaigns and direct interventions focused on individuals to promote dietary changes and increased levels of exercise and physical activity. Such interventions have unfortunately not succeeded in reversing trends toward less healthy diets. Nonetheless, segments of the population are heeding the message, and the expertise of these professional communities could have a much greater impact if the dialogue among major stakeholders could be productively intensified.

National governments are charged with protecting the public's food supply and health. But having a wide range of responsibilities, from administering agricultural subsidies to approving health claims on food labels, government agencies have other interests to balance against improved public health, namely the autonomy and prosperity of the industries that grow, process, distribute, serve, and export crops, livestock, foods, and meals. The agencies operate within regulatory environments shaped over many decades but are faced with new global environmental and economic challenges. Government agencies are an interested party in formulating the kinds of scenarios described in this article and understanding their policy implications.

Corporations are another important stakeholder in the provision of foods to households, and some will serve as pioneers in offering healthier foods and meals. Analysis of scenarios that distinguish diets of different categories of households within a country or region will be of interest for their projection of future demand for a different mix of products or for new products. Corporations will also be highly interested in global sources of food supply and the changing price structure for agricultural products.

The WHO's Global Strategy on Diet, Physical Activity, and Health, aimed at reducing the burden of chronic disease (WHO 2003), was recently approved after several years of preparation by the

World Health Assembly (WHO 2004). WHO aims to make use of international legal mechanisms, including international standards for advertising and labeling, and to establish partnerships with industry leaders in the food, sports, insurance, and advertising industries. The WHO strategy calls for public and private sector agreement on emphasizing intake of fruits and vegetables; smaller portion sizes; limiting fats, salt, and sugar; and standards for marketing to young children (Chopra et al. 2002).

Recent experience with tobacco demonstrates that sharp changes in lifestyles can be achieved relatively quickly. The proportion of adult smokers in the U.S. dropped from 42% in 1965 to 23% in 2001 (Centers for Disease Control and Prevention 2003) as a result of antismoking campaigns, labeling requirements, and mass communication of compelling scientific evidence of the ill effects of smoking on health. Dietary changes are likewise fundamentally important for promoting improved public health, and more healthful diets have the potential to substantially reduce the pressures of the agricultural and food systems on the environment. The environmental and public health communities are in a position to reinforce each other's efforts in terms of research collaboration and common programs for working with the general public, governments, and corporations.

Conclusions

It is conceivable that the American diet could be emulated in all parts of the world. Relative to that baseline, a global shift toward a Mediterranean-type or other plant-based diet could be expected to have a more favorable impact on the environment and on health. The upgrading of nutritionally deficient diets, though, especially in developing countries, could more than offset the environmentally beneficial impacts of adopting a plant-based diet in the rich countries. The outcomes will depend not only on dietary choices but also on changes in the current practices of the food production, processing, handling, and service sectors. Better understanding of the implications of these changes will facilitate the identification of specific agricultural, trade, or other policies that could promote effective dietary innovation and indicate the extent of changes that will be required.

In developing countries traditional diets, which still feed most of the population, are based on staple plants such as rice, wheat, corn, millet, sorghum, and roots and tubers. Increasing affluence is bringing more diversity into these diets in part through purveyors such as McDonald's and Coca-Cola and the rapidly globalizing retail grocery industry, all of which exercise increasing pressure for global dietary standardization. Dietary diversity from these sources has generally taken the form of more fat and animal products and more sugar and processed foods, but in the future this need not be the case. This article has highlighted health motivations for moving the standard diet in a different direction and has described a research program that can anticipate the major environmental and economic implications in order to reduce some of the uncertainty that could inhibit innovation and action.

A conceptual framework was described for the quantitative representation of dietary scenarios, along with a modeling framework to analyze them. These require simplification of complex relationships through discerning choice of variables and parameters. This objective can be met by integrating life-cycle inventories and an input-output model of the world economy.

The need for dietary changes in the affluent societies has been recognized by nutritionists and the public health community, and WHO has developed a global strategy on diet and health. The analysis of alternative scenarios for future diets and for how and where the crops and foods are produced and consumed could provide a basis for engaging major government, corporate, and civil society stakeholders in productive dialogue with an emphasis on action. Such an outcome could help promote the cause of improved public health while also advancing the case for changes in consumption behavior to reduce environmental deterioration.

Notes

1. One kilogram (kg, SI) ≈ 2.204 pounds (lbs).
2. The model is "open" when all components of final demand (i.e., consumption, investment, and trade)

are exogenous. The model is "closed" for households when consumption and employment are endogenous; it is dynamic when investment is endogenous; and a one-region model becomes a world model when trade is endogenous.

3. According to O'Brien, the "traditional Mediterranean eating patterns" are "quite similar to those recommended in [the USDA's] Dietary Guidelines for Americans . . . and the US Department of Agriculture's (USDA's) The Food Guide Pyramid" (O'Brien 1995, 1390S). In fact, as discussed below, the latter two guidelines are considerably higher in meat products than the Mediterranean diet.
4. USDA recommendations for intake from the meat group are even higher than the already high consumption levels of meat in the United States. The latter have in fact been increasing, although much more slowly than in many European countries, which start from lower levels.
5. One acre $\approx$ 0.405 hectares (ha) $\approx$ 0.004 square kilometers (km^2).
6. The primal program is a mathematical model of the relationships between physical stocks and flows, while the dual program uses the same variables and data to describe the relationships between costs and prices.

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