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# **Sustainable Consumption of Food: A Framework for Analyzing Scenarios about Changes in Diets**

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**Abstract.** This paper proposes an 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 paper 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 those attributes of foods and diets identified by nutritionists as reducing the risks of obesity and major chronic diseases. The predominantly plant-based Mediterranean-type diet is an important example that can satisfy both sets of concerns. The likely resource implications of a shift toward this diet from the current average diet in the United States are discussed. The set of one-country studies reveals the advantages of analyzing scenarios about global dietary changes using a model of the world economy that consistently tracks consumption, production and trade in physical and price units. The World Health Organization's newly-approved, global strategy on diet and health intends to enlist the support of stakeholders in governments, corporations, and civil society. Analysis of the environmental and economic implications of alternative scenarios describing healthy diets can enrich the information base fostering a more intensive dialogue, debate, and action among the interested parties.

**Keywords:** diet and environment, diet and health, life cycle assessment, input-output models, world trade model, scenario analysis

# **Sustainable Consumption of Food: A Framework for Analyzing Scenarios about Changes in Diets**

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## 1. Introduction

Every day vast quantities of food are produced, processed, distributed, and consumed, and these activities have extensive impacts on human health and on the environment. The complex links from specific lifestyles and diets to environmental degradation have recently begun to be explored, while links between the choice of diet and chronic illnesses have been under investigation for at least the last half-century. 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 paper I define a sustainable diet to have these two characteristics. The Mediterranean-type diet characteristic of Greece in the 1960s (described in Section 3) 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 the mix of foods, and the differences grow greater as time passes. These diets of the affluent countries set the model being emulated in the developing world as well.

There are two compelling reasons to believe that current food-choice trends can be reversed: people are concerned about the environment and, even more, about their personal health. However, moving toward a Mediterranean-type diet on a global scale 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 paper is to describe a framework, based on life cycle analysis and input-output economic models, for analyzing alternative scenarios about 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.

The paper is organized as follows. Section 2 describes a body of work 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 for the Netherlands, Sweden and Switzerland, but the main results appear to be generalizable to other settings. 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 5 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 analyzed the implications for American agriculture of a scenario in which domestic consumers comply with official dietary recommendations, expressly described in the 1995 study as being based on a Mediterranean diet. Results of these studies, described in Section 3, indicated 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 US agriculture would run counter to the objectives of current national farm policy.

Section 4 describes an analytic framework based on a 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 life cycle assessment 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 can be evaluated and compared. Such a research program requires collaboration across several scholarly communities.

Economists and industrial ecologists need to rely on the public health community to understand the health implications of different diets and can benefit from their experience promoting dietary change. Section 5 describes the newly approved global strategy of the World Health Organization as it relates to diet and health and its attempt to engage government, corporate and civil society stakeholders in anticipating and shaping future diets and relevant policies. The final section of the paper provides some conclusions and recommendations.

## 2. Environmental and Health Consequences of Dietary Choices

In the 1980s a few voices among nutritionists expressed concern with the environmental implications of dietary choices (Gussow and Clancy 1986), and by the 1990s several researchers concerned mainly about the environment recognized the significance of diet for health as well as for agricultural sustainability (Goodland 1997). Since that time, a growing body of work by industrial ecologists has focused mainly on quantifying the energy required for alternative practices in food production and consumption. These are described below, followed by a brief review of scientific studies about what comprises a healthy diet.

### Environmentally Preferred Diet

Carlsson-Kanyama and Linden 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, Carlsson-Kanyama, et al. (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, Ekström, and Shanahan (2003) provided estimates of life cycle energy inputs for foods, meals, and diets for Sweden as a basis for planning household menus. They made the important point 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 pointed out 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 cycle 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, Tietje and Scholz (2000) also carried out a simplified LCA, this time for a region of Switzerland. They focused on 2 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 US (Gerbens-Leenes and Nonhebel 2002). The authors also reported changing land requirements over a several-decade period and the 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 beverages: beer, wine, coffee and tea. Relative to the European diets, the US diet (even standardized to a common energy intake) required more land, due to the 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 US patterns of meat consumption while developing countries move increasingly toward affluent European diets. In another LCA study of Dutch diets, Dutilh and Kramer (2000) found no systematic difference in energy use for home-made relative to industrially-produced foods, but restaurants used substantially more energy per kg of food in the cooking process. These comparisons require, and merit, closer examination.

While LCA studies typically examine the environmental impacts of individual products or groups of products, Faist, Kytzia and Baccini (2001) undertook to describe a complete, sustainable food-production and consumption system that is 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 an 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 et al. (1999) found that transportation of imported and exported foods increased substantially 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.

There is a substantial body of research using 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 model.<sup>1</sup> Kytzia and Faist (forthcoming) 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 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, Kytzia and Baccini (2001). While the price model could have been used to calculate changes in relative prices of foods, this direction was not pursued by the authors.

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<sup>1</sup> 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.

Fuchs and Lorek (2000) reviewed the literature on household consumption of food for their analysis of the implications of globalization for sustainable consumption. While many sources affirmed 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. In order 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.

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 US 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: while 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.

While 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 US and many European countries and that trade liberalization can be a beneficial counterbalance. They observe 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 the most promising options for deeper analysis. All these points provide motivation for the global framework for scenario formulation and analysis described in Section 4.

### 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 US 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 substitute olive oil by 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. The term Mediterranean-type diet refers to one with these properties although they may be realized through different choice of 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 -- China, India, Indonesia, Thailand -- was included in the study, and there is no comparable historical data for them. The "Asian diet" has also been called a healthy one; 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 et al (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 et al. (1995a) found that high consumption of plant foods, 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 with lung cancer is strong and consistent; and for cancers of the esophagus, stomach and pancreas, evidence of a protective effect is "overwhelming." Rimm et al. (1996) found an inverse association between fiber intake from vegetables, fruits, and cereals and risk of coronary heart disease. Martinez-Gonzalez et al. (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 et al. (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 while Liu et al. (2000) found that



higher intake of fruits and vegetables in women may be protective against cardiovascular disease. Kushi et al. (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 contributing factor to cardiovascular diseases, some cancers and diabetes and has now reached epidemic proportions that are truly global (Chopra, Galbraith, Darnton-Hill 2002). Recent research shows that a diet of low energy-density (kJ/g) 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 US or northern European diet, despite the substantial quantity of olive oil, 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 most 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 processed foods and confers additional health benefits. Under many circumstances, a diet comprised of locally and regionally produced foods is to be preferred because it reduces the energy and pollution associated with transportation and will, in part for this reason, be less expensive and therefore more affordable. Avoiding excess energy intake (provided the diet is nutritionally adequate) is healthier, and less food requires fewer resources. While 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.

### 3. 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 changes 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 dietary guidelines of the US Department of Agriculture (USDA) to approximate the latter and constructed a hypothetical diet that complied with its basic recommendations. 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 obstacles that would be encountered if American farmers were to provide a

diet more reliant on plant-based foods. 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 US diets (Kantor 1998), Young and Kantor (1999) showed that compliance with the official dietary guidelines would require:

- Significant increases in fruit and vegetable consumption, especially dark-green leafy vegetables and deep-yellow vegetables.
- Moderate increase in dairy product consumption with marked shifts from full-fat to low-fat items.
- Small increase in the consumption of the meat product group<sup>2</sup> 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.

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)

Young and Kantor estimated that about 5.6 million additional acres (15.3-9.7) would need to be planted to food crops in the US if all adjustments to meet the dietary requirements were made in the domestic supply; this is shown by food group in Table 2.

<sup>2</sup> USDA recommendations for intake from the meat group are even higher than the already high consumption levels of meat in the US. The latter have in fact been slowly increasing although much more slowly than in many European countries, which start from lower levels.

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

Table 2. Acreage Adjustments for Compliance with Dietary Recommendations

(millions of acres)			
Crop	Average Planted	Change in Acreage	
	Area, 1991-1995	Increase	Decrease
<b>Fruits</b>			
Citrus	0.9	1.4	
Melons, berries	0.6	0.7	
Other	1.9	2.1	
<b>Vegetables</b>			
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		
<b>Feed grains</b>			
From sweeteners	5.6		3.5
From oilseed*	0.0	2.0	
From meat, dairy	55.7	5.0	
Other	36.9		
Soybeans	60.5		3.0
<b>Sugar</b>			
Beet	1.4		1.1
Cane	0.9		0.7
<b>Land in food crops</b>			
(total of above)	247.1	15.3	9.7
Other cropland	108.7		
Total cropland	355.8		
Source: (Young and Kantor 1999, Table 3)			
*offsets loss of soybean meal			

under 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 US for most of its vegetable imports.

Soybean oil comprises over 80% of added fat and oil supplies in the US (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 non-food 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 animals are required to deliver a kg 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 converter of feedgrain, would continue under this scenario.

The feedgrain 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 there would also be pressures for increasing corn exports to limit the decrease in acreage planted to corn. Young and Kantor make 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 Cornbelt 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 US agriculture mainly through price and income supports for feed-grain and livestock producers. (This history helps explain why the USDA interpretation of a Mediterranean-type diet is so heavy in meat.) Fruits and vegetables, by 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, p. 314). The 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 reflect concerns for the economic well-being of these sectors. Under other assumptions than those made by Young and Kantor, demand for cropland might be seen to decrease instead of increasing with the adoption of a Mediterranean-type diet.

Evaluating alternative scenarios requires moving from the 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 changes in demand patterns, production technologies, and policies on resource use, the international division of labor, trade flows, and incomes and prices.

#### 4. Global Framework for Scenario Analysis

One vision for future food consumption is that regional average diets will remain basically unchanged from current patterns while the world population grows and an altered climate system affects the mix and yields of crops in different regions (see (Julia 2004) for the analysis of scenarios about the impact of climate change on agriculture). Another possibility is that diets continue to shift in the directions experienced in recent decades: more calories per capita and a larger share of calories from animal products and added fats and sweeteners in most rich countries and an emulation of that pattern by the relatively affluent in developing countries. The physical feasibility of these business-as-usual scenarios and their environmental and economic consequences have barely begun to be explored.

Describing diets in a modeling framework requires a decision about the level of detail: 30 food categories, 300 or 3000? Thirty categories is probably an adequate order of magnitude to distinguish, say, the average US diet, a northern European one, a Mediterranean-type diet, an Asian-type diet, and a diet 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 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 to many consumers, needs to be represented in a manageable number of categories. Assessing the physical feasibility of supplying a particular diet would require assumptions about resource endowments in different regions, namely 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. Present diets can be measured in great detail, 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. Future diets can obviously not be measured. The quantitative description of an average diet (or technology) is a stylized representation that succeeds when it captures the characteristics most important for a particular 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 be able to address new questions about the workings of much larger and more complex systems. The corresponding challenge is to pose questions for which order-of-magnitude answers are useful.

Compared to detailed life-cycle inventories, many models of an entire economy, 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 assure that important physical constraints are satisfied. The collaboration of input-output economists with life-cycle analysts makes it possible to handle systematically a moderate level of detail and to represent the interdependency among variables while also respecting the physical constraints of the system. The studies described in the first part of Section 2 demonstrate the feasibility of this approach in one-region settings.

The scenarios of greatest potential interest would involve a shift in all countries to a plant-based Mediterranean-type diet -- or some other template, such as the grain-based Asian-type diet -- to provide insight into whether the given resource base can support some 9 billion people by mid-century on palatable, nutritionally adequate diets without substantial environmental degradation or economic hardship. The analysis of these kinds of dietary-change scenarios needs to be situated within the global system of production, consumption, and trade.

The author's recently constructed model of the world economy, the World Trade Model, has all the features that make input-output models attractive to many industrial ecologists working with life-cycle or material flow data, and it extends these properties to a global scale by making operational a theory of trade based on comparative advantage (Duchin 2003). The model requirements provide structure for the database needed to analyze scenarios of dietary changes. Model results include near-optimal solutions, which may be as interesting as the one identified as optimal, and the model could be modified to minimize environmental problems, such as carbon emissions, instead of economic costs.

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. The solution to the primal determines where production takes place, on the basis of lowest relative production costs, and the volumes of trade. It also solves for the amounts of factors used in each region and pollutant emissions. The dual determines world prices for all products and regional rents on scarce resources, like cropland or water. The World Trade Model provides closure for the input-output model of the world economy developed by Leontief (1974) and implemented by Leontief, Carter, and Petri (1977) by making imports and exports endogenous.

The data requirements for the computation of a scenario for each country or region are an inter-industry 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 inter-industry matrix is an input-output matrix extended to include greater detail on food production coming from life-cycle inventories.

## 5. 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 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 to promote dietary changes and increased levels of exercise and physical activity. Such interventions have unfortunately not succeeded in reversing the trends toward less healthy diets. Nonetheless, segments of the population are heeding the message, and the expertise of these professional communities could have much greater impact if the dialogue among major stakeholders could be productively intensified.

National governments are charged to protect the public's food supply and health. However, 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 paper 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 might be of particular 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 World Health Organization'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 on advertising and labeling, and establish partnerships with industry leaders in the food, sports, insurance, and advertising industries. WHO Strategy calls for public sector 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, p. 954).

Recent experience with tobacco demonstrates that sharp changes in lifestyles can be achieved relatively quickly. The proportion of adult smokers in the US dropped from 42% in 1965 to 23% in 2001 (Centers for Disease Control and Prevention 2003) as a result of anti-smoking campaigns, labeling requirements, and mass communication of compelling scientific evidence of its ill effects on health. Dietary changes are likewise fundamentally important for promoting improved personal and public health, and more

healthful diets have the potential to substantially reduce pressures of the agricultural and food systems on the environment. The environmental and public health communities are in a position to reinforce each others' efforts in terms of research collaboration and common programs for working with the general public, governments, and corporations.

## 6. 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 diet could be expected to have a more favorable impact on the environment and on health. Changes in the current practices of the food production, processing, handling, and service sectors to satisfy such a scenario about the future demand for food need to be systematically quantified. Better understanding of the implications of these changes will facilitate the identification of specific agricultural, trade or other policies that could promote dietary innovation.

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 a 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.

In developing countries traditional diets, which still feed most of the population, are based on staple plants such as rice, wheat, corn, millet, or sorghum and roots and tubers. Increasing affluence is bringing more diversity into these diets through purveyors like McDonald's and Coca Cola and the rapidly globalizing retail grocery industry, all of which exercise increasing pressure for global dietary standardization. Unfortunately, this dietary diversity has been taking the form of more fat and animal products and more sugar and processed foods. The objective of this paper was to highlight health motivations for moving this abstract standard diet in a different direction and to call for a research program that could evaluate the associated environmental and economic implications.

The need for dietary changes has been recognized by nutritionists and the public health community, and the World Health Organization has developed a global strategy on diet and health. The construction and analysis of alternative scenarios about future diets and how and where the crops and foods are produced and consumed could prove informative enough to engage major government, corporate, and civil society stakeholders in productive dialogue with an emphasis on action.



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