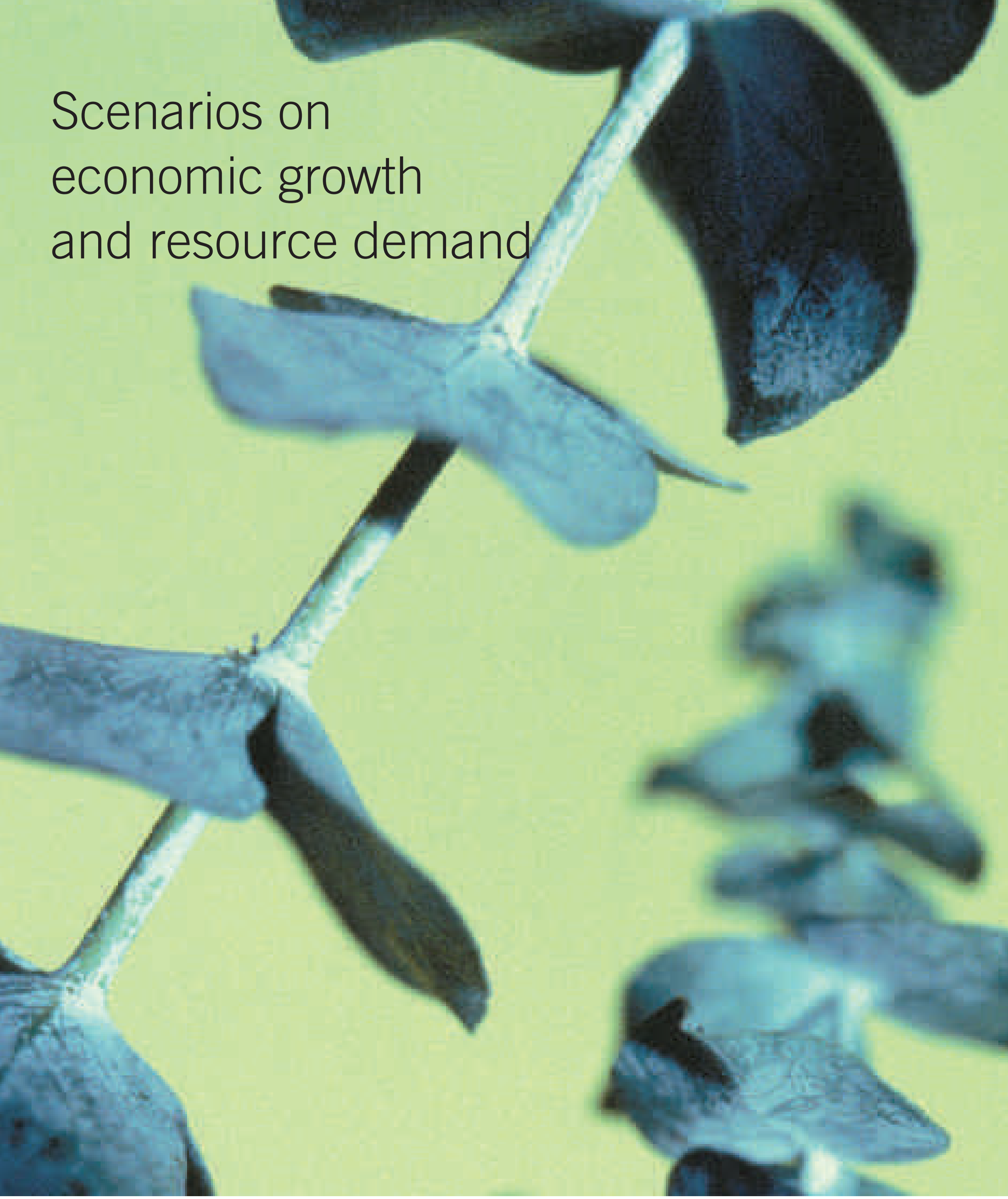

Scenarios on economic growth and resource demand

Background report to the Swedish
Environmental Advisory Council
memorandum 2007:1

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Swedish Environmental Advisory Council
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Scenarios on economic growth and resource demand

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The eucalyptus plant on the cover in many ways illustrate dilemmas dealt with in the Swedish Environmental Advisory Council memorandum on growth and the environment in a global perspective (Memorandum 2007:1). Eucalyptus is fast-growing and can be an important source of energy. However, the establishment of fast-growing bioenergy plantations can result in land-use changes resulting in loss of forests or other ecosystems, or lead to increased competition for water and land in areas where these resources are scarce. Fertilization on plantations increase productivity but can lead to eutrophication of water courses, lakes and seas. There is thus a risk that the climate-related gains will be won at the expense of ecosystem services that are important for human well-being. Eucalyptus is at times grown in poor countries and used in countries in the industrial part of the world. The transparency in the production is low, which illustrates the complexity of the global market that environmental policies have to take account of.

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The memorandum can be ordered from
the Secretariat for the Swedish Environmental Advisory Council

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Front cover photo: Eucalyptus plant, Scanpix
Back cover photo: Free falling (with parachute), Pix Gallery Agency

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Preface

The Swedish Environmental Advisory Council (SEAC) advises the Swedish Government on issues of environmental concern. The following is a background report to a memorandum by the Swedish Environmental Advisory Council on economic growth and the environment in a long-term global perspective (Memorandum 2007:1).

The importance of a sustainable use of natural resources and ecosystem services is not sufficiently highlighted in the current debate and has therefore been chosen by SEAC as a main focus in its analysis. The council has identified the use of forest products, fresh water, arable land and marine fisheries as particularly important biological resources. Significant issues are the environmental effects of the use of these resources especially considering the effects of climate change on productive capacity.

This background report consists of four chapters, dealing with issues related to climate change and the use of natural resources. The first chapter describes some of the available long-term economic models (spanning to 2045) and complements these with a demographic model that is used for the analysis in chapters 2 and 3. Chapter 2 presents scenarios on potential future demand for energy, forest products and some possible scenarios for carbon dioxide emissions. In chapter 3, the economic scenario in chapter 1 is used to estimate future water demand given that diets will change substantially as countries attain a higher income. Using information from chapter 2 and IPCC, water demand for an estimated use of bioenergy is also calculated. The results presented in chapters 2 and 3 are used as a basis for estimating the areas of land needed to produce the potential demand for biomass. Chapter 4 presents a range of scenarios for the potential use of bioenergy. The aim of developing the scenarios is not to make forecasts about the future but to indicate a possible development if trends prevail as in the past.

Contents

1 Global income growth in the 21^{st} century – a comparison of IPCC, Solow, and dividend models

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1.1 Introduction

During the last ten years different attempts have been made to project global income growth in the 21^{st} century. Among these different projections, three types of models can be distinguished.

The first and most common type of projections are not based on an explicit formal model. Instead, they provide numerical estimates of GDP growth across the world that reflect different assumptions about future development trends, for example high growth/low growth or decreasing/increasing income gaps. With some justification this models can be called IPCC models. The reason is that many of these scenarios have been developed and used by the International Panel of Climate Change as a basis for their CO_2-emissions scenarios (Nakicenovic and Intergovernmental Panel on Climate Change 2000).

A second type of models are explicitly based on the Solow growth model framework. A Solow growth model considers primarily labor, capital and technology inputs as the determinants of economic growth. Solow-based projections, thus, are based on assumptions about savings rates, labor-force growth, and technical change. Recently, much attention have been given to long-term forecasts for the world economy based on the Solow framework (Wilson and Purushothaman 2003; Hawksworth 2006).

A third type of model is based on the demographic-dividend approach. This approach is based on new findings on the role demographic factors plays in economic development. An important difference from earlier demographic approaches is that age structure, not population growth, is seen as the primary determinant of economic growth. In addition, the dividend approach emphasizes that low mortality is not only the result, but also an important stimuli for economic development (Malmberg and Lindh 2005).

The aim of this paper is to compare the scenarios generated by these different approaches. To what extent do they give a consistent or divergent pictures of world development during the first half of the 21^{st} century? Another question is which scenario is most plausible? It will be argued that the dividend model has several advantages.

First, the dividend model provides a growth scenario that is consistent with the demographic-macro economic correlations that have been observed since 1960. Scenarios that use the same demographic assumptions as the dividend model but presents different economic outcomes, therefore, implicitly assume that the economic-demographic correlations observed in historical data will no longer hold in the 21^{st} century. This is, of course, perfectly possible, but to be accepted the assumption of such a structural break should be supported by a convincing argument.

Second, the dividend model has been demonstrated to be relatively stable in out-of-sample tests. This is not the case with the IPCC and Solow-model projections. A lack of out-of-sample tests clearly makes it difficult to judge how reliable the non-dividend models are.

Third, the dividend model clearly pin-points to possible mechanisms whereby the projected growth trajectories can be influenced by policy interventions: Family planning policies that have an effect on fertility and health policies that change life-expectancy. The non-dividend models are not policy models in this regard.

In Section 1.2, 1.3, 1.4 below the assumptions of the IPCC-, Solow-, and Dividend-projection models are presented more in detail. Section 1.5 compares quantitative GDP per capita projections for the different models.

1.2 IPCC projections

Scenarios for future CO_2 emissions into the atmosphere are one of the main inputs into the models of climate change that researchers around the world are working with. The emission scenarios, in turn, are based on different economic scenarios. Considering the importance of the CO_2-issue for future changes in the climate and for global policy-making it is natural to give the economic scenarios used by the IPCC special attention. For the IPCC economic projections are but a stepping-stone towards a forecast of future climate change. Their report is not a statement on future trends in global economic development. This, however, is not necessarily a disadvantage, since it promotes a pragmatic approach to economic projections.

The emission scenarios presented by the IPCC are the result of a large-scale, multi-continent, scenario-building effort. In a first step, more than 400 different scenarios where assembled in a shared database. Eventually a set of 40 scenarios were presented, each of which was based on assumptions about both population growth and economic development in the world. The scenarios were produced by six independent groups using IPCC guidelines for assumptions about global economic growth rates, population growth, and economic trends in broad world regions. IPCC economic scenarios, thus, are not the results of independent scenario building. Instead, they are different implementations of similar economic-demographic frameworks (Nakicenovic and Intergovernmental Panel on Climate Change 2000).

Table 1 presents the different economic-demographic frameworks that are uses in IPCC's report on emission scenarios. As Table 1 shows, A1 and A2 represents the extreme cases: A1 with strong growth in global GDP and relative slow population growth. A2 with relatively slow growth in GDP and high rates of global population growth. B1 and B2, in turn, represents more moderate variants of A1 and A2. In B1 the rate of GDP growth is somewhat slower than in A1 but both have the same rate of population growth. In B2 the rate of population growth is lower than in A2 but the rate of GDP growth is the same. It can be noted that the IPCC implicitly assumes a negative correlation between population growth and GDP growth since the highest rates of GDP growth are associated with low levels of population growth. And there is an even stronger negative effect of population growth on GDP per capita.

Table 1 IPCC's Economic-Demographic assumptions

		Global GDP growth		
		Medium	*High*	*Very high*
Global	Low	-	B1	A1
Population	Medium	B2	-	-
Growth	High	A2	-	-

All four IPCC variants are based on assumptions on global trends. Thus, the scenarios do not start from an analysis of conditions for economic growth in different countries and then aggregates the results to the global level. Instead there is a top-down approach where the scenario assumptions are made at the global level.

How then, does the IPCC arrive at the global assumptions? The discussion in the report gives the following answer:

For A1 the IPCC states that "the global economy is projected to expand at an average annual rate of 2.9 % … roughly in line with historical experience over the past 100 years". Assuming such a high growth rate for global GDP is radical and bold. On the other hand, if the global economy has expanded at roughly this rate for a long time, why not build a scenario on the assumption that this experience can repeat itself?

In B1, the assumption of rapid global growth in GDP is somewhat moderated. It is assumed to be 2.5 % per year, "slightly less than the long-term historical average" of 2.7 %. The effect is that A1 and B1 can be seen as representing confidence bounds around the "long-term historical average" annual growth rate of global GDP.

A2, instead, starts out from the experience of relatively slow GDP per capita growth in recent decades. During the 1970–1995 period global average growth rate in per capita income was 1.2 %. If that experience repeats itself we can get the A2 projection of 1.3 % annual growth in per capita income. Also the slow-growth A2 scenario, thus, is based on historical precedence.

The population growth in the A2 scenarios is assumed to around 0.9 %. This gives a growth rate of total GDP of 2.2 % per year. This level corresponds to the median growth rates in the scenarios of the IPCC database. Thus, the A2 growth rate can also be seen as consensus level GDP growth.

The B2 scenario is also based on an assumption of a 2.2 % growth rate in total GDP. In B2, however, the population growth rate is lower and this gives room for higher GDP per capita levels. Since the population growth rate is based on the UN median population projections it is possible to see B2 as a consensus alternative with respect to both population and economic growth.

1.3 Solow-model-type projections

A major advantage with the Solow-model type projections of long-term income growth is that they are based on an explicit economic model. Although the Solow model is very simple it has proved to be a valuable tool in the analysis of economic growth. Moreover, the Solow model has been used in literary thousands of studies. Economists, therefore, have a detailed knowledge of how the model works in both empirical and theoretical applications.

Still, it is only recently that the Solow model has been applied to the study of growth processes at the global level. In order to explain why a short discussion of the Solow model can be of interest.

The basis of the Solow model is a production function that relates output (GDP) to the input of labor and capital. In addition to labor and capital the production function contains a productivity index, often called “technology”. An increase in the productivity index (often called technical change or technological growth) implies a higher output even for an unchanged input of labor and capital. In a Solow model it is assumed that the production function is characterized by constant returns to scale. This signifies that a doubling of both labor and capital inputs will lead to no more and no less than a doubling of output. More specifically it is generally assumed in empirical applications that the production function is of a particular form, called Cobb-Douglas, where total output, Y, is expressed as below (equation 1):

$$Y = AL^{\alpha}C^{1-\alpha},\ 0 < \alpha < 1$$

Here, L stands for total labor input (number of workers), C is the input of capital, and A is the productivity index. From (1) output per worker (*Y/L*) can be obtained by dividing both sides with *L*, i.e. equation (equation 2):

$$\frac{Y}{L}=\frac{AL^{\alpha}C^{1-\alpha}}{L}=A\left(\frac{C}{L}\right)^{1-\alpha}$$

In an economy output per worker is one of the most important variables. The reason is that output per worker, together with share of workers in the population, determines GDP per capita, or per capita income. What equation (2) does is to help us explain how output per worker and, hence, per capita income can be increased.

One way to increase output per worker is to increase the amount of capital that workers have at their disposal. That is, to increase C/L, generally called the capital-labor ratio. What will be the effect of an increase in capital on output per worker? If α had been close to zero a doubling of the capital-labor ratio would have nearly doubled output per worker. But if α is higher, doubling of the capital-labor ratio will less than doubled output per worker. In practice, economists think that a probable value of α is around 2/3. This implies that increases in the amount of capital per worker will result in smaller and smaller increases in the amount of output per worker. This is called diminishing returns and is what happens in a model with constant returns to scale if only one factor, in this case, capital is increased.

Solow's conclusion is that an increasing capital-labor ratio cannot bring about continuous growth in output worker. His argument is this. If a given share of annual output is saved each year, this gives room for an increase in the capital stock. An increasing stock of capital, in turn, generates a higher output and hence an even larger volume of saving. However, because of diminishing returns, output per worker will increase less than in proportion to the increase in the capital stock per worker. Moreover, as the capital stock increases more capital will wear out. This increases the requirement for replacement investments, an increase that will be proportional to the increase in the capital stock. Eventually, diminishing returns will lead to a situation where the additional saving coming from the extra output that an increase in the capital stock generates, will be just enough to cover the extra capital-replacement requirements that the newly added capital gives rise to. When this situation arises and all the new saving will be used for capital replacement, there will not any longer be any increase in the capital stock per worker. Hence, there will be no increase in output per worker. Economic growth will come to a halt.

The second possibility to increase output per worker is a higher productivity index, A. This has a strong and direct effect on the ratio of output per worker. Solow's conclusion is that technological change that generates increases in A is necessary for generating sustained growth in output per worker and per capita GDP. Simple capital accumulation will not do the trick.

For GDP forecasting this is an important conclusion. Different rates of capital accumulation-that is, savings rates-and changes in the ratio of workers to total population will have effects on per capita income. But for longer time-horizons the rate of change in the productivity index will, in most cases, be the most important determinant of the long-run growth rate.

An important challenge when the Solow-model is applied to real world is how to account for the large gaps in per capita income between poor and rich countries.

One way is to assume that these gaps reflect different capital-to-labor ratios. The problem is that if large differences in capital-to-labor ratios would imply that capital investments in poor countries where the capital-labor ratio is low would generate much higher returns than investment where high capital-labor ratios have led to diminishing returns to capital. Since we do not observe very high rates of inwards investment to the poorest countries this line of explanation is problematic. If, on the other hand, the productivity index is on a lower level in poor countries then differences in per capita level of income are consistent with low levels of inward investment in these countries.

The idea that technology levels differs between countries implies that growth in per capita income can result from four sources: (1) A high savings rate that generates increases in the capital-labor ratio (2) demographic change that increases the share of working age adults in the population. (3) An increase in the productivity index as low income countries approach the technological levels of the most advanced countries. (4) Improvements in best-practice technology.

Solow-model-type projections takes into account all these sources of per capita income growth. Typically, savings rates assumptions can be based on the observed levels during the last years. Labor force and population growth assumption can be based on populations projections from the Population Division of the

United Nations. Numerous studies of growth in developed countries have also led to a consensus that the long-run growth rate of the productivity index in the leading countries can be assumed to be around 1.5 percent per year. A more difficult question is how the process of technological convergence should be modeled for low-income countries. A model that has proved to be successful for the technological catch-up of developed countries is the following (equation 3):

$$\frac{\Delta A_i}{A_i} = \beta * \frac{A_{USA} - A_i}{A_i}$$

What this model assumes is that the growth rate of the productivity index is higher in countries that have a large productivity gap in relation to the technological leader, assumed to be the United States. How much of this productivity gap that is closed each year is dependent on the speed-of-technological-convergence parameter b. Empirical studies of developed countries have shown that b is about 1.5 %.

During the last years, Solow models of the type outlined above have been put to use in making forecast up to 2050 for a number of large countries. The results have been given much attention. For example, one report from Goldman-Sachs (Wilson and Purushothaman 2003), has analyzed the future growth of Brazil, Russia, India, and China with the Solow model. Another report, "The World in 2050" from PriceWaterhouseCoopers, uses a similar model to analyze the 17 largest economies in the world measured by purchasing power, including the emerging economies Indonesia, Mexico and Turkey in addition to the four countries that were analyzed in the BRICs report (Hawksworth 2006).

The results from these two studies are similar. They project strong growth in these emerging economies with the result that will catch up rapidly with the today's richest countries. A convergence of per capita income in combination with large population implies that countries like China, India and others will become major players in the world economy, and in many cases overtaking today's dominants.

Analyzed more in detail, it is evident that these results to a large extent are based on the assumption that technological convergence will be rapid for these emerging economies. For example, in 2000 the GDP per capita in the United States was 14 times larger than in India. With a speed of convergence of 1.5 % this would translate into a per capita income growth rate for India of 4 % thanks only to technological catch-up. Moreover, after 50 year of technological convergence the per capita income of the United States would not be 14 times, but only twice as large as India's.

Thus, technological convergence of the scale envisioned in Solow-model-type projections has the power to drastically reduce the income difference between rich and poor countries. But this is also perhaps on of the most important explanation for the fact that the economists have been reluctant to use the Solow-model for long-term projections of global income growth. Such an hesitation is also present in the recent application of the Solow model to such projection. Wilson and Purushothaman, for example, call their report "Dreaming with the BRICs", indicating that their projections is perhaps not literally a forecast but a vision based on the Solow model. Moreover, neither Hawksworth (2006) nor Wilson and Purushothaman (2003) include countries like Nigeria in their projections. The explanation can be that for emerging economies that recently have achieved impressive growth rates it is conceivable that the Solow model can capture future growth rates. However, for countries that have failed to demonstrate any clear improvements in per capita income a Solow model with technological convergence doesn't provide a convincing story.

Goldman-Sachs and PriceWaterhouseCoopers have carried out Solow-type projections for some of the largest economies in the world but not for all countries. In order to obtain a global projection the methods used by Goldman-Sachs and PriceWaterhouseCoopers where applied to a dataset of 129 countries for which the necessary input data could be obtained. This needed input is data on labor force growth and population growth for the projection period, data on the current aggregate savings rate, per capita income and data on the current capital stock. Data on labor force (working age population) growth and population growth was obtained from UN (2004). Current per capita income and investment rate were taken from WDI. Since no data for the capital stock could be found for these countries it was simply assume that the capital stock is equal to GDP times five. This is crude an will give yield false medium-term projections for countries with capital stocks that are far from their equilibrium levels. For the long-term forecast of GDP per capita the initial capital stock has no effect though.

Since the observed values of the aggregate investment rate can be influenced by transitory factors these were not used directly in the projection. Instead countries where assigned to one of six different levels of investment based on their mean level of investment after 1995. The lowest level assigned was 17.5 % and the highest 32 %, see appendix.

As discussed above, the most important in Solow-based projection is, however, the assumption made with respect to technological change. Here, three different assumptions have been tried. The first is to assume fast technological convergence for all countries. This implies setting the value of b in equation to 1.5 % the standard value for technological convergence in developed countries. This will generate very fast growth in today's poorest countries since these are the ones that have the largest technological gap to close.

The assumption of unconstrained technological convergence does not, however, fit with the growth experiences globally of the last fifty years. An important pattern in this period is that a large number of poor countries have failed to achieve any substantial gains in per capita income. To capture this patter a constrained convergence pattern can be assumed according to which technological convergence is slow for very poor countries, picks up speed in middle income countries, and reaches the standard level only when a country has joined the club of developed economies.

A third more optimistic assumption is that countries reach a take-off point when the enter the group of middle-income countries and then can profit from the standard level of technological convergence. The assumptions made in the unconstrained, take-off, and constrained convergence model are detailed in Table 2.

Table 2 Rate of Technological convergence, three assumptions

	GDP per capita		
	Less than 7,000 US$	*7,000-22,000 US$*	*More than 22,000 US$*
Unconstrained convergence	1.50 %	1.50 %	1.50 %
Take-off convergence	0.10 %	1.50 %	1.50 %
Constrained convergence	0.10 %	0.75 %	1.50 %

1.4 Demographic dividend projections

Demographically-based projections of economic growth are based on a set of empirical findings made in the mid-1990s and onwards. The most important of these findings is the demographic-dividend effect, a discovery that solved a 200-year old problem in economic analysis. Ever since the time of Adam Smith and Robert Malthus economist have debated how population growth affects economic growth. Some have argued that population growth, via a positive effect on demand, stimulates economic development (Boserup 1981; Simon 1981). Others insisted that an expanding population, by lowering land-labor and capital-labor ratios, brings about a lower per-capita income. Empirically, the issue stayed largely unresolved until the 1990s (Kelley 1988), which is surprising considering how simple the solution turned out to be.

What the mid-1990s studies demonstrated was that the effects of demographic change on economic development depends on the nature of population growth. Is there an expansion of children, working-age adults or post- working-age adults? The economic behavior of individuals varies of the life-cycle and, therefore, the macro-economic effects will differ depending on the age-composition of population growth. Once this is acknowledged the empirical correlation between population change and economic growth turns out to be strong and clear-cut: An increase in the young dependent population has a negative effect on per capita income growth, whereas an increase in the working-age population has a positive effect (Brander and Dowrick 1994; Malmberg 1994;

Kelley and Schmidt 1995; Crenshaw, Ameen et al. 1997; Bloom and Williamson 1998).

It can be asked why it took so long for a simple idea like this to be acknowledged and empirically demonstrated? One possible explanation is that the empirical data required didn't become readily available until the early 1990s. One example is the Penn World Tables that were supplied on floppy disks in 1988 and reissued in a new version in 1991. The Penn World Tables, also referred to as the Summers-Heston data set, contain PPP-adjusted measures of per capita income for more than 100 countries for the post-1960 period. As second important data set, The World Population Prospects, with data on age distributions, was first released electronically on floppy discs in 1989. The first CD-ROM release of the World Development Indicators (registered in the Library of Congress) is dated 1991. When these data were at hand it became straight forward to decomposition population growth into different age components and then asses their effect on per capita income growth separately from each other.

Differential age group effects was one finding that paved the way for demographically based long-term economic forecast. Another important step was taken when the relation between low mortality and high per capita income was given a radical re-evaluation. Increasing income has traditionally been seen as a major driving force for improved health and increased life expectancy. No one questions this but from the late 1990s there was an increased interest also in the possibility that improved health also can stimulate economic development. Theoretically, four different paths can be of importance. First, higher life expectancy can increase the expected returns to education. Individuals that can expect longer working lives benefit more from an education that raises their annual wage than individuals with a short working life. Second, increased life expectancy implies that more people can expect to reach retirement age. This is likely to increase the amount of saving for retirement purposes. Third, low mortality is a trigger of low fertility. The mortality decline, therefore, has been as a driving force for a shift from investments in child quantity to child quality. Fourth, lower adult mortality also stimulates a more extensive division of labor. These theoretical considerations have also been given strong support by empirical studies (Ehrlich and Lui 1991; de la Croix and Licandro 1999; Kalemli-Ozcan, Ryder et al. 2000; Blackburn and Cipriani 2002; Kalemli-Ozcan 2002; Bloom and Canning 2003; Boucekkine, de la Croix et al. 2003; Lagerlof 2003; Bloom, Canning et al. 2004).

Taken together, age-structure and life-expectancy effects on per capita income implies that population projections such as the ones published by the United Nations can be used to forecast future changes in per capita income. This is not to say that demography is the only factor that determines economic growth. To the contrary, there is a broad range of circumstances that have been demonstrated to correlate with per capita income growth. However, in many cases, these correlations are difficult to use in forecasting since we do not have access to projections of the explanatory variables. Thanks to the UN projections this is not the case for the demographic variables. Using historical time-series to estimate a demographic model of per-capita-income growth, thus, will yield a model that can generate predictions of future economic development for countries that are included in the UN demographic projections.

Such an estimation has been done by Malmberg & Lindh (2004). The results of the estimation are presented in table 3. The model is based on life-expectancy at birth, and log population shares for the 0–14, 15–29, 30–49, 50–64, and 65+ age groups. A hallmark of the model is that the parameters estimated for each age group are allowed to vary in response to changes in life expectancy. The motivation for this is exactly that life cycle patterns in economic behavior with respect to saving, human capital formation, and fertility change with shifts in life expectancy. The table thus shows what the age effects look like at different level of life expectancy.

Table 3 Parameter estimates for the Dividend model

	Level of life expectancy				
	40	*50*	*60*	*70*	*80*
Intercept	19.96	21.17	22.16	22.99	23.72
Log 0-14	-1.53	-1.30	-1.10	-0.94	-0.80
Log 15-39	0.49	0.29	0.13	0.00	-0.12
Log 30-49	0.73	0.55	0.40	0.27	0.16
Log 50-64	0.31	0.32	0.32	0.32	0.33
Log 65+	-0.69	-0.27	0.07	0.36	0.61

Several things can be noted in the table. First, the increase in expected per capita income that results from lower mortality should be noted. But age structure also plays an important role. There are, for example, strong negative effects of high shares of children in the population. Therefore, especially at low levels of life expectancy, there will be large gains in per capita GDP when a decline in fertility reduces the share of children and increases the share of young adults. The model, thus, contains a strong demographic dividend effect.

As life expectancy increases, the age pattern changes and increasing population shares for older adults becomes a more important driving force for higher per capita income. This should come as no surprise considering the large differences in economic structure that exists between countries with high and low life-expectancies. An important message of the model, though, is that population aging, so far, has been associated with increasing per capita incomes. Although more research is needed here, this model does not single out population aging as a factor that will bring an economic downturn.

The original dividend model was estimated on data for 111 countries over the 1960–1996 period but it can be used for all countries for which both demographic and data on initial GDP per capita are available. The projection presented below includes 158 countries and is based on United Nations (2005) and World Bank (2006). The jump-off year for the projection is 2000, that is, the projections have been calibrated in order to have a correct value at that date. The calibration was done using ppp GDP per capita from the on-line version of World Development Indicators.

An overview of the projection results is given in Figure 1a, 1b, 1c, and 1d. Consequences for growth in total GDP are presented in Table 4.

Figure 1a Per capita income growth, dividend model projection, 2000–2050, Africa, US$

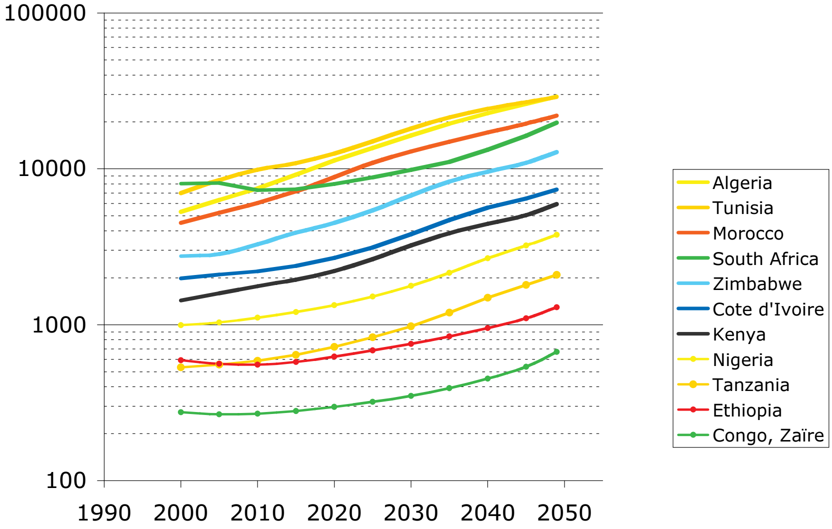


Figure 1b Per capita income growth, dividend model projection, 2000–2050, Asia, US$

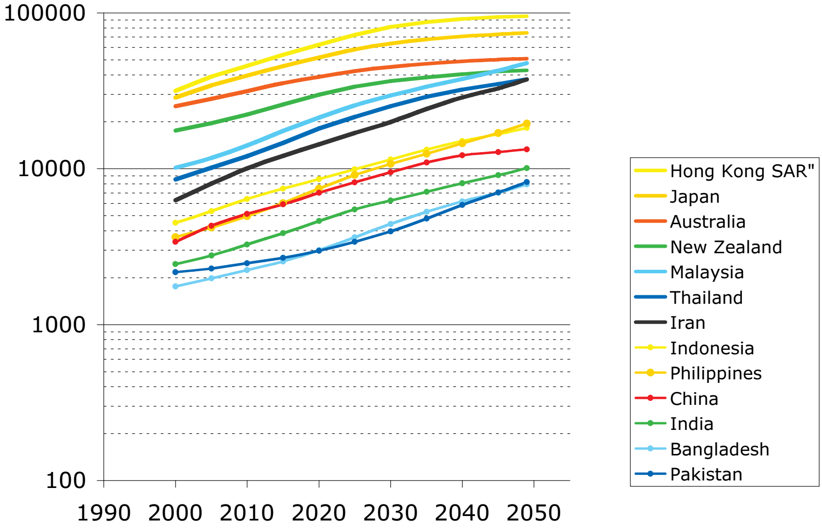


Figure 1c Per capita income growth, dividend model projection, 2000–2050, America, US$

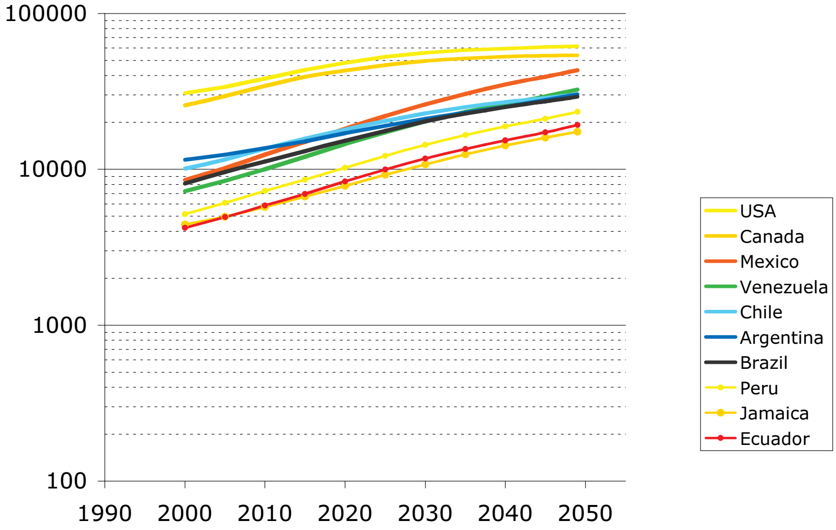


Figure 1d Per capita income growth, dividend model projection, 2000–2050, Europe, US$

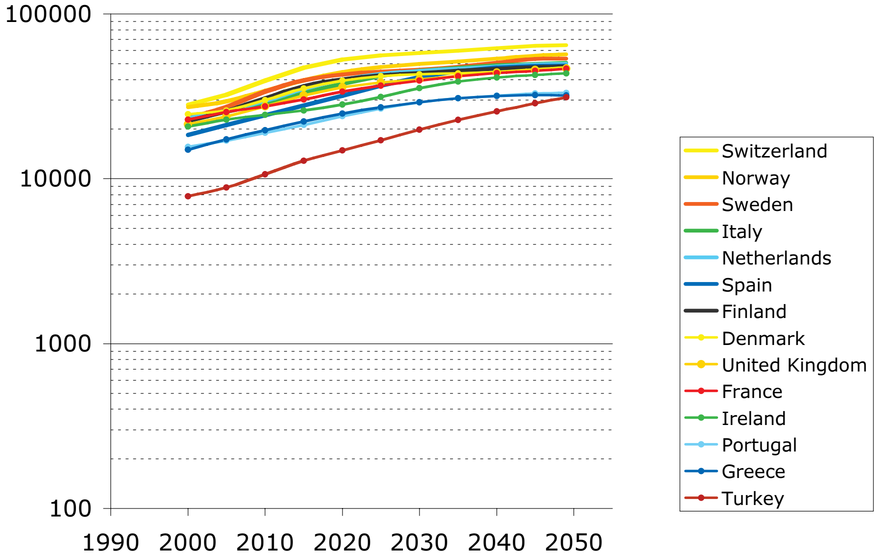


Table 4 Distribution of global GDP by world regions 2000-2050, Billion US$

	2000	*2020*	*2035*	*2050*	*2000-2050 growth rate*
EU 25	10 400	16 500	20 200	21 300	1.4 %
North America	10 600	18 400	25 500	31 000	2.1 %
Latin America and the Caribbean	3 700	9 400	17 600	27 400	4.0 %
East Asia	9 000	19 800	29 000	32 900	2.6 %
South East Asia and Oceania	2 400	5 900	10 300	15 300	3.7 %
Middle East	2 000	5 200	11 000	19 100	4.5 %
Sub Saharan Africa	1 100	1 800	3 200	5 900	3.4 %
South Asia	3 100	7 300	14 200	23 700	4.1 %
Former SU	1 500	2 000	2 600	2 800	1.2 %
Non EU Europe	600	1 100	1 300	1 400	1.7 %
Total	44 300	87 500	135 000	180 800	2.8 %

1.5 A comparison of projections

The IPCC scenarios are, as explained above, not based on country-level projections but on assumptions on the global growth rate of GDP. The comparison, therefore, can start with a look on the global implications of the Dividend and Solow projections in relation to the IPCC scenarios. Such a comparision is provided in Table 5.

Table 5 Growth rates of global GDP and global GDP per capita

	Per capita	*GDP*
IPCC, B1		2.5 %
Constrained	1.6 %	2.6 %
Take off	1.8 %	2.7 %
IPCC, A1		2.9 %
Dividend	1.9 %	2.9 %
Unconstrained	3.1 %	4.1 %

A first observation here is that the Solow model with unconstrained convergence generates a very high growth rate both in global GDP and global GDP per capita. 4.1 % growth in global

GDP is 33 % faster than in the very-high-growth IPCC scenario. Although such a fast growth cannot be ruled out, few people would consider it a probable scenario.

A second observation is that the Solow take-off scenario and the dividend projection gives similar results on the global level. The difference is only one-tenth of a percentage point.

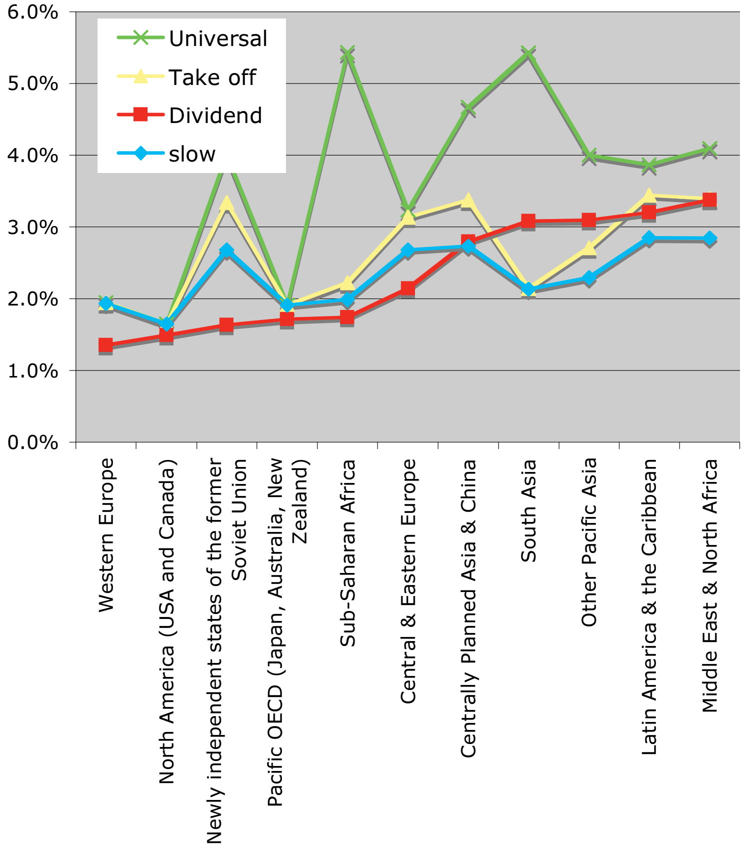
A third observation is that 2.9 % growth rate in global GDP projected in the dividend scenario is equal to the growth rate assumed in IPCC's very-high growth scenario A1. The take-off scenario growth rate is equal to the long rate growth noted in the IPCC report. The growth rate in the constrained technological convergence scenario of 2.6 %, on the other hand, lies close to IPCC's moderated, high growth scenario B1.

The conclusion is that the IPCC high growth scenarios, Solow-based projections and the Dividend projections generates remarkably similar predictions of the growth rate in global GDP. Is this a coincidence? Not really, all these projections are to a large extent based on the growth experiences of the second half of the 20th century. This is the case both for the standard 1.5 % value of the technological convergence parameter, the 2.7 % long-term growth rate used by the IPCC, as well as the estimated dividend model.

What is reassuring, however, is that the different approaches reach similar results in the projection despite being based on different models of the growth process. The IPCC, in principle, uses a trend-conservation assumption, even if they also verbally discuss convergence as an important driving force. In the Solow-projections technological convergence is explicitly what drives the projection, whereas the dividend approach relies strongly on the importance of mortality trends and age structure shifts. If the end result is not critically sensitive to the approach taken this can be seen to indicate that the processes under study demonstrate a level of persistence that makes them amenable to long-term forecasting.

The regional level projections for per capita income growth in the 2000–2050 period are presented in figure 2 below. The regions have been sorted by the growth rate as predicted in the Dividend projection. According to this projection, the relatively slow growth will be experienced by Western Europe, North America, the former USSR- region, and Sub-Saharan Africa. High growth will characterize China, South Asia, South-East Asia, North Africa and the Middle-East, Latin America and the Caribbean.

Figure 2 Per capita income growth by world regions



The constrained-convergence (slow) and Take-off projections gives a similar picture with some exceptions, most importantly the former Soviet Union. Here, the Solow-models (universal, take-off, slow) predict strong growth, since low per capita incomes in this region gives much room for catch-up. The dividend model, on the other hand, predicts low per capita growth since this area will have relatively little demographically driven economic growth. A similar but somewhat weaker difference is present for Central and Eastern Europe. On the other hand, for South, and South East Asia the dividend model predicts higher growth than the constrained (slow) and take-off convergence models.

However, also in the regional analysis it is the unconstrained convergence (universal) projection that differs most fundamentally from the others. The largest discrepancies are found for poor regions like Sub-Saharan Africa, China and South-Asia.

The conclusion for these projections is that the prospects for convergence in per capita income over the next decades are good. In 2000 only 800 million people lived in regions with a mean level of GDP per capita above 10,000 US$. In 2050, according to the dividend projection, 7 billion people, about 80 % of the world population will live in such regions. Among the US$ 10,000+ regions there will still be differences but they will not be as deep as they are today.

Sub-Saharan Africa is the region that will not reach above 10,000 US$. Here the dividend projection suggest that the mean level of per capita GDP in 2050 still will be less then 5,000 US$. At the same time, Sub-Saharan Africa's share of the world population will have increased from 10 % to 20 %. The dividend model points at continued high fertility and lingering high mortality as the main reason why Africa will lag behind. However, both fertility and health are factors that can be influenced by concerted policies. Continuing poverty in Africa, thus, isn't destiny but a situation that is possible to address.

Appendix

Savings rates assumptions

17.5	*20*	*22.5*	*25*	*28*	*32*
Colombia	Denmark	Ireland	Austria	Algeria	Mongolia
Niger	Tajikistan	Lebanon	Chile	Czech Rep.	Azerbaijan
Angola	Argentina	Albania	Congo Rep.	Eritrea	China
Bolivia	Armenia	Australia	Croatia	Hong Kong	Honduras
Burundi	Belgium	Bangladesh	Haiti	Jamaica	Iran, Islamic Rep.
Cambodia	Benin	Belarus		Korea, Rep.	Nicaragua
Cameroon	Bosnia and Herzegovina	Brazil	Hungary	Portugal	Singapore
Central African Republic	Bulgaria	Burkina Faso	Japan	Slovak Republic	Turkmenistan
Congo, Dem. Rep.	Canada	Chad	Latvia	Vietnam	
Cote d'Ivoire	Costa Rica	Dominican Republic	Malaysia		
Egypt, Arab Rep.	Finland	Ecuador	Mozambique		
El Salvador	France	Georgia	Nepal		
Ethiopia	Guinea	Germany	Panama		
Guatemala	Italy	Ghana	Spain		
Kenya	Kyrgyz Republic	Greece	Sri Lanka		
Kuwait	Mauritania	India	Thailand		
Madagascar	Pakistan	Indonesia	Tunisia		
Malawi	Papua New Guinea	Israel	Turkey		
Oman	Philippines	Jordan			
Rwanda	Poland	Kazakhstan			
Sierra Leone	Saudi Arabia	Lao PDR			
South Africa	Senegal	Lithuania			
Sweden	Sudan	Mali			
Tanzania	Togo	Macedonia			
United Kingdom	Uganda	Mexico			
Uruguay	Ukraine	Moldova			
Zimbabwe	United States	Morocco			

Uzbekistan	Netherlands
Yemen, Rep.	New Zealand
Zambia	Nigeria
	Norway
	Paraguay
	Peru
	Romania
	Russian Federation
	Switzerland
	Syrian Arab Republic
	Venezuela

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2 Global scenarios for energy, carbon dioxide and forest products

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2.1 Introduction

In this report we construct simple projections of primary energy supply[1], carbon dioxide emissions and consumption of forests product based on historical data. Making scenarios or forecasts of future resource use is a difficult task. In some cases, long time scenarios are based on storylines where different features of the development are qualitatively described, and these storylines thereafter influence assumption in the scenarios made. The scenarios we put forward here should be regarded as projections rather than scenarios. We simply assume that the past development continues into the future. By using regression analysis we find relationships between economic development and resource use, and assume that these remain in the future. By adopting this methodology we stay close to the historical data and refrain from making our own assumptions as much as possible.

The report is structured as follows: In section 2.2 we introduce the general regression and projection method used. In section 2.3 and 2.4 results for wood product consumption and energy use respectively are presented. In section 2.5 our projections are discussed in relation to other studies.

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[1] We use the concept primary energy supply instead of energy demand, since what is really demanded by consumers is final energy delivered, or even energy services. Ideally our analysis would be based on final energy demand, but due to lack of data we study primary energy supply.

2.2 Method

The methodology used for constructing projections is based on the historical relationship between time, GDP/capita and consumption/use of resources. From these historical data regression analysis is used to estimate income elasticities and non-income related time trends. Other methods would have been possible, but the chosen method is common for these kinds of analyses and is rather simple and transparent.

In these projections we are mainly concerned with the relationship between GDP/capita and resource consumption. Therefore we try to estimate the income elasticity, i.e. approximately how many percentages the resource use per capita increase for a one percent increase in GDP/capita. However, it is reasonable to assume that the income elasticity is dependent on the level of income. For high-income levels resource use may be saturated, whereas resource use may increases rapidly for lower income levels (Schmalansee et al 1998). We therefore make a piecewise linear regression of the income elasticity. We divide the GDP/capita into different intervals, with breakpoints, $\hat{Y}_j$ and estimate the income elasticity, γ_j, within the interval $\hat{Y}_j$ and $\hat{Y}_{j+1}$. For different resources we use different income breakpoints in order to get significant estimates of the coefficients.

We assume that the resource use per capita in a country *i* at time *t*, C_{it}, is dependent on a country dummy α_i an exogenous time trend β and the per capita income Y_{it}. We then get the expression

$$\ln(C_{i,t}) = \alpha_i + \beta \cdot f(t) + \sum_j \gamma_j \cdot \ln\left(\frac{Y_{i,t}}{\hat{Y}_j}\right) + \varepsilon_{i,t} \qquad \gamma_j = 0 \text{ for } Y_{i,t} < \hat{Y}_j$$

where ε is the stochastic error term. In order to decide the best functional form *f(t)*, we introduced time dummies for each year and plotted the time dummies in order to evaluated a reasonable functional form. For all resources $f(t) = \ln(t)$ gave the best fit.

The country dummies, α_i,, separate out what are country specific factors such as affluent forest resources or coal reserves etc from factors that are only dependent on time and GDP/capita.

When making the projection we transform the function above to its exponential equivalent, leaving out the error term and the country dummies. Thus, we rewrite the above expression as

$$C_{i,t} = K_i \cdot t^{\beta} \cdot \prod_j \left(\frac{Y_{i,t}}{\hat{Y}_j} \right)^{\gamma_j} \qquad \gamma_{\mathrm{j}} = 0 \text{ for } Y_{jt} < \hat{Y}_j$$

Instead of the country dummy we recalibrate the function using the constants Ki which are calibrated so that the resource use per capita for the year 2000 match the official average for the years 1999–2001 for every country. This expression is subsequently used to do the projections. For future GDP estimates we use scenarios made by Malmberg and Lindh (2004).

2.3 Paper and wood products projections

2.3.1 Data

For *paper and paperboard* consumption as well as s*awnwood and wood for panels* a total of 67 countries were used. For the countries included in the analysis, samples of GDP/capita in PPP terms from Heston et al (2002) and consumption of the *paper and paperboard and sawnwood and wood for panels* from FAOSTAT (2006) were taken for the years 1961 to 2000. The consumption was calculated as production plus import minus export. However, the data are probably quite uncertain since the consumption varies quite a lot from year to year for some countries. Still, the data should give a sufficiently good indicator of the actual consumption. Further, data for production of *recovered paper* was obtained from FAOSTAT (2006) to calculate the paper recovery rate.

2.3.2 Scenario design

For paper and paperboard we found two different income breakpoints with significant coefficients, 5000 and 12000 USD/capita. The regression coefficients are found in table 1, and should be summed up to be interpreted as elasticities, thus for income below 5000 USD/capita the income elasticity is 0.696. For incomes between 5000 and 12000 USD/capita the income elasticity is 0.696+0.166=0.862, and so one. For paper and paperboard we found a positive time trend. For sawnwood and panels we found significant coefficients for three breakpoints; 3000, 6000 and 15000 USD/capita and a negative time trend, see table 1.

We further estimated the GDP:s effect on the paper recovery rate. We assumed the recovery rate (expressed in ‰) at time t in country i, Z_{it}, to be dependent on a country dummy α_i, time and income per capita Y_{it}, thus

$$Z_{it} = \alpha_i + \beta \ln(t) + \eta Y_{it}$$

Using regression we found the coefficients shown in table 1

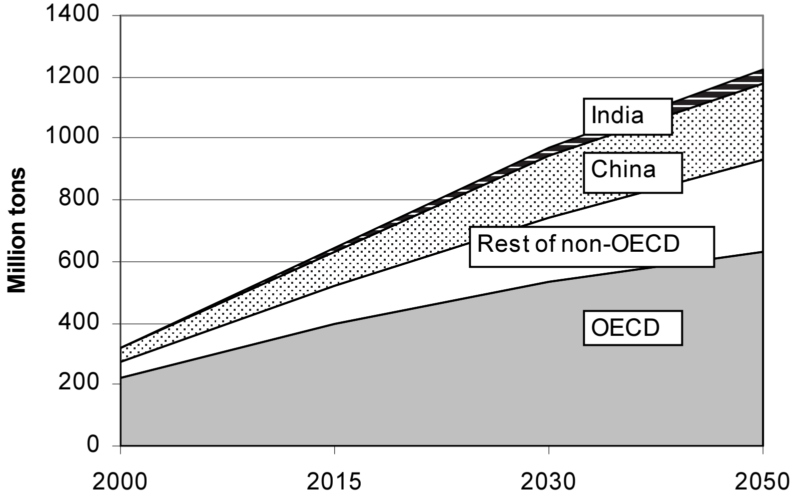
Table 1 Regression coefficient for consumption of wood products

	Coeff	*Standard error*
Paper and paperboard	--	--
β	0.172	0.014
$\gamma_0,\ \hat{Y}_0 = 1$	0.696	0.051
$\gamma_1,\ \hat{Y}_1 = 5000$	0.166	0.097
$\gamma_2,\ \hat{Y}_2 = 12000$	-0.597	0.133
Sawnwood and wood for panels	--	--
β	-0.080	0.015
$\gamma_0,\ \hat{Y}_0 = 1$	0.523	0.063
$\gamma_1,\ \hat{Y}_1 = 3000$	-0.255	0.118
$\gamma_2,\ \hat{Y}_2 = 6000$	0.442	0.129
$\gamma_3,\ \hat{Y}_3 = 12000$	-0.390	0.174
Paper recovery rate	--	--
η	0.007	0.001
β	60.351	2.880

2.3.3 Projections

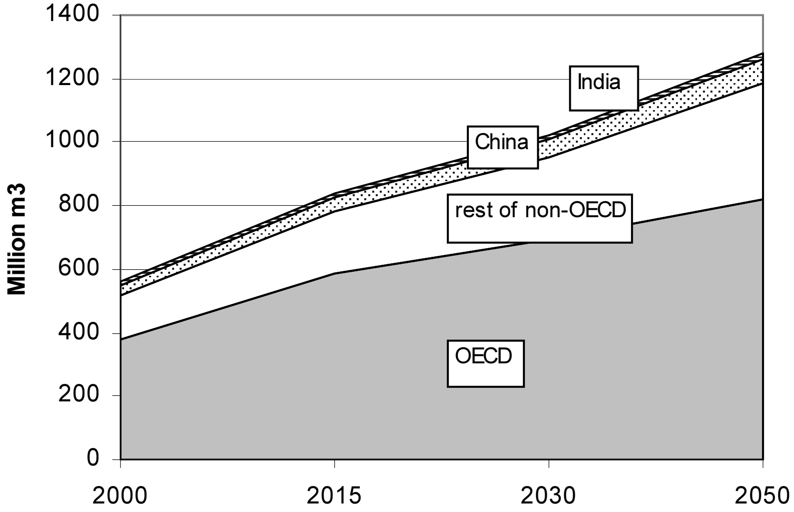
The result from the projection of paper and paperboard consumption at the global level shows that the paper and paperboard consumption increases considerably, as seen in figure 1. Paper consumption increases most in relative terms in the non-OECD countries, while the absolute increase is roughly equal in OECD and non-OECD countries.

Figure 1 **Projection of global paper and paperboard consumption**



Consumption of sawnwood and wood based panels increase less than paper consumption, see figure 2. The OECD countries remain responsible for the largest part of the world's consumption in 2050.

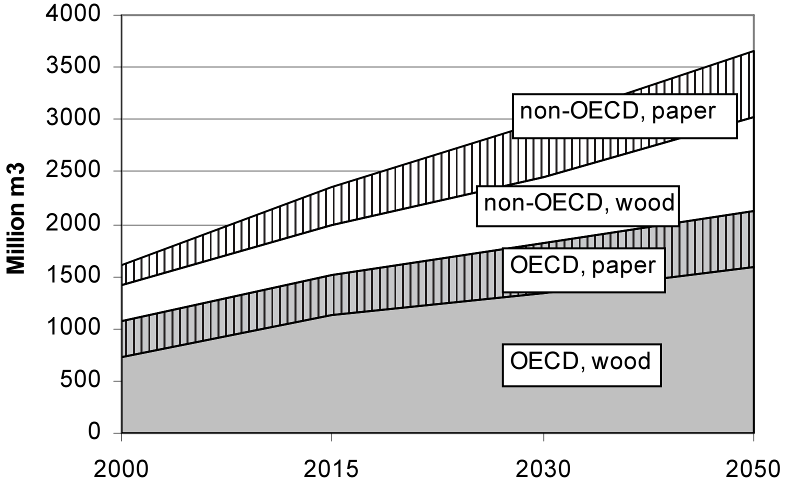
Figure 2 **Projection of global consumption of sawnwood and wood based panels**



Total industrial roundwood consumption

Both sawnwood and pulp wood originates from industrial roundwood. By assuming that the mix of sawnwood and wood-based panels, as well as chemical and mechanical paper remain the same as today, we may estimate the average losses from the industrial roundwood to final product. Thereby we can estimate the demand of industrial roundwood corresponding to our consumption projections. Furthermore, industrial roundwood required to supply paper is highly dependent on the paper recovery rate. We assume that the highest possible paper recovery rate is 80 % and that 10 % of the fibres are lost in each recycling. We make a linear projection for each country up to that level, based on the coefficients obtained in the regression analysis. In the year 2000 38 % of the paper was manufactured from recycled fibres. Our projection suggests that the corresponding figure in 2050 is 67 %. This drastically reduces the demand of wood pulp. In figure 3 we estimate the global demand for industrial roundwood, assuming the losses from primary wood to final product to remain the same as in the year 2000.

Figure 3 **The total demand for industrial roundwood, losses and paper recovery taken into accoun**



It is interesting to note that even if paper consumption increases faster than sawnwood and wood panel consumption, the demand for industrial roundwood for paper production is only slowly increasing, especially in the OECD countries. In total our projections estimate that the total demand for industrial roundwood will increase by about 100 % the next fifty years. If we on the other hand assume that the paper recovery rate remains on the present level, 38 %, the demand for industrial roundwood increases by 170 % by 2050.

2.4 Energy and carbon dioxide projections

2.4.1 Data

For estimating the energy supply trends we used data on primary energy supply per capita, GDP/capita in PPP terms, carbon dioxide intensity in the energy supply and electricity production per capita from 74 countries for the years 1971–2000. All data except GDP/capita was obtained from World Development Indicators (WDI, 2004), whereas GDP/capita was obtained from Heston et al (2002).

2.4.2 Scenario design

Ideally, energy scenarios should be constructed from estimates of the final energy demand in different sectors, such as electricity, transport and industry. For non-OECD countries there are, unfortunately, a lack of this kind of historical data.

Using regression on primary energy, we find the coefficients shown in table 2. We may thus see that there is no clear trend for the income elasticity for lower income levels, whereas the income elasticity decreases significantly for income levels over 16000 USD/capita.

Table 2 Regression coefficient for primary energy supply

	Coeff	*Standard error*
Primary energy	--	--
β	0.030	0.004
$\gamma_0,\ \hat{Y}_0 = 1$	0.687	0.105
$\gamma_1,\ \hat{Y}_1 = 1000$	-0.449	0.121
$\gamma_2,\ \hat{Y}_2 = 2000$	0.451	0.054
$\gamma_3,\ \hat{Y}_3 = 4000$	0.218	0.044
$\gamma_4,\ \hat{Y}_4 = 16000$	-0.664	0.053

Carbon dioxide emissions

The most important emission potentially arising from increased energy use is carbon dioxide. There are several ways of estimating future carbon dioxide emissions. One is to make a regression on carbon emissions per capita as a function of GDP/capita. Here the assumption on functional form is essential (Richmond and Kaufmann, 2006). Assuming an logarithmic development means that the emissions inevitable will increase as GDP grows, whereas assuming a parabolic function, will give us a so called Kuznet curve, where there is a turning point. Thus, for a GDP/capita over a certain level the emissions start to decrease. These kinds of curves have been found for different kinds of emissions, for example sulphur emissions. However, for carbon dioxide there are no turning point as a result of GDP/capita level in sight, thus the timing of the tuning point would be a pure artefact on assumption on the functional forms and variables included in the regression.

We therefore use a different approach based on assumed carbon intensities of the primary energy supply (kg CO_2/GJ primary energy supply) and simulation in an energy system model. The carbon intensity of the energy mix differs greatly among the countries in the world. African countries tend to have low carbon intensities, since the energy supply in many of these countries are largely based on traditional biomass and in some cases hydropower. Probably, there are also some data problems among these countries. Industrialised countries on the other hand, have energy systems largely based on oil, natural gas and coal and have thereby higher carbon intensities. We make the crude assumption that every country converges linearly to a carbon intensity of 55 kg CO_2/ GJ in 2050, which is the world average today.

In order to make a more detailed assessment of the carbon dioxide emissions we also use a version of the GET model (Hedenus et al 2006, Azar et al 2003) called GET-LFL. GET-LFL is an energy system model with estimates of costs of technologies, resource availably etc. We adjust the energy demand so that approximately the same primary energy supply as in the regression-based projection is obtained. We then let the model calculate the energy supply mix, and thereby the carbon emissions. The GET-LFL model make the calculation for the whole world, thus local developments are omitted and of course resource and technology estimates are uncertain. Still, using both the simple assumption of carbon intensity and the GET model, we may get a rough estimate of the carbon emissions associated with the energy supply scenarios.

2.4.3 Projections

Our projection shows a fast increase in primary energy supply from 400 EJ in 2000 to almost 1200 EJ[2] in 2050, as seen in figure 4. The major share of the increase takes place in non-OECD countries. This is a result of the fact that income elasticity is significantly higher for income levels below 16000 USD/capita than above.

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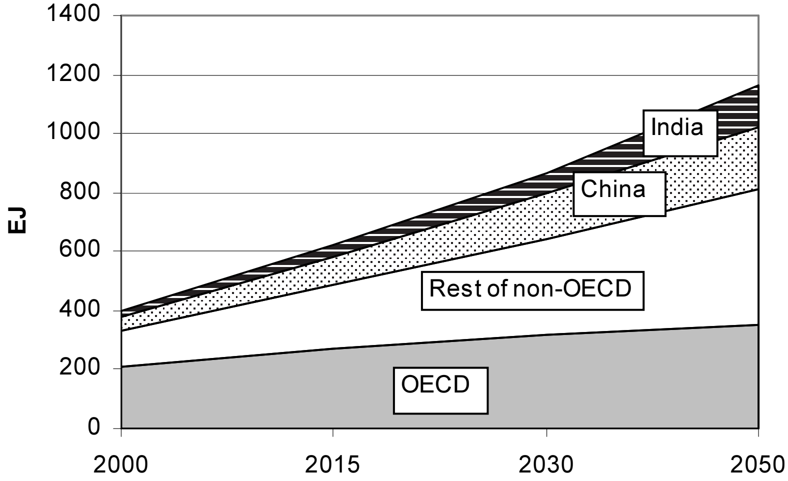
[2] EJ mean 10^{18} J.

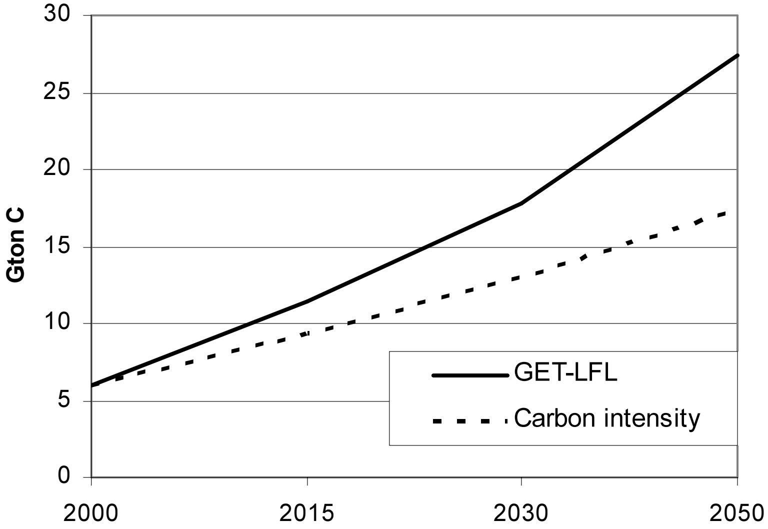
Figure 4 Global primary energy supply



To estimate the future carbon dioxide emission we use two different methods, either a convergence in carbon intensity in the primary energy supply, and a simulation in the GET-LFL model. The average carbon intensity of the world today is 55 kg CO_2/GJ, which roughly is the same as the carbon intensity of natural gas. However, in the GET-LFL model simulation, oil and gas becomes quite expensive 2025 and onwards due to scarcity rents and depletion. Therefore the energy system is largely based on coal which has a high carbon intensity, thus in 2050 the emissions in the GET-LFL simulation is around 27 Gton/year, compared to around 16 Gton/yr in the carbon intensity projection (figure 5). We assume the carbon dioxide emissions from land use change are the same as in the baseline scenario IS92a (Houghton et al 1992).

We calculate the atmospheric carbon dioxide concentration in the two projections. In the GET projection the carbon dioxide concentration in the atmosphere is 557 ppm in 2050, whereas the concentration is 498 ppm in the projections based on carbon intensity convergence. Extrapolating the different trend into 2100 would have given even larger differences.

Figure 5 Global carbon dioxide emissions scenarios using an energy system model GET-LFL, and assumption on carbon intensity



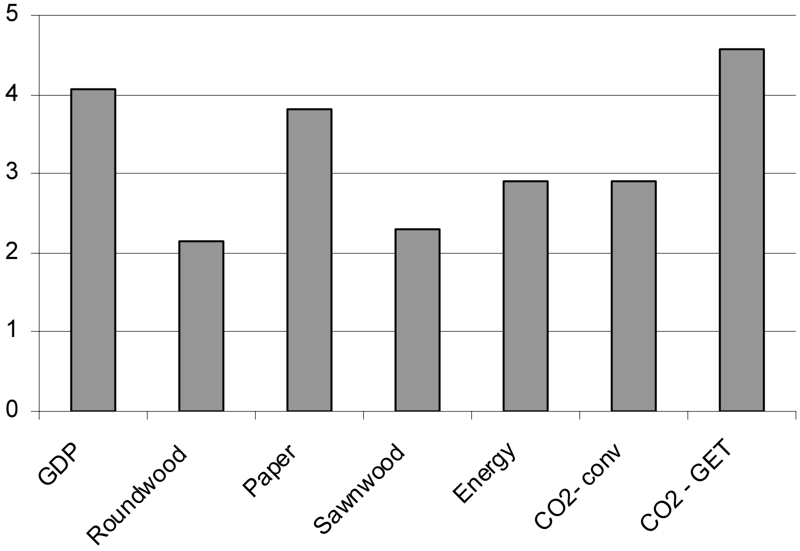
2.5 Discussion

2.5.1 Decoupling

One way to assess the growth in resource consumption is to compare it with the GDP growth. If the resource consumption grows at a slower rate than GDP, it is called weak decoupling, whereas if the consumption decline in absolute term, even if GDP is growing, it is referred to as strong decoupling. The global GDP is about 4 times larger in 2050 than in 2000, see figure 6. Global paper consumption increases almost as much, whereas sawnwood consumption increases by a factor of 2.3. Due to the increasing recycling of paper, the demand for industrial roundwood increase by only a factor of 2.1. We thus see a weak decoupling for all these three resources, see figure 6.

Primary energy demand increase by a factor of three, again a week decoupling, and the same holds for CO_2 emissions based on the assumption on carbon intensity convergence. However, the CO_2 emission projection based on the energy system model show a larger increase in CO_2 emissions than GDP. This is due to the fact that scarce resources of oil and natural gas are replaced by coal which has higher carbon intensity.

Figure 6 **Increase in consumption between 2000 and 2050 for different resources. Consumption in the year 2000 is equal to 1**



2.6 Comparison with other studies

A range of studies have been undertaken to study past trends of resource use and emissions or various pollutants. Much of the discussions have been related to the existence of a turning point in the traditions of Kuznet curves or not. Some papers have focused on carbon dioxide and energy use, e.g. Schmalansee et al (1998). The results from the literature concerning the connection between energy use and income levels are in line with what we find for the relationship between energy use and GDP/capita level, i.e. the income elasticities decreases with increasing income and that the elasticity is in general less than one. The decrease in elasticity with income may represent that the economies as they get richer shift production and consumption towards products and services that are less energy intensive.

Further, Schmalansee et al (1998) and Judson et al (1998) find, as we do, that the exogenous time trend is positive. This might be contrary to what one expects if one interprets the exogenous time trend as technical change leading to increased energy efficiency. However, if it is interpreted as economy-wide technical changes and structural changes, the exogenous time trend might represent diffusion and innovation of products and services (that become cheaper over time) that uses relatively much energy. The balance of the income elasticity and the exogenous time trend determines if the energy use increases faster or slower than the GDP growth, i.e. if there is a decoupling or not. Our results indicate that there is a decoupling between energy and income. Important to note is that similar analyses to ours, which have found a decoupling, have been criticized for not including energy prices in their regression analysis. Kaufmann (2004) does include prices among other aspects and does not find any evidence for autonomous decoupling (price independent decoupling). In one regression that we performed, we included the international oil price as a proxy for energy prices. The regression test gave that the oil price was a non-significant parameter for the energy use per capita.

Common practice in long-term energy-economy-climate models is to assume a autonomous decoupling, a so called autonomous energy efficiency improvement (AEEI) factor of 0.5 to 1 % per annum, see for example Azar and Dowlatabadi (1999) and Nakicenovic et al (2000). What one means with the AEEI is that the unit energy to the unit GDP ratio decreases with 0.5 to 1 % per annum. Several influential models like RICE (Nordhaus and Yang, 1996) and EPPA (Webster et al, 2002) use this methodology. Estimating an equivalent value for our projections give a value of about 0.7 % per annum. Since our equivalent AEEI is in line with those used in many models included in the IPCC SRES scenarios (Nakicenovic et al 2000), we get a result for primary energy supply in line with the high growth scenarios A1 and A2.

The carbon dioxide emissions reported here are in the upper range compared to the SRES scenarios. This is quite reasonable since the SRES scenarios B1 and B2 are environmentally driven, thereby using more renewable energy, whereas our projection is more of business-as-usual. The carbon emission we report from both the energy system model as well as from the carbon intensity estimates is in the range of the A1 and A2 scenarios. The main uncertainty for the carbon intensity in the primary energy supply in a business-as usual scenario is the development of nuclear power. In our GET run nuclear power is more expensive than coal-fired power plants, and therefore hardly enters the energy system. However, other cost assumption may have lead to a expansion of nuclear power and thereby reducing the carbon intensity considerably.

Just as for energy, we find that the exogenous time parameter for paper is positive, indicating a more paper intensive society over time. This is maybe what can be guessed from the general direction towards a more information-based society (and it turned out that there is not such a thing as a paper free office). Further, as what have been shown in other studies, there is a strong link between paper consumption and income level. In our regression we find income elasticities around one for middle incomes, but lower for higher incomes.

Different from paper and energy regressions, the exogenous time trend for the use of wood products is negative, indicating a substitution of wood products to other materials, or just less demand for wood products. Further, the income elasticity for wood products is lower than income elasticity for energy and paper.

We estimate that the global industrial round wood demand increase from 1600 million m^3 in 2000 to 3500 million m^3 in 2050. This is significantly higher than 1600–2500 million m^3 found in Sohngen et al (1997). They however, use a simplified method of making projections assuming 1 % demand growth in 2000, declining linearly to 0 % in 2150. Furthermore, there are reasons to believe that we underestimate the demand for final wood products. The reason is that we start out from the consumption data in 2000. For some non-OECD countries, the per capita consumption is very low, and even if the consumption triples during the next fifty years, the consumption is still a factor of 10 to 100 lower than the per capita consumption in the OECD countries today. Thus, it might be that incomplete statistical data actually underestimate the future consumption in non-OECD countries.

Our estimate, however, does not take into account future scarcity of accessible forests resources that may increase the price of forest products and thereby hamper the demand. This suggests that our estimates may be in the upper range.

2.7 Acknowledgement

We would like to thank Ulrika Lundqvist for compiling and analysing preliminary data for this project. We also thank Christian Azar, John Holmberg and Martin Persson for valuable comments.

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Appendix

Illustrative calculation of land required to supply industrial roundwood

Introduction

There are around 3500 Mha of forests globally, of which 1900 Mha are closer than 10 km from a road, and thereby accessible for timber supply (FAO, 2001). Besides the direct value of timber, forests also have considerable value through other important services such as biodiversity, recreational value etc, which, of course, are affected by harvest of timber.

There are, roughly speaking, three different sources of industrial roundwood; natural forests, production forests and plantations. Natural forests are forests that have been little affected by humans, but may be harvested, with or with out replanting. These forests mainly occur in former Soviet Union and in the tropics. Production forests are maintained and harvested to supply forests products. Finally plantations forests are intensively managed forests, replanted with seedling. In 2000 there were 187 Mha forest plantations of which 89 Mha was used for industrial wood supply. These plantations are presently rapidly, during the 1990s the annual expansion of successful plantations was about 3Mha (FAO, 2001).

The timber yield achieved on plantations is 5 to 10 times higher than the yields in production forests. Hence, if plantations expand rapidly in the future land requirement decreases significantly as compared to a future where timber is mainly supplied from production and natural forests. The expansion of plantations is mainly limited by local environmental concerns such as land and water availability and aesthetic values. In some places, plantations are referred to as “green deserts” due to its lack of biodiversity and large water requirement. However, the difference of quality between wood from plantations and managed forests is not any major obstacle for wood supply. Sedjo and Botkin (1997) claim that several wood species that are suitable for plantations are good substitutes for the wood obtained from managed forests for approximately 90% of the industrial round wood demand.

We are here making illustrative calculations of the land required to supply industrial roundwood to the year 2050. We evaluate two scenarios, one with no further expansion of plantations, and one scenario where plantation forests are further expanded.

Method

We use two different types of forests in our calculations production/natural forests and plantations. The Mean Annual Increment (MAI) is estimated to $2 m^3/ha$ yr for natural and production forests, whereas plantations forests MAI is estimated to $12 m^3/ha$ (Sohngen et al 1997).

We evaluate two scenarios. In the first scenario forest plantations used to supply industrial roundwood does not expand beyond the present 89 Mha. In the second scenario plantation forests expand 1.2 Mha/year, i.e. in 2050 there are in total 203 Mha of plantations supplying industrial roundwood in the world.

In order to make these calculations we made an important simplification. We consider the forest as a static system. Thus, in order to supply a certain amount of timber we calculate the area required to grow the amount of wood during a year. Thus, we assume that the production of forest and the supply is in a steady state. However, the forest is a dynamic system, and production and supply is not in a steady state. For example, in order to meet the increased demand for wood in the future we have to expand the forest area already today, or harvest natural forests. This means that our calculations rather underestimate than overestimate the required area needed for plantations and productions forest.

The plantation area is given by the scenario stated above, whereas the area of natural/production forest is assumed to cover the rest of the demand. Thus, the demand for industrial roundwood must be supplied, and there are no price mechanisms included, i.e. no price sensitive demand functions or land supply functions. The demand that needs to be met is found in table 1.

Table 1 Demand for industrial roundwood

(Million m^3)	*2000*	*2015*	*2030*	*2050*
Industrial roundwood	1615	2350	2978	3655

Result and discussion

In the scenario with no expansion of industrial roundwood plantations, the forest land required to meet the required global industrial roundwood demand scenario amount to 1300 Mha, see figure 1. In the scenario where the plantations are expanding the required land area is considerably reduced, an area of 800 Mha is required, see figure 2.

Figure 1 **The demand for land in the case of no further expansion of plantations**

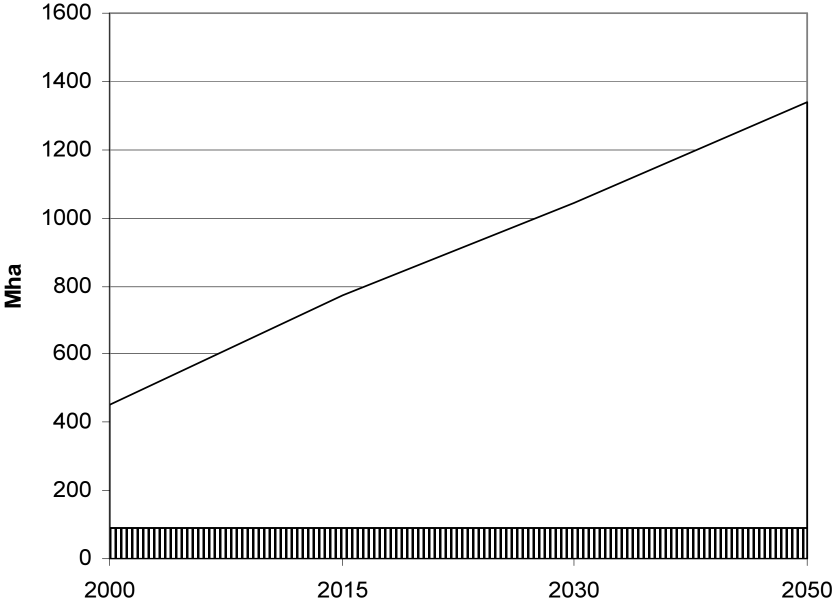
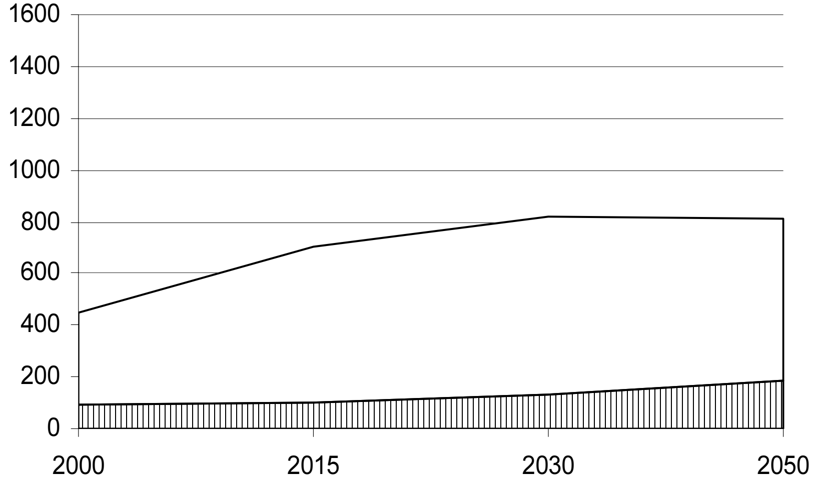


Figure 2 The demand for land in the scenario where plantations are expanding



In reality, demand is not fixed but price dependent. Such a large scale expansion of forest production as is suggested here would by certainty increase the industrial roundwood production costs and hence the price. Thereby the demand would be lower. Further, the industrial roundwood production would likely be intensified if prices increase, thereby increasing the yields and hence the commercial forest area required would be reduced.

There is a trade off between intensive production with high inputs, such as fertilizers, mechanical power etc, versus land extensive production. In the first case one can expect a higher load of environmental impacts and locally low level of biodiversity. In the latter case larges areas would be directly affected by forest production. For instance, in the scenario where plantations are not expanded, most of the accessible forests in the world are needed for forest production to meet the prescribed demand. The scenario with expanding plantations, on the other hand, is more restricted by local environmental problems associated with plantations than total land availability. Still, even in the scenario with expanding plantations, the required amount for production forest almost doubles.

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3 Water pressure and increases in food & bioenergy demand implications of economic growth and options for decoupling

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3.1 Summary and conclusions

The purpose of this report is to estimate the likely increase in the demand for food and bioenergy and the implications for the consumptive use of water as a result of an anticipated growth of GDP during the period up to 2045[1]. Growth of GDP, throughout the world, in combination with demographic trends, means that increases in the demand for food, energy and other goods and services are inevitable. What are the implications for water and land resources? And what are the options for decoupling? In this context, decoupling refers to increased GDP *without* a corresponding increase in the pressure on land and water resources. In other words, is the expected boom in the demand for more food and bioenergy commensurable with the pending world water crisis?

The open landscape character of food production makes it one of the most water intensive sectors in society. Since many crops that are used as food for humans or for feed for animals, can also be used to produce energy, the consumptive use of water to meet the expected increase in bio-based energy is also quite significant.

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[1] Calculations about anticipated future demand for food and the associated consumptive use of water are based projections on growth in GDPppp and demographic forecasts presented in chapter 1, this volume. These projections are made for 2015, 2030 and 2045. Some of the projections presented in this chapter, which are based on other statistical sources of information, refer to the period up to 2050.

Water can be used more or less efficiently, but in biological production there is no substitute for it.

Naturally, estimates about the future consumptive use of water for food and bioenergy crop production rely on current knowledge and certain assumptions. Based on predictions of growth in GDP up until the year 2045, the consumptive use of water to cater for growth in food demand is estimated to increase by some 50 %, from about 7,000 to about 10,600 km^3 per year, that is, if current levels of productivity and efficiency would prevail also in the future. Estimates of water requirements for production of energy crops are more difficult to make. It is, however, a plausible assumption that production of energy crops will expand. The pressure on water resources may be at the same order of magnitude as for food production.

If current practices and levels of productivity and efficiency were to continue, it is unconceivable that the accelerated demand on water resources, as indicated above, could be realised. Consequently, there are major challenges in terms of balancing finite freshwater resources between different uses in the near future and to stimulate improvements in efficiency. Blue water sources will not be enough. Strategies, which make it possible to better utilise a larger fraction of the rainfall for intended, beneficial use are vital.

It would be futile to believe that improvements in yields and water productivity, as well as agricultural area expansion, alone can solve the problem. The actual consumption is a critical driver. With increasing purchasing power, consumer preferences and behaviour are vital bricks in the dynamic interplay between production, demand and consumption and the efficiency of the whole system. As consumers, we are all intervening in the water cycle through our preferences for, and use of, various goods and services. In the search for decoupling opportunities between GDP growth and pressure on water and land resources, it is logical to pay adequate attention to both production and consumption dynamics.

The conclusions of the report may be summarised as follows:

- With increasing GDP/capita, the demand/supply of food increases rapidly at low levels of GDP or income. Beyond a GDP level of about 15,000 US$/capita, year, the incremental increase in food supply is declining significantly.

- Even at the same level of GDP/capita, the span in the dietary water requirements is considerable between countries.
- The span in the dietary water requirement may, to a large extent, be interpreted as a variation between countries in terms of the fraction of animal food items. At higher levels of GDP, the fraction of animal food items does, however, increase and may be above 40 %, which is much higher than what is usually assumed to be a “proper” level of intake of animal food items.
- The variation in food supply and composition in diets may to a considerable extent mirror cultural circumstances and norms, i.e., not only level of economic development (GDP).
- With current levels of water productivity, the global consumptive use of water required to augment food supply in relation to GDP and demographic changes has been estimated to increase from 7,100 km^3 (year 2000) to almost 10,600 km^3 (year 2045).
- Two main decoupling options have been identified; (i) water productivity improvements, i.e. improvements on the production side, and (ii) a more efficient food chain, primarily in terms of reduced losses and wastage from “field to table”. Water productivity improvements in the order of 25 % are considered feasible and realistic with reference to a number of studies. Losses and wastage in the food chain can also be reduced. In this report, we have argued that it is possible and desirable to reduce losses and wastage by half, which would also include a reduction in the over-consumption of food. Since losses and wastage is in the order of 30 % of the food produced, halving these types of inefficiencies will mean that 15 % of the production is saved for human consumption. Losses and wastage in the food chain contribute to augmented resource pressure and environmental and social costs since more is produced as compared to what is beneficially used. Related to this problem is the growing intake of food which results in overweight, obesity and high social and public health costs. Policies that will modify consumer behaviour are obviously problematic to launch as compared to policies directed to the producer.
- An important conclusion from the analyses in the report is: it is possible and desirable to meet expected future food requirements in 2045 with about the same water requirement as in 2005, provided that the two types of decoupling principles are integrated in policy and adhered to. This development

could be achieved without changes in food composition. These changes will however not come easily or quickly. A gradual improvement must be planned and systematically implemented over a period of a few decades.

- The total bioenergy demand in 2050 may grow to several hundred EJ/year[2]. Residues generated in forestry and agriculture may supply on the order 50–100 EJ/year in 2050. The utilisation of residues for energy mitigates the demand on water for bioenergy: the water that is consumptively used to produce the primary products in forestry and agriculture is the same water as will also produce the residues.
- Nevertheless, to meet a prospective bioenergy demand of several hundred EJ/year, dedicated bioenergy plantations are required. Indicative calculations suggest that for a global plantation supply at about 150 EJ/year, total water demand for bioenergy production from plantations in 2050 ranges between 4,000–12,000 km^3/year, depending on how much energy that can be derived per unit of transpired water. This large range illustrates the high degree of uncertainty that underlies the calculations. It also indicates decoupling opportunities of ET-minimizing strategies.
- Even if reduction of losses and improvements in agricultural and water productivity are accounted for, meeting the future food demand will most likely require addition of new cropland. This was estimated to range between 20 to 45 % a real expansion from today's 1,500 million ha, depending on the degree of improvements in land area productivity. The annual cropland expansion needed was estimated to be 0.48 % on average from now until the year 2045.
- Assuming different levels of energy outputs per land area, additional land requirements for biomass production was estimated to be approximately 400–800 million ha.
- The total land area requirement in 2050 for food and bioenergy production would then be in the order of 2,000–3,000 million ha. In some regions, the required area is most likely not available, which means that trade-offs between food and bioenergy production, as well as global trade between regions, is going to be increasingly important in the future.

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[2] EJ = ExaJoule = 10^{18} Joules.

A number of cross cutting issues warrant further considerations:

- The competition for water and land will increase. Production of biomass for energy and expansion of commercial non-food agricultural products is likely to affect food production quite considerably. A key question in this regard is if the crops for energy production will be grown on the same land as is/could be used for food production or if "other" land areas and "other" water can be used, for instance, part of the so-called grazing lands. The environmental consequences are, of course, important to assess.
- It will be important to look for various options to meet future demands for food and bio-fuels. Bioenergy, for instance, may be produced in a variety of ways, e.g. algae from the sea, biomass in lakes, bioenergy plantations using nutrient rich waste water.
- From a social point of view, it is relevant to analyse what the new mix in the demands for different products mean for those who manage land and water, i.e. for farmers and land owners in general. For many years, the small farmer and especially those who produce staple food crops have experienced a worsening terms of trade for their products as compared to the price they have to pay for the inputs they need and the goods and services they may want to buy. The possibilities to grow energy crops may open up new possibilities for farmers. One pertinent question is: who will win and who might loose and what policies can be implemented that will facilitate a socially and environmentally sound development?
- The comments above refer to the global situation. Water is unfortunately not available in agreement with increasing demands. Already today, the water situation is quite precarious in parts of the world. Growth of GDP and demographic trends are not in harmony with global distribution of land and water resources. This implies that trade will be more important.
- It is perfectly clear that increases in food and biofuel supply cannot be met through increases in the exploitation of blue water sources. A large part of the decoupling effect of water productivity refers to possible gains in upgrading rainfed systems, for instance through rainwater harvesting

for supplementary irrigation in combination with improved land husbandry. There are also opportunities to enhance productivity in irrigation systems, e.g. more widespread use of drip irrigation, farmer managed systems (with decentralised responsibilities), etc.

- This report has concentrated on quantitative water aspects. Water quality should be brought into the picture. It is, for instance, possible that improved water productivity will be achieved through a more intensive application of fertilisers and other chemicals. Improvements in a quantitative sense, may therefore lead to a deterioration of quality.
- Similarly, climate change has not been taken into account in the calculations. Further calculations on this issue are highly relevant.
- Finally, the connections between production and consumption are increasingly important. What is happening in the households and how they influence food and energy production is a very potent driver of land and water use.

3.2 Scope of the study

3.2.1 From production to consumption of food and bioenergy

The pressure on finite and vulnerable freshwater water resources is bound to increase as a result of an anticipated growth of GDP during the coming decades. Enhanced purchasing power will enable and induce people to demand more food and energy, among other things. Analyses of the augmented resource pressure that will follow should refer to both production of food and energy as well as the actual consumption, i.e. food intake and energy use among consumers. Three aspects are particularly relevant to consider in such analyses:

- Food and bioenergy production in general is very water intensive. Additional production will increase the pressure on freshwater resources, but the relationship between level of production and resource pressure and environmental implications can be modified through policy and management interventions.
- The actual consumption of the food, or the food intake, is influenced by level of income, among other things and a large

fraction of the food produced will not be consumed. With increasing income, or GDP, the demand for food and composition in the diet but also food losses and waste tend to increase. Changes on the consumption side are therefore important for resource pressure and environmental consequences.

- Bioenergy demand cannot in the same way as food be forecasted based on projections for driving forces such as population growth and economic development. Energy demand is expected to increase and bioenergy is expected to play an important role in meeting this demand. However, the exact contribution very much depends on national priorities in relation to issues such as energy security and climate change, as well as development of other energy supply options.

Biophysical circumstances, including freshwater availability, constitute the context and precondition for sustainable production. Food and biomass production are biological processes in the open landscape and are very much conditioned by hydroclimatic circumstances. Already today, the pressure on freshwater resources is alarmingly high in many parts of the world with consequences for the environment and fierce competition between sectors and interests in society.

Sustainable consumption is a complex issue. With reference to food, a prime objective is to ensure that people have access to a diet which enables them to “lead a healthy and productive life”. Too little food increases risk of under nourishment and deterioration of health, with repercussions for the individual, family and society. An intake of food, i.e. energy, in excess of what the body requires for a healthy and productive life, on the other hand, increases the risk for overweight and obesity. Again, the costs in terms of health problems are considerable to individuals, family and society. In addition, “excessive” consumption and composition of the diet has implications for consumptive use of water and environmental status.

Similarly, energy consumption is highly linked to issues of sustainability. Access to energy services such as lightning, mobility and a comfortable indoor climate can be considered a prime objective, although it can be debated at what level such services constitute a basic human need. As for food, “over-consumption” might be unhealthy: shifting from driving cars to going by bicycle or public transport would likely be beneficial for the health within a substantial segment of the population. It would also reduce society's energy demand and thus possibly also water demand for bioenergy.

Analyses of linkages between production and consumption are therefore most valid in both the food and bioenergy sector. Even though production and consumption of for example food may be seen as two sides of the same coin, there is a lack of understanding of how they are related to one another. In the food chain, i.e. between production and actual intake of food, a number of activities take place: transport, conversion from vegetarian to animal calories, processing (value adding, preservation, etc) and marketing.

Enhanced efficiencies in the food chain are crucial for sustainability. At low levels of GDP, losses are high at field level and at the initial stages of the food chain. With increasing levels of GDP, i.e. enhanced purchasing power and urbanisation (and globalisation), the concern should shift to what happens in the latter parts of the food chain, including losses and wastage in households. With more money for the consumers to spend, changes on the demand side increasingly determine how much and what type of food items that are produced and processed. As will be commented upon below, there is a clear tendency that improved purchasing power and urbanisation increase the preference for water intensive food items. In addition, food intake tends to be in excess of the requirement to lead a healthy and productive life. With growing affluence, it is therefore relevant to analyse wastage and conversion of food items in the various steps between production and consumption. In addition, part of the food that could have been used for direct human consumption ends up as feed or is used in energy production or other non-food uses. Consequently, there is a big difference between the amount of food that is produced and supplied in society on the one hand, and the actual consumption of food, on the other. In terms of policy interventions, different approaches are required to promote more efficient production and to stimulate improvements in the food chain.

3.2.2 Information about food supply dominates

Discussions about food security are generally related to supply side information. Data about food consumption at the household level, or among various socioeconomic groups of the community, and what happens in between production and consumption are more difficult to find. Analyses of production and consumption are usually not published in the same journals and reports, which is another drawback for a proper understanding of an increasingly complex interaction between the various components of sustainability.

It is important to note that the data that we have used do not include information on wild food and garden produce. Production of fish is an important food item in many parts of the world. In our calculations, we have not made a distinction between fish and other animal food items in terms of water requirements. This means that the estimates for the consumptive use of water are too high for countries relying to a large extent on fish from oceans.

3.2.3 Food production, supply, apparent consumption and intake of food

In the publications and reports that we have used as a basis for the analyses, a clear distinction is seldom made between food production at field level, food supply in retail shops (similar), the amount of food bought or otherwise accessed by the households, the actual intake of food and waste of food. FAO is the leading organization at the international level that collects and analyses this complex chain. In the main, the data sets and analyses are based on Food Balance Sheets (FBS) for individual countries.

In FAO (2003), food consumption is defined as: "... the sum of production, plus net exports, minus the non-food use of food commodities" (p. 47). This definition, which is used in many reports, is deceptive. The data and analyses are not about the actual consumption but refer to production corrected with estimates of non-food uses. According to Smil (2000) "supply data derived from food balance sheets are not in any way direct measures of food availability but rather outcomes of complex constructs all too frequently resting on dubious foundations" (p. 192). However, it is fair to make a distinction between a dubious terminology and availability and quality of the dataset. Information on actual intake of food is not collected systematically for most countries and it is obviously difficult to measure food intake in a reliable manner.

It is noted in the FAO document that a more correct term for food consumption would be "national average apparent food consumption" since the data used do not come from consumption surveys but from FBSs. The direct human consumption or the actual intake of food (energy) deviates quite substantially from figures on "apparent consumption". Instead of using the label "consumption" it is relevant to refer to food supply in society. A more appropriate term, which is also used in FAO reports, is "dietary energy supply" (DES).

In this report, we have primarily made a distinction between: (1) food supply (in society) and, (2) food intake (amount of food, or energy, actually eaten). Additional analyses of the amount of food produced and the losses, conversions and wastage through the food chain are beyond the scope of this report.

3.2.4 The context and scope of the study

Food and biomass production is one of the most water intensive activities in society. In comparison to other types of water uses in society, e.g. in industry or households, food and biomass production is distinguished in terms of being a biological production taking place in the open landscape. Re-use of water is, in principle, not an option (apart from re-use of drainage or "excess" water) and improvements in productivity are different as compared to mechanical, closed systems. There is no substitute for water in food and biomass production, it can be used more or less efficiently/productively, but it cannot be substituted by other resources.

A number of reports, high-level meetings and declarations have underlined the fundamental and unique role of water in development, for instance, in the efforts to achieve the 2015 targets for the MDGs. From Sweden, the interest has been strong in contributing to the ambition to reach the MDGs (SIWI and IWMI, 2004; SIWI et al., 2005, SEI, 2005). A common denominator in these reports is that freshwater resources in many parts of the world are under severe pressure. In addition to the quantitative challenges, a deterioration of water quality poses considerable problems.

Anticipated growing affluence in the world and the fact that about 15 % of the world's population currently are undernourished means tremendous challenges. As will be shown in the report, the picture is complex in terms of variation in food supply and food composition – and thus water requirements – between countries. The report also identifies and evaluates the possible decoupling mechanisms that could change pressure on water resources significantly. Moreover, the report presents estimations of land area requirements for future food and bioenergy production, as well as the impacts of urban expansion and industry. Finally, the last section deals with policy interventions of two main types: those that are directed towards the production side and those directed towards the consumption side.

3.3 Demand on water for food production

3.3.1 Water consumed in food production

In general, much more water is required when producing animal based foods compared to vegetarian food, since only part of the vegetal energy consumed by animals is transformed into meat, milk or eggs. Most of the energy consumed in animal based food production is lost as heat during the life time of the animal. However, there is an important difference between animal food that is produced through grazing as compared to animal rearing where feed lots are used and where the fodder is made up of cereals; some of which may be produced on irrigated lands. If the feed comes from areas where no alternative agricultural production or no alternative land use is feasible, animal production may be the most worthwhile resource use. On a global scale, however, an increasing share of the feed in animal production systems originates from crop-based fodders (grains, oil crops such as Soya etc.). Therefore, production of animal food often competes with vegetal food products. According to FAO (2003), approximately 35 % of the world total cereal produced is used for feed while Smil (2000) estimates that the fraction is higher; in 1900, it was just over 10 %, it surpassed 20 % by 1950, and it was about 45 % in the late 1990s.

With reference to current average water productivity levels (volume of consumed freshwater, as green water flow, or evapotranspiration, ET, per unit biomass production, m^3/ton) in agriculture, our estimates indicate that 0.5 m^3 of water is consumed to produce the equivalent of 1,000 kcal vegetal food and 4 m^3 of water are consumed when producing 1,000 kcal of animal products (Table 1). These estimates on freshwater requirements per amount of food type produced are derived from a compilation of water productivity data for different agricultural products and climatic zones, reported in Rockström et al. (1999).[3] The estimate for animal products considers consumptive water use to generate both cultivated feed and fodder gained from grazing lands (Falkenmark and Rockström, 2004). Based on information in FAOStat (2002), a conversion from the amount per weight of various food items to their nutritional value is made. The global freshwater requirement to produce the amount of food supply that corresponds to the international norm of 2,700 kcal/person, day and with a 20 % animal and 80 % vegetarian composition is estimated to be about 3.2–3.3 m^3/person/day or 1,200 m^3/person/year (Box 1). As can be seen from Figure 1, this corresponds to the water requirement at a very low GDP level (approximately 5,000 US$/person/year).

In the estimates of water requirements for a specific diet, an equation based on standard values for water needs to produce vegetable and animal based foods was used (Box 1). It would have been desirable to apply a more detailed calculation, where figures on the variation in water productivity for different food items were considered as well. However, for a global analysis, such a detailed calculation would be quite demanding and the reliability of the information in FBSs may not warrant such a detailed analysis without thorough data checks. A more detailed calculation is, however, done for a couple of countries (section 3.5.2).

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[3] In the literature, a wide range of estimates of water productivity are presented. In de Fraiture et al. (2004), for instance, it is noted that crop water requirements vary from 350 to 800 mm. It is also shown that water productivity for crops like wheat, rice, maize etc. varies by a factor of about three between countries. For all cereals, in the major exporting and importing countries, water productivity ranges between 4,500 m^3/t and 600 m^3/t (pp. 6-7). The variation in water productivity is consequently quite significant. Climatic and agronomic circumstances together with water management are the prime factors determining water productivity.

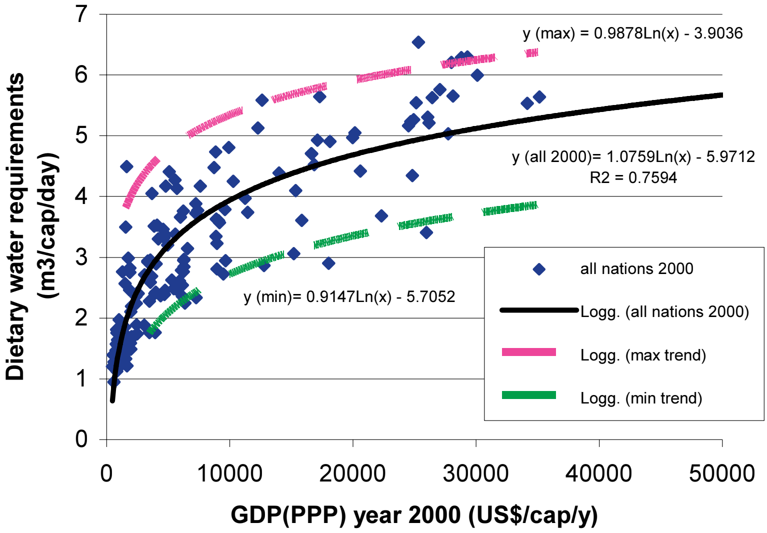
Table 1 Estimated volumes of freshwater required for producing different food items based on current estimates of average water productivity in food producing systems (Source: Rockström et al., 1999)

Food type	*m^3/kg*	*m^3/1000 kcal*
Cereals	1,5	0,47
Starchy Roots	0,7	0,78
Sugarcrops	0,15	0,49
Pulses	1,9	0,55
Oilcrops	2	0,73
Vegetable oils	2	0,23
Vegetables	0,5	2,07
	Average	0,53
	Used in present study	0,5
Meat		4
Diary products		>6
	Used in present study	4

For valid estimates on the probable increase in the pressure on water resources, it is important that the water productivity figures in Table 1 are realistic. One important assumption behind our estimated water productivity figures is that future food production will expand more in the tropical region as compared to the temperate zone. In the former areas, the current water productivity tends to be low. Another assumption behind the calculations of total water requirements is that the proportion of animal to vegetable food remains the same also in the future. This may lead to conservative estimates since current trends in the composition of the diet suggest that relatively more water intensive food items will be demanded in the future.

In the analyses, the focus is on the *consumptive use of water* in connection with food and biomass production. In both irrigated and rainfed systems, a part of the water that is available, in the soil and/or in storage systems, returns to atmosphere as evaporation and transpiration, which together form the consumptive water use, or the green water flow. Water may also be "used" without returning to atmosphere, e.g. seepage and drainage water in irrigation systems. This water is generally available for re-use. Water will, of course, return to atmosphere and circulate in the landscape all year around, irregardless if food or other intentional biomass production takes place.[4] In line with other food-water calculations it is, however, natural to relate water use to the crop season.

Figure 1 Water requirements for the food supply in countries at different levels of GDP (US$ per capita in year 2000). Regression lines for approximate 'maximum' and 'minimum' food supply in terms of water requirements are plotted. For identification of individual countries, please see figure 3



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[4] It is relevant to emphasise that water returns to the atmosphere primarily as a combination of evaporation and transpiration. Return flow to atmosphere is a continuous process primarily determined by the climate and available water in the landscape. The beneficial return flow in terms of transpiration through the crops takes place during part of the year. A crucial challenge and a significant opportunity lies in the possible shift in the balance between unproductive and beneficial return flows (i.e. reducing evaporation and increasing transpiration through crops and other biomass that are demanded in society). The possibilities for and the principles of a "vapour shift" are discussed in Falkenmark and Rockström (2004) and SIWI et al. (2005).

3.3.2 Water for food as a function of GDP

Increases in GDP, or purchasing power, in combination with demographic change result in enhanced demand for food, which in turn will augment the pressure on water and land resources. The character of these causal relations depends on a host of circumstances. First of all, socioeconomic and demographic trends look quite different in different parts of the world. For instance, cultural circumstances will affect composition of diet, i.e. the relative preference for animal and vegetarian products, which has considerable implications for water demand. Several reports have also shown that the elasticity in food demand varies with level of income; at higher levels of GDP/capita, a saturation level in the demand for food should be expected. Rapid urbanisation and increased interaction between countries and people play an important role. In large parts of the developing world, significant demographic and geographical transformations are associated with a shift in diets, towards a larger portion of animal based foods (diary and meat products). Food demand and the attitude to and handling of food in urban and affluent societies tend to be influenced by trends in lifestyle. These trends are very difficult to quantify, but as will be discussed in sections 3.5 and 3.7, urbanisation affects composition and range of diet as well as turnover and wastage of food items in stores and households.

Box 1: An illustration of the range in consumptive water use with different composition of diet (in litres/capita, day; lpd).

Based on the figures presented in Table 1, the consumptive use of water (W_{cons}) can be calculated as:

$W_{cons} = 0.5\ m^3 \cdot$ vegetarian calories in diet $+\ 4\ m^3 \cdot$ animal calories in diet. (Eq.1).

With reference to the international norm of food security in society of 2,700 kcal/person, day and with an assumption that 80 % of this supply is vegetarian (2,160 kcal) and 20 % animal food items (540 kcal), the consumptive use of water to produce that food supply for a daily requirement will be:

W_{cons} (2,700 kcal; 80 % veg & 20 % animal) $= 0.5 \cdot 2{,}160 + 4 \cdot 540 = 3{,}240$ lpd (about 1,200 m^3/year).

As illustrated in figures 2 and 3, the share of animal food is much higher for some countries. Countries at high levels of GDP/capita also tend to have a food supply much higher than the norm of 2,700 kcal/capita/day. Below, the projected average figure for industrialised countries, 3,500 kcal/capita, day, in 2030 is used (FAO, 2003). Compare figure 4.

W_{cons} (3,500 kcal; 60 % veg & 40 % animal) = 0.5 2,100 + 4 · 1,400 = 6,650 lpd (> 2,400 m^3/year).

Cultural and traditions play an important role in food preferences. India, for instance, is to a large extent vegetarian and average food supply today is comparatively low. Below, an example is provided of a 100 % vegetarian diet and a food supply of 2,700 kcal (same as first example).

W_{cons} (2,700 kcal; 100 % veg) = 0.5 x 2,700 + 4 x 0 = 1,350 lpd (< 500 m^3/year).

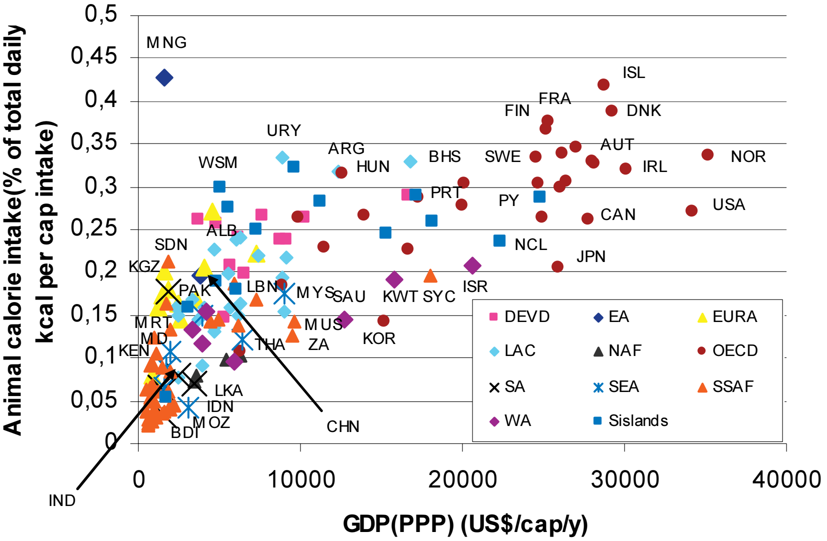
All three examples refer to *food supply in society*, i.e. not the amount of food consumed. Depending upon losses from field to table/stomach, the water consumed to produce the food that is actually eaten, i.e. food intake, is lower or much lower (see section 3.5).

In order to assess the future impact on freshwater requirements for food as a result of economic growth and demographic change, we start by analysing the current relationship between per-capita water consumption for current food supply and per-capita GDP (average country-level data). The GDP and population data are taken from the World Bank and data on diets are from FAO (FAOStat, 2006; World Bank, 2006). As seen from Figure 1, there is a log-function relationship between water for food and economic growth. The increase in food supply is particularly fast in connection with economic growth at the lower GDP range, up to about 10,000 US$ per capita, year. At higher levels of GDP, i.e. at levels beyond 15,000–20,000 US$/capita, year, there is still a growth in food supply but at a lower pace. Clearly, large water savings could be made if composition in food supply was altered from a high intake of animal food ('maximum' curve representing 20–40 % animal intake) to a more vegetarian diet ('minimum' curve representing 6–20 % animal intake).

3.3.3 The composition of the food supply – variation between countries/cultures

Apart from GDP level, the cultural norms/consumer preferences in a country will influence the supply and demand for food. The dietary water requirements, Figure 1, illustrate that food supply varies considerably between countries, even at the same level of GDP per capita. This variation is significant also at low levels of GDP/capita, year. One reason behind these variations is that the fraction of animal food items of the total food calorie supply varies substantially between countries (Figure 2). In year 2000, this fraction was above the frequently used "norm" of 20 % for virtually all countries having a GDP per capita above 15,000 – 20,000 US$/per capita, year.

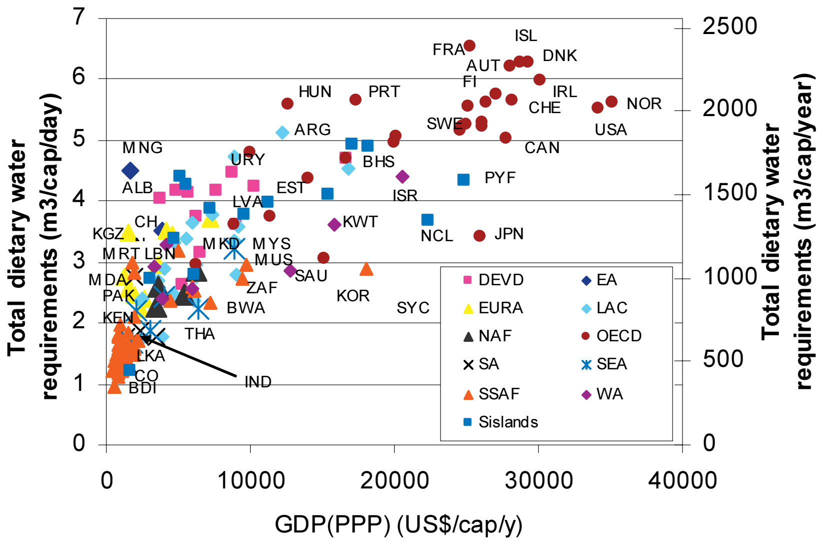
Figure 2 **The fraction of animal calories in the dietary supply (y-axis) and GDP per capita (x-axis). Regional groups: DEVD=transition countries Europe, EA=East Asia, EURA=transition and developing former USSR, LAC=Latin America and Caribbean, NAF=North Africa, OECD=Members of the Organisation of Economic Cooperation and Development, SA=South Asia, SEA=South-East Asia, SSAF=Sub-Sahara Africa, WA=West Asia, Sislands=Small Islands**



With the large variation in the fraction and absolute supply of animal calories, a considerable difference in water requirements between countries is natural, even at similar GDP levels, as shown in Figure 3. Some countries form a cluster around the "conservative water-GDP function" with a relatively low meat/dairy supply compared to the average. This cluster includes the Arab countries, Republic of Korea and Japan. Some countries are significantly above the average, primarily the OECD countries (with both higher kcal food supply and a larger meat-based proportion). France, Denmark and Iceland are at the top in terms of dietary water requirements.

Countries characterised by a pastoral culture, e.g., Mongolia, have a high water requirement even at a low level of GDP. However, the implications in terms of water and land pressure are very different in this kind of production system as compared to animal production in feed lots. Meat production in Mongolia is primarily through grazing and the options to use these areas for alternative kinds of production may be limited. In other countries, the feed to animals comes to a considerable extent from crops that could have been used for direct human consumption. The distinction between the modes of production of different animal products becomes even more important if the feed is produced through irrigation.

Figure 3 Present dietary water requirements and GDP levels (year 2000) for the countries of the world. The Y-axis shows the daily water requirement. The dataset is identical to the one that is presented in figure 1. Regional groups: DEVD=transition countries Europe, EA=East Asia, EURA=transition and developing former USSR, LAC=Latin America and Caribbean, NAF=North Africa, OECD=Members of the Organisation of Economic Cooperation and Development, SA=South Asia, SEA=South-East Asia, SSAF=Sub-Sahara Africa, WA=West Asia, Sislands=Small Islands



It is important to note the position of rapidly growing economies in the world, such as China and India. As seen in figures 2 and 3 they are situated at the steep left part of the "dietary water-GDP" relationship, which suggests rapid growth in water demand during the coming decades.

There is a striking imbalance in the food supply situation in the world. About 850 million people are under nourished and have poor access to food, while about a billion are overweight and obese. Food supply in countries with GDP levels exceeding 20,000 USD/per capita, year is far in excess of the 2,700 kcal norm and is associated with dietary water requirements in the order of 5 to 6 tons of water per person and day (or 1,800–2,100 m^3/person/year). Apart from a heavy pressure on land and water resources, this level of food supply will result in an increasing risk of overweight and obesity among the population and/or a high proportion of food being wasted.

3.3.4 Food supply and water requirements based on GDP development and demographic scenarios

According to FAO (2003) the "apparent consumption" (i.e. an estimate of the amount of food that is available for consumption) increased from an average of 2,360 kcal/person/day in the mid 1960s to about 2,800 kcal/person/day at the turn of the century on a global basis. The "apparent food consumption" is likely to continue to increase to almost 3,000 (from 2,054 in 1964/66 to 2,980 in 2030) for developing countries and to 3,500 kcal/person/day (up from 2,947 in 1964/66) for industrialised countries in 2030 (ibid.).

Based on the projections of future population and economic growth at the national level (Table 2) the future consumptive water use is estimated. We assume that all countries within the same regional group will increase in dietary water requirements with time according to the projected regional ln-functions depicted in Figure 1 (for details on the methodology, please refer to Appendix 1). Thus, it is assumed that no major shifts occur in diet composition, except that total calorie supply per capita increases for a variety of reasons with increased GDP.

Table 2 Projected population growth and total regional and global dietary water requirements based on projected GDP$_{PPP}$ for 2005, 2015, 2030 and 2045. The regions and the countries included in these are presented in Appendix 1. (Data on demographic and GDP$_{ppp}$ projections: Chapter 1, this volume). Regional groups: DEVD=transition countries Europe, EA=East Asia, EURA=transition and developing former USSR, LAC=Latin America and Caribbean, NAF=North Africa, OECD=Members of the Organisation of Economic Cooperation and Development, SA=South Asia, SEA=South-East Asia, SSAF=Sub-Sahara Africa, WA=West Asia, Sislands=Small Islands

	2005	*2015*	*2030*	*2045*	*2005*	*2015*	*2030*	*2045*
	tot pop (100 000	*tot pop (100 000*	*tot pop (100 000*	*tot pop (100 000*	*tot water (1000 km^3)*	*tot water (1000 km^3)*	*tot water (1000 km^3)*	*tot water (1000 km^3)*
DEVD	60	58	53	48	0,09	0,09	0,09	0,08
EA	1318	1396	1450	1421	1,77	1,95	2,13	2,16
EURA	264	259	249	234	0,35	0,35	0,36	0,36
LAC	440	500	575	622	0,58	0,71	0,91	1,07
NAF	148	174	206	230	0,14	0,17	0,22	0,26
OECD	1172	1234	1296	1320	2,04	2,22	2,43	2,54
SA	1451	1677	1966	2168	1,01	1,21	1,51	1,76
SEA	504	566	638	679	0,45	0,55	0,69	0,80
Sislands	4	5	6	6	0,01	0,01	0,01	0,01
SSAF	738	917	1224	1551	0,48	0,61	0,86	1,19
WA	156	189	235	273	0,19	0,23	0,31	0,39
Global sum	6256	6975	7897	8552	7,11	8,11	9,53	10,61

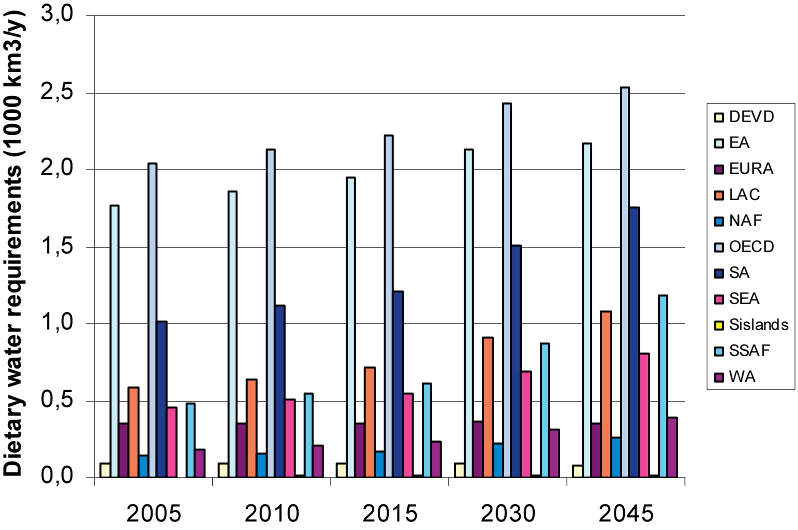
Dietary water requirements at country level are calculated using a regional regression function for the relationship between water-for-food and GDP growth. Using this approach the current global freshwater requirement for food is estimated to be about 7,110 km^3/year (Table 2). This is similar to previous estimates by Rockström et al. (1999) and Falkenmark and Rockström (2004), where the global water for food requirement 2002 was estimated to 6,800 km^3/year, and also to a recent estimate of 7,130 km^3/yr (CA, forthcoming).

The population growth and economic development are likely to result in a substantial increase in global freshwater requirements to produce the increase in food demand in the future (Table 2). In 2045, the projected water use for food production is estimated to be about 10,610 km^3/yr, which compares well to a recent estimate of water for food production in 2050, which ranges between 12,050–13,500 km^3/yr (CA, forthcoming). Considering the fact that pressure on freshwater resources is already significant in many parts of the world and that new demands are growing, e.g. for bioenergy production, an immediate conclusion is that improvements in water productivity, modifications in diet composition and improved efficiency in the food chain must be accomplished.

In order to obtain a better picture of the regional variation in future water demand, we have divided the world in the 11 regions, as shown in Figure 4. The most rapid immediate growth in water pressure is expected in East Asia and South Asia, with an initially slower, but in due course more rapid growth also in sub-Saharan Africa.

The demographic factor in combination with composition of diet plays a significant role in the total national water requirements, as illustrated in Figure 5. According to the calculations used in this report, China is, by far, the country with the highest dietary water requirement in the world. China is already today importing a growing part of its food supply and is likely to increase imports. India, which has a population size almost at the same level as China, has a far lower water requirement. USA with a much lower population number, on the other hand, has a water requirement at about the same level as India.

Figure 4 Regional projections of future dietary water requirements based on data in table 2. The regions and the countries included in these are described in Appendix 1. The sum of the water requirements for the 11 regions for 2005, 2010, 2015, 2030 and 2045 corresponds to the bars presented for the same years as in Figure 5. Regional groups: DEVD=transition countries Europe, EA=East Asia, EURA=transition and developing former USSR, LAC=Latin America and Caribbean, NAF=North Africa, OECD=Members of the Organisation of Economic Cooperation and Development, SA=South Asia, SEA=South-East Asia, SSAF=Sub-Sahara Africa, WA=West Asia, Sislands=Small Islands



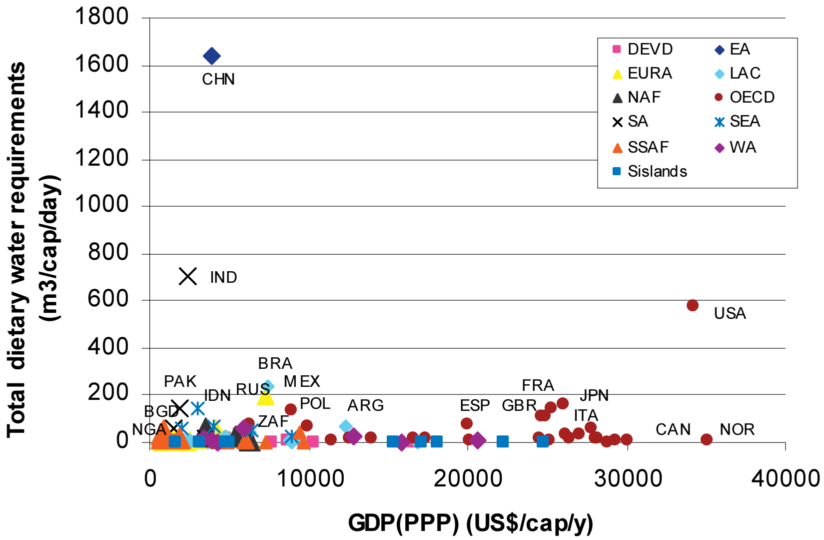
3.3.5 Will freshwater be the constraint to augmented food supply?

Assessments of the amount of water that is available to satisfy different demands in society typically refer to the annual renewable amounts of water in rivers, lakes and aquifers (groundwater resources). This is the liquid *blue water resource,* which is possible to dam, extract, convey and allocate to a range of alternative use(r)s. The prevailing focus on blue water means that only a fraction of the rainfall is taken into consideration. Most of the rainfall never reaches the rivers, lakes or groundwater. Out of a total estimated rainfall in the world of about 110,000 km^3, about 35–40 % will form blue water, or about 40,000 km^3, whereas the major part, or about 70,000 km^3, is *potentially a green water resource.*

The current annual total withdrawal of water from blue water sources is in the range of 3,800–4,500 km^3. This corresponds to about 8–10 % of the annually renewable flow of 40,000 km^3. These figures may indicate that additional withdrawals are possible. However, about half of the 40,000 consist of uncaptured flood water and another 7,000–8,000 is flow in remote areas. The potentially accessible flow is in the order of 12,000–14,000 km^3. The possibilities to increase withdrawals are therefore quite limited. Already today, many rivers are desiccated and ground water levels are falling at alarming rates in many parts of the world, e.g. in Ogallala aquifer in the US, north India and China Plains (Postel, 1995; Shah et al. 2000; Lannerstad, 2002; SIWI et al. 2005).

The pressure on blue water sources increased significantly during a brief historical period. For the entire century, 1900–2000, the rate of water withdrawals was about two to two and a half times faster than population increase. The era of rapid water developments and withdrawals, especially for irrigation schemes, commenced in the 1960s with the onset of the Green Revolution. The pace in technical water development efforts slowed down in the mid 1980s (WCD, 2000).

Figure 5 National water requirement (y-axis) corresponding to food supply in each country and GDP/capita in US$ in year 2000 (x-axis). Regional groups: DEVD=transition countries Europe, EA=East Asia, EURA=transition and developing former USSR, LAC=Latin America and Caribbean, NAF=North Africa, OECD=Members of the Organisation of Economic Cooperation and Development, SA=South Asia, SEA=South-East Asia, SSAF=Sub-Sahara Africa, WA=West Asia, Sislands=Small Islands



Additional withdrawals are planned, but the upper limit in these withdrawals is generally set at 10–20 %. A further withdrawal is circumcised due to a number of reasons:

Regional dimension: The availability of water is poorly correlated with distribution of population and future water requirements. Much of the water is available in remote areas, far away from areas where demand is or will be articulated. Estimates suggest that about 1.4 billion people are living in basins where all practically available (blue) water is already committed (Smakthin et al. 2004). Conveying water over large distances is not a viable option.

Ecological requirements and environmental concerns: During the era of rapid water development, the awareness and concern for ecological and environmental issues were subordinate to the high expectations to give a boost to food production. Many countries had been haunted by recurrent food crises and famine was a serious and real threat. With the green revolution, national and donor interests converged and a boom in dam construction took place around 1960–1980. After decades of steady improvements in global food supply, also on a per capita basis, the ecological concerns have increased in importance. The attention given to "environmental flows" (Moore, 2004), for instance, illustrates that regulations and withdrawals should be subject to a broader set of objectives and thus that the opportunities to increase withdrawals are curtailed.

Financial and practical circumstances: Building of dams and other structures means huge investments. Representatives of the major water use sectors, e.g. in agriculture, are however reluctant, and partly unable, to contribute to cost recovery. Donors are not enthusiastic about spending money on sensitive projects, which may not generate enough revenue for the borrowing country to repay loans. Since the best sites for water infrastructure have already been exploited, the potential schemes have become more expensive in relation to each cubic metre of water stored/conveyed.

Considering these circumstances, a heavy reliance on blue water resources for additional food production is fallacious. The additional amounts of blue water that can be mobilised are quite limited and far less than the gap between current total withdrawals of some 4,000 km^3 and the gross availability of 40,000 km^3 may suggest. The increase in water demand as projected in Table 2 and Figures 4 can only marginally rely on a further exploitation of blue water resources.

In addition to improvements in water productivity in irrigated agriculture, one window of opportunity for realising future increases in food supply, bio-energy and other competing agricultural products, refers to a better utilisation of the rainfall, i.e. a green water strategy. Through rainwater harvesting, a larger share of the precipitation can be captured in local ponds. This water may be used for supplementary irrigation to offset effects of dry spells during the crop season. Part of the harvested precipitation will infiltrate through soil surface and replenish soil moisture. The total rainfall during a season is often sufficient for a doubling of yields but unless interventions are made, its "natural distribution" implies high risk of crop failure or reduced yields (SIWI et al. 2005).

3.4 Demand on water for bioenergy production

3.4.1 Projecting future biomass use for energy

Many scenarios of energy system development suggest a huge growth in the biomass use for energy; with dedicated bioenergy plantations being the major biomass supply source (see Berndes et al. (2003) for a review). At the same time there are studies that dismiss biomass as an important future renewable resource, especially in the context of energy system transformation and climate stabilization (see, e.g. Hoffert et al., 2002; Reijnders, 2006).

Bioenergy demand cannot in the same way as food demand be forecasted based on knowledge about how demand has correlated with basic driving forces such as population growth and economic development. History shows that the demand for energy services increases as population and economic activity grow, but not in a manner that makes projections an easy task. For example, the energy intensity of economic activity depends on how the relative importance of different sectors (industry, services, etc) and subsectors evolve in different countries and on how innovations influence sector-specific energy intensity.

The translation of energy service demand into primary energy demand is complicated by uncertainty about efficiency improvements and the relative importance of different primary energy sources such as biomass depends on national priorities in relation to issues such as energy self sufficiency, oil versus natural gas import dependency, climate change, and energy related job creation.

However, it is clear that technology development has put us in a situation where industry can produce biobased products with a quality that satisfies a high consumer demand. This opens up for a wide range of options for the substitution of fossil resources. Since the quantitative production of fossil resources, primarily for energy purposes, is substantially larger than the biomass production in agriculture and forestry (Figure 6), a far-reaching substitution of fossil resources with biomass would require a dramatic increase in the output from agriculture and forestry (and consequently a huge increase in human appropriation of evapotranspiration).

3.4.2 Indications from contemporary energy policy targets

Thus, there is no way to narrowly determine the potential contribution of biomass in the future primary energy supply, since it depends on many parameters that can develop in very different directions. Advanced technologies, such as nuclear fusion, may eventually satisfy safe requirements and offer abundant energy supplies, but a prudent strategy for tackling the energy challenges cannot rely on those to aid CO_2 stabilization and reduce energy insecurity during the 21st century. Therefore, rather than awaiting the prospective (30–50 year ahead) realization of potential silver bullet solutions, society now turns to what is available closer in time (regardless of whether the estimated ultimate long-term contribution of these options correspond to 30 or 300 % of the present world energy use) and bioenergy is presently regarded as one of most promising options.

Energy supply from biomass has been assigned an important role among renewable energy sources (RES) in several world regions. The use of biofuels for the production of heat and electricity has been successfully increased in countries like Finland and Sweden. As the utilization has increased, the techniques and technologies to collect, transform and transport biomass has improved so as to reduce costs. Due to such developments there are optimistic scenarios suggesting that biofuels could also be used to substitute significant parts of the fossil fuels used for transport. Stimulated by directives and regulations, the use of so-called “first generation” biofuels, such as ethanol and biodiesel based on traditional starch, sugar and oil crops, increases in for example the European Union, North and South America, and Asia/Pacific. Second generation liquid biofuels, such as Fischer Tropsch fuels, Dimethyl Ether, lignocellulose-based ethanol and biohydrogen are envisioned to become increasingly competitive to their fossil alternatives as technologies develop and allow production based on more abundant and potentially much cheaper lignocellulosic feedstocks[5] .

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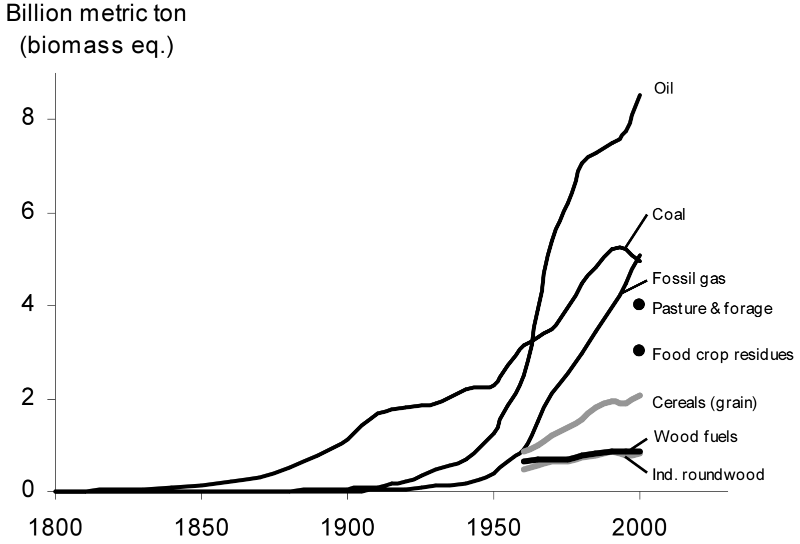
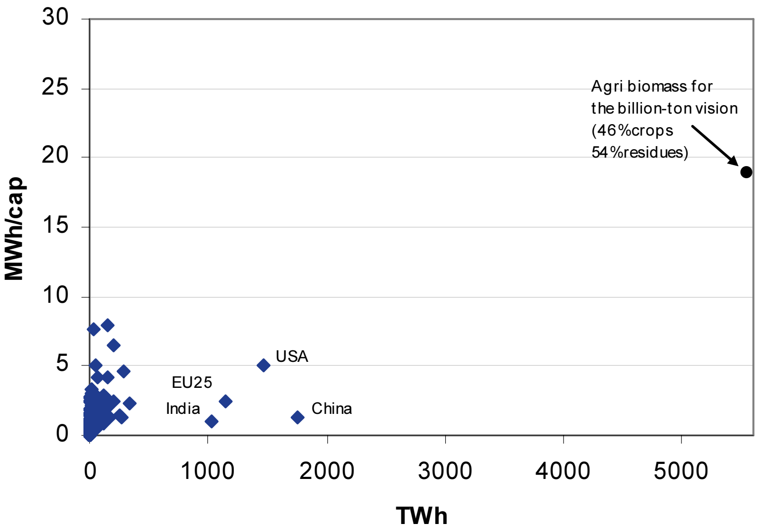
[5] Feedstock refers to the part of a plant that can be used to produce bioenergy.

Figure 6 Global annual production of major biomass types in agriculture and forestry, and of selected major products and basic resources. The fossil resources are given on a biomass equivalent basis (tbe) in order to facilitate a comparison with the different biomass types (conversion based on 1 ton oil equivalent = 42 GJ; 1 tbe=18 GJ). "Pasture & forage" refers to the part eaten by grazing animals. "Wood fuels" (FAO data) does not include all biomass uses for energy. For example, the FAO "Wood fuels" data for year 2000 corresponds to about 15 EJ, while the global biomass use for energy is estimated at about 35–55 EJ/ year. Source: Berndes 2006



As an illustration of the magnitude implications of bioenergy targets in contemporary energy policy, Figure 7 presents the assessed potential agricultural biomass supply supporting the US "Billion-ton vision" for the year 2030 along with the present cereal production in the world. The joint USDA/DOE assessment of the technical feasibility of a billion-ton annual supply report that more than 1.3 billion dry tons of biomass per year could be supplied from forests and agricultural land, with about 73 % of this from agriculture. The goal set by the Congress-established Biomass R&D Technical Advisory Committee, to replace petroleum corresponding to 30 % of the present petroleum consumption in the USA, would require about 1 billion dry ton of biomass. As can be seen, the agricultural biomass supply for energy envisioned is very large compared to other major biomass supply in agriculture.

Figure 7 **Agricultural biomass supply for the US "Billion-ton vision" compared to present cereal production in the world. The biomass volumes are recalculated to energy units assuming 4.4 MWh/ton dry**



3.4.3 Illustrative estimates of the demand on water for bioenergy production

Acknowledging the uncertainties discussed above, calculations of prospective demand on water for bioenergy production will be presented as a complement to the analyses of future food sector water demand. A distinction will be made between biomass from dedicated plantations and biomass in the form of residues that are generated in the food and forest sectors. Residues from these sectors can be used for biofuel production without allocating water specifically to this purpose. Thus, from a water perspective, the bioenergy from food and forest residues can be produced *without* an increased pressure on water resources. For example, using crop residues means that the area for this kind of bioenergy is the same as the area used for food production. Hence, the water that is consumptively used to produce the food is the same water as will also produce the crop residues and the same fields are used for food production as will produce the residues potentially available for bioenergy.

The exercise intends to indicate magnitudes rather than providing detailed modelling. The calculation procedure is:

- based on energy scenarios and consideration of quantitative/qualitative aspects, to estimate a regional biomass demand for energy in 2050;
- based on food and forest sector scenarios, estimate the residue flows in the two sectors and their availability for energy purposes: the residue supply potential,
- an estimate of the regional demand for biomass from dedicated plantations by subtracting the regional residue supply potential from the regional biomass demand,
- An estimate of the regional bioenergy ET demand. Residue utilisation for energy is defined not to induce any ET in addition to that linked to the production of food and forest products. Therefore, the bioenergy ET demand comes from dedicated energy crop production.

3.4.4 Regional biomass demand for energy in 2050

The calculations start from the IMAGE 2.2 interpretation of the IPCC SRES scenarios. These scenarios were constructed based on four storylines[6] for world development, including climate change, which were developed for the IPCC Special Report on Emission Scenarios (SRES). The SRES storylines do not include explicit policies to limit GHG emissions or to adapt to the expected global climate change. All four SRES "futures" represented by the distinct storylines are treated as equally possible and there are no "central", "business-as-usual", or "surprise" futures. Each storyline takes a different direction of future developments so that they differ in an increasingly irreversible way. They describe divergent futures that reflect a significant portion of the underlying uncertainties in the main driving forces. The differences among the storylines cover a wide range of the key "future" characteristics, such as technology, governance, and behavioural patterns.

The storylines are briefly presented in Box 2 below. The development in the four so-called SRES Illustrative Marker

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[6] A narrative description of a scenario (or a 'family' of scenarios), highlighting the main scenario characteristics and dynamics, and the relationships between key driving forces.

Scenarios along selected crucial parameters is presented in Appendix 3. For full documentation, see (IPCC, 2000).

Box 2: Storylines for world development

The **A1 storyline** and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenarios develop into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

The **A2 storyline** and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which result in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

The **B1 storyline** and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

The **B2 storyline** and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

Table 3 presents the total primary energy demand in the different regions in 2050, for the four different markers scenarios. The calculations of regional biomass demand for bioenergy 2050 is based on the IPCC SRES A1B marker scenario, since this reaches similar energy demand (given in bold in Table 3) as the energy scenario produced for the Swedish Environmental Advisory Council by Chalmers University of Technology (see chapter 2, this volume). The B in A1B denotes "balanced" in relation to emphasis on different energy sources and technologies.

Table 3 Total primary energy demand 2050 in the IMAGE 2.2 interpretation of the IPCC SRES scenarios (EJ/year). (EJ = ExaJoule = 10^{18} Joule)

Region	*Scenario*			
	A1B	*A2*	*B1*	*B2*
Canada	15	15	10	11
USA	137	143	89	103
C America	48	41	32	27
S America	97	90	63	59
N Africa	51	41	33	27
W Africa	38	23	26	21
E Africa	23	13	16	11
S Africa	38	26	26	22
W Europe	100	84	64	66
E Europe	32	25	18	24
Former USSR	87	68	45	57
Middle East	107	102	70	60
S Asia	254	109	127	135
E Asia	204	137	105	150
SE Asia	91	50	47	64
Oceania	9	9	6	7
Japan	26	22	15	17
World	**1355**	998	792	860

As mentioned above, the A1B scenario does not include policy regimes corresponding to ambitious (e.g. <450 ppm) greenhouse gas stabilization levels. It does not capture the possible mitigation of primary energy demand growth linked to the implementation of energy efficiency measures. Moreover, changes in lifestyle are possible if a sense of urgency would prevail in society. Obviously, several circumstances could provide incentives for politicians and citizens to adopt stabilization targets.

For the calculation of the regional bioenergy demand, we therefore modify the A1B scenario by assuming that the demand for both transport fuels and electricity is 30 % lower than in the original A1B scenario. We then assume that biomass is used to supply part of the electricity and transport fuels that are demanded in the different regions in 2050, namely:

- We assume that half of the year 2050 regional electricity demand in the modified A1B scenario that is *not* met by non-thermal electricity technologies such as wind, hydro and solar PV, is generated based on biomass (biomass-to-electricity conversion efficiency = 50 %). In the original A1B scenario, much of this electricity is instead generated based on fossil fuels. In addition, to the extent that this biomass based electricity generation takes place in cogeneration units, part of the heat demand would also be supplied from this biomass (i.e. not requiring more biomass but leading to a higher overall conversion efficiency).
- We assume that half of the year 2050 transport fuel use in the modified A1B scenario consists of biofuels such as ethanol, DME[7] and FT-diesel. The efficiency in converting biomass to these biofuels is set to be the same as the average primary energy-to-transport fuel conversion efficiency in the original A1B scenario.

The total biomass demand for energy in the different regions based on these assumptions is presented in Table 4.

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[7] DME = dimethylether; FT-diesel = Fisher-Tropsch Diesel.

Table 4 **Total biomass demand for energy production in different regions. (EJ = ExaJoule = 10^{18} Joule)**

	Regional biomass demand 2050 (EJ/year)
Canada	3
USA	29
C America	9
S America	16
N Africa	8
W Africa	5
E Africa	3
S Africa	7
W Europe	20
E Europe	6
Former USSR	15
Middle East	19
S Asia	41
E Asia	27
SE Asia	16
Oceania	2
Japan	4
World	231

3.4.5 Regional residue supply potential for energy in 2050

As a basis for the calculation of the residue supply potential in the forest sector in 2050, we use the scenario for paper and industrial roundwood produced for the Swedish Environmental Advisory Council by Chalmers University of Technology (see chapter 2, this volume). The global residue flows in the forest sector up to 2050 and the availability for energy purposes are calculated based on the following assumptions:

- All residues generated at logging site: 60 % more than roundwood extracted from the forest.
- 25 % of all logging residues is assumed to be collected.
- Sawmill residues: 50 % of the logs supplied to the mill.
- 50 % of the generated mill residues is assumed to be recovered.
- 40 % of the energy in logs supplied to pulp mills is assumed to be available for energy in the form of black liquor.

- Energy content of available forest residues is 10 GJ (GigaJoule) per cubic meter.

Due to lack of access to the regional breakdown of the Chalmers scenario the global residue volume available for energy in 2050 is distributed among regions based on the regional distribution of forest residues in 2050 in another scenario study: the renewable-intensive global energy scenario (RIGES) by Johansson et al. (2003), which was prepared as an input to the 1992 United Nations Conference on Environment and Development. RIGES is based on the high economic growth variant (IPCC, 1991). The forest residues available for energy production in different regions are presented in Table 5.

The residue supply potential in the food sector is calculated based on data for 2050 in RIGES, considering selected major biomass flows in the food sector: cereals, sugar cane and dung:

- Sugarcane production is assumed to increase in proportion to the population. Cereal production levels are assumed to be those projected by the IPCC Response Strategies Working Group (IPCC, 1990). Dung production is assumed to increase in proportion to meat production in all regions except South and East Asia and OECD Europe, where dung production increase in proportion to production of dairy products, as projected by IPCC (ibid.).
- Sugarcane residue generation is assumed to be 150 dry kg of bagasse (2.85 GJ) plus 279 dry kg of tops and leaves (5.30 GJ) per ton of cane. All the bagasse and two thirds of tops and leaves are available for energy purposes. In China residues from only half of sugarcane production are available for energy, due to the fact that cane residues are often used for papermaking in China.
- Cereal residues generation is assumed to be 1.3 times cereal production (weight basis). 25 % of the residues are assumed to be available for energy purposes (heating value=12 GJ/ton).
- Estimates of dung production are based on livestock inventories, together with dung production coefficients and dung heating values reported for different animals. It is assumed that 25 % of the produced dung is recoverable.

The food sector residues available for energy production in different regions are presented in table 5. It is difficult to say how realistic it will be on the local scale to actually utilise the total 50EJ/yr as projected for 2050. It will largely depend on energy prices as well as available infrastructure and the location of markets.

Table 5 Forest and food sector residues potentially available for energy production in different regions. (EJ = ExaJoule = 10^{18} Joule)

	Forest sector residues available for energy in 2050 (EJ/year)	*Food sector residues available for energy in 2050 (EJ/year)*
Africa	2.1	7.6
Latin America	2.2	12.1
South and East Asia	2.4	18.3
Centrally Planned Asia	1.8	2.9
Japan	0.4	0.2
Australia/New Zealand	0.3	1.2
United States	4.6	2.2
Canada	2.0	0.4
OECD Europe	2.7	2.2
Former centrally planned Europe	4.9	3.2
Middle East	0.5	0.0
Total	24	50

3.4.6 Regional demand for biomass from dedicated plantations

The regional demand for biomass from other sources than residues can now be calculated by subtracting the regional residue supply potential from the total regional bioenergy demand. Since RIGES does not use the same regional breakdown as IMAGE 2.2 some "residue allocation rules" have been defined as:

- Residues generated in OECD Europe are allocated to W Europe.
- Residues generated in centrally planned Asia are allocated to E Asia.
- Residues generated in Australia and New Zealand are allocated to Oceania.

Residues generated in RIGES regions that correspond to groups of sub-regions in IMAGE 2.2 are allocated to the sub-regions based on the relative size of bioenergy demand in these sub-regions: bioenergy demand in C and S America is about one third and two-thirds, respectively, of the total bioenergy demand in the two regions. Therefore one-third of residues generated in the RIGES region "Latin America" are allocated to C America and two-thirds are allocated to S America. Using the same approach:

- Residues generated in Africa are allocated to N, W, E and S Africa.
- Residues generated in Former Centrally Planned Europe are allocated to E Europe and former USSR.
- Residues generated in South and East Asia are allocated to S Asia and SE Asia.

Finally, there are some RIGES and IMAGE 2.2 regions that are identical, making the calculation straightforward.

One additional aspect to consider is that some regions may have the potential to produce more biomass from dedicated plantations than what is required within the same region – and at costs lower than production costs in other regions. Such regions could export biofuels to other regions experiencing either that the supply potential within the region is limited or that meeting the domestic bioenergy demand solely based on domestic production would involve energy crop production at high costs. Thus, one may expect that interregional biofuel trade exists in a future world where large amounts of biomass are used for energy.

In the calculation of regional demand for biomass from dedicated plantations, it is assumed that the regions will cultivate as much energy crops as possible at production costs below 2 US$/GJ. If this is not sufficient to meet the regional demand for biomass from other sources than residues, the regions will import from other regions that can produce more than what is required to meet their own regional demand. This interregional trade follows simple "trading rules":

- Canada exports to USA and W. Europe.
- C&S America exports to Middle East.
- W&E Africa exports to N Africa and Asia.
- Former USSR exports to W. Europe and Middle East.
- Oceania exports to Asia.

The data on how much energy crops that the different regions can produce at costs below 2 U$/GJ is taken from an assessment of regional biomass supply potentials from dedicated plantations (Hoogwijk, 2004). The resulting regional demand for biomass from dedicated plantations is presented in Table 6 below.

3.4.7 Demand on water for bioenergy production

The consumptive use of water, i.e. evapotranspiration (ET) in energy crop production is given for different bioenergy systems in Table 7. The wide ranges in Table 7 can be explained by: (i) varying water productivity (WP) among energy crops, related to crop type, soil and climate, and agronomic practice, including WP modification options such as changing sowing date and plant density, supplemental irrigation and microclimate manipulation; (ii) variations in the share of the aboveground biomass that is usable as feedstock in electricity/fuels production; and (iii) different conversion efficiencies of technology options available for electricity/fuels production.

Table 6 Biomass energy demand from dedicated plantations. (EJ = ExaJoule = 10^{18} Joule)

	Energy crop demand (EJ/year)
Canada	11
USA	18
C America	7
S America	12
N Africa	1
W Africa	14
E Africa	12
S Africa	4
W Europe	3
E Europe	7
Former USSR	21
Middle East	0
S Asia	12
E Asia	16
SE Asia	9
Oceania	9
Japan	0
World	157

The lower bound data for energy crop ET in Table 7 combine the highest WP data with technology options having conversion efficiencies in the upper range of what is found in literature, and where harvest residues and process by-products are used for energy purposes. The higher bound data in Table 7 combine the lowest WP data with options with lower conversion efficiencies that do not use harvest residues or process by-products for energy.

In the calculation of demand on water for bioenergy production, numbers for ET per GJ bioenergy feedstock will be used. However, data on ET per unit electricity or gross biofuel output are also presented in Table 7 to emphasize that the performance of systems converting the biomass feedstock to biofuels, heat and electricity will have a large impact on how much water that is consumed in energy crop ET per unit bioenergy consumed: one major strategy for decoupling bioenergy demand from demand for energy crop ET is development of highly efficient conversion systems that maximizes the output of useful energy per unit biomass consumed.

Compared to the ET in energy crop production, the subsequent conversion to fuels or electricity generation consumes little water: typically a factor 100 less (Berndes, 2002). The calculations of demand on water for bioenergy production will therefore focus on the ET losses in energy crop production.

The energy crop ET is calculated for two different cases corresponding to regional average energy crop ET at 25 and 75 ton per GJ feedstock. The corresponding crop water productivity (WP) depends on how large part of aboveground biomass that is usable as feedstock for bioenergy. For example, 25 ton per GJ feedstock and 80 % of aboveground biomass available as feedstock implies a WP at about 2.5 g dry matter per kg water; 75 ton per GJ feedstock and 50 % of aboveground biomass available as feedstock implies a WP at about 1.3 g dry matter per kg water.

Table 7 Energy crop ET per unit bioenergy feedstock and gross bioenergy output. See Berndes (2002) for elaboration and original references

Feedstock	*Biofuel / electricity*	*WP*[a]	*Energy crop ETb*	
		(kg DM/mm ET)	*(ton/GJ feedstock)*	*(ton/GJ gross electricity or biofuel output)*
Rapeseed	Biodiesel	9-12	46-81	100-175
Sugarcane	Ethanol	17-33	23-124	37-155
Sugarbeet	Ethanol	9-24	57-151	71-188
Corn	Ethanol	7-21	37-190	73-346
Wheat	Ethanol	6-36	21-199	40-351
Lignocellulosic crops		10-95	7-68	
	Ethanol			11-171
	Methanol			10-137
	Hydrogen			10-124
	Electricity			13-195

aDM=dry matter.

bLower range numbers refer to systems where: (i) harvest residues from non-lignocellulosic crops (50 % of total) are used for power production (at 45 % efficiency); or (ii) higher efficiencies in processing lignocellulosic crops are achieved. When ethanol is produced from sugarcane or lignocellulosic feedstocks, process by-products (bagasse and lignin, respectively) are used for internal heat and electricity. Here, lower range numbers refer to systems designs allowing for export of electricity in excess of internal requirements.

Considering the unpredictability of factors influencing the evapotranspiration per unit biomass (e.g., climate change, crop choice, biotechnology development, land use practices and relative cost of land, water and other inputs) a more refined approach, such as using different WP for different regions, is hard to motivate. Especially since the purpose has not been to provide exact estimates of global ET from large-scale energy crop production, but to provide indications of the increase of evapotranspiration requirements that can be expected if large areas were dedicated to energy crops production.

The regional energy crop ET arising from meeting the demand for biomass from dedicated plantations calculated above is presented in Table 8. The incidence of energy crops irrigation is difficult to project, but it can lead to substantial additional withdrawals if employed extensively. Assume, for example, that 15 % of the energy crop ET calculated here was provided by means of irrigation. If the average efficiency in irrigation water supply is 50 %, then about 1,175–3,525 km^3 of additional water would have to be withdrawn in 2050 (Table 8). This can be compared with the present withdrawal for irrigation estimated at roughly 2,600 km^3/yr (CA, forthcoming). Clearly, such additional blue water demand from energy crop irrigation implies tough challenges.

At the same time, it is important to emphasize that also rainfed energy crop production could potentially lead to similar impacts, by redirecting runoff water to ET and thereby affect downstream blue water availability and quality. Establishment of bioenergy plantations can lead to increased ET, especially if tree crops replace shallow-rooted grasses, herbs, or food crops. It is not possible to make general statements about the impact in terms of water depletion of expanding energy crop production since the net change of ET is uncertain and depends on site specific circumstances, including the current land use that it aims to replace.

Table 8 Evapotranspiration from energy crop production in 2050 and an indication of volume implications for blue water withdrawals

	ET from energy crops (km^3/year)		*Irrigation withdrawal if 15 % of ET losses are supplied by irrigation at 50 % efficiency in irrigation water supply (km^3/yr)*	
	25 ton/GJ feedstock	*75 ton/GJ feedstock*	*25 ton/GJ feedstock*	*75 ton/GJ feedstock*
Canada	275	825	83	248
USA	450	1350	135	405
C America	175	525	53	158
S America	300	900	90	270
N Africa	25	75	8	23
W Africa	341	1023	102	307
E Africa	309	927	93	278
S Africa	104	312	31	94
W Europe	75	225	23	68
E Europe	175	525	53	158
Former USSR	534	1602	160	481
Middle East	0	0	0	0
S Asia	300	900	90	270
E Asia	400	1200	120	360
SE Asia	225	625	68	203
Oceania	229	687	69	206
Japan	0	0	0	0
World	3917	11751	1175	3525

3.5 Potential for decoupling

As argued in section 3.3, the pressure on available water and land resources is already high or very high in many parts of the world. It is also in areas which are endowed with relatively less freshwater resources that we may expect rapid change in economic and demographic terms during the coming decades. Difficulties and costs to get access to the required water for food and biomass production, the objective to safeguard the functioning of natural ecosystems and reduce of emissions of greenhouse gasses and extraction of non-renewable energy sources, make it vitally important to increase productivity per unit water and land (the "more crop per drop" argument).

Improvements on the production side represent one strategy to achieve a decoupling. Below it is also argued that it is equally important to make sure that there is a high efficiency in the food chain from production to consumption. Today, there is a considerable slack in the food chain, which may increase with growing affluence. The slack implies a higher pressure on available resources than would be the case with a more efficient food chain. As Smil (2000) puts it, "there is an enormous range of opportunities of doing things better". We need to identify and implement these opportunities, at various segments of the food chain, to achieve a decoupling.

As highlighted in the report, the demand for water and land is also likely to grow as a result of the expected importance of biofuels in the energy supply. One strategy for making better use of the biomass flows in the food system is to utilize food sector residues for energy. This improves the water productivity – more utility (both food and bioenergy) per unit water consumed – and also mitigates the demand on water for bioenergy since bioenergy from food and forest residues can be produced *without* an increased pressure on water resources. The water that is consumptively used to produce the food is the same water as will also produce the crop residues potentially available for bioenergy. On the other hand, there is strong competition for crop residues for other uses, such as mulch, fodder, feed and green manure, and thus the potential for using these residues for bioenergy production will depend largely on for example prices for food in relation to energy.

To the extent that bioenergy demand exceeds the residue supply potential, energy crop production can only meet part of the demand. A very important question is to what extent an expansion of energy crop cultivation will take place on land that is currently used for food production and, similarly, if energy crops will compete for "the same water" that is currently available for food production. This need not be the case since several approaches to decoupling exist: energy crop production can in various ways be localised and managed to mitigate water competition with food production and even so that water-related benefits are obtained. This is further discussed in Section 3.5.7.

3.5.1 Water productivity increase

As shown by Rockström (2003), there is a highly dynamic relationship between plant growth and water productivity, particularly in tropical regions, in agricultural systems currently experiencing low yield levels. Improvements in agricultural productivity (i.e., yield levels) will also raise water productivity. A major task is to change the relationship between the non-beneficial evaporation and beneficial transpiration. Currently, a large part of the water from precipitation returns to the atmosphere without any benefits to agriculture or other sectors in society. A progressive decline of non-productive evaporation (E_0) in favour of productive green water flow, transpiration (E_t), is possible through a combination of rainwater harvesting techniques and improved soil and land management. If a larger fraction of the rainfall can be harnessed and consumed in plant production, a boost in productivity and total production can be accomplished without a corresponding increase in the pressure on freshwater in rivers, lakes and aquifers.

Considerable improvements in productivity are possible. Falkenmark and Rockström (2004), for instance, have estimated that water productivity improvements can be significant, from a current 1,800 m^3/t to some 1,200 m^3/t over the coming 50 years, in tropical farming systems currently producing around the global average for developing countries, i.e. 2 t/ha for cereals. In a detailed study, Botha et al. (2005) showed that similar improvements of water productivity occurred after implementation of water harvesting strategies to enhance yields in South Africa. As 95 % of population growth, and the bulk of countries in the steep end of the diet-GDP curve, predominantly are located in tropical regions, we have for our global decoupling analysis assumed that the water productivity improvements estimated by Falkenmark and Rockström (2004) can be applied.

Implementing a strategy for water productivity improvements requires substantial efforts from authorities and different development agencies. A combination of incentives and sanctions are required to overcome social inertia and to demonstrate that it is a viable option. We have assumed the same relative improvements in water productivity are possible and realistic for all types of food in a diet (for both vegetarian and animal food items). As shown in table 9, this means that the 0.5 m^3 that is needed to produce 1,000 kcal of vegetal food will successively decrease to 0.38 m^3 per 1,000 kcal, and the 4 m^3 needed for 1,000 kcal of animal products will decrease to 3.04 m^3 per 1,000 kcal. (SEI, 2005; Falkenmark et al. 2007).

Table 9 Possible water productivity improvements till 2050

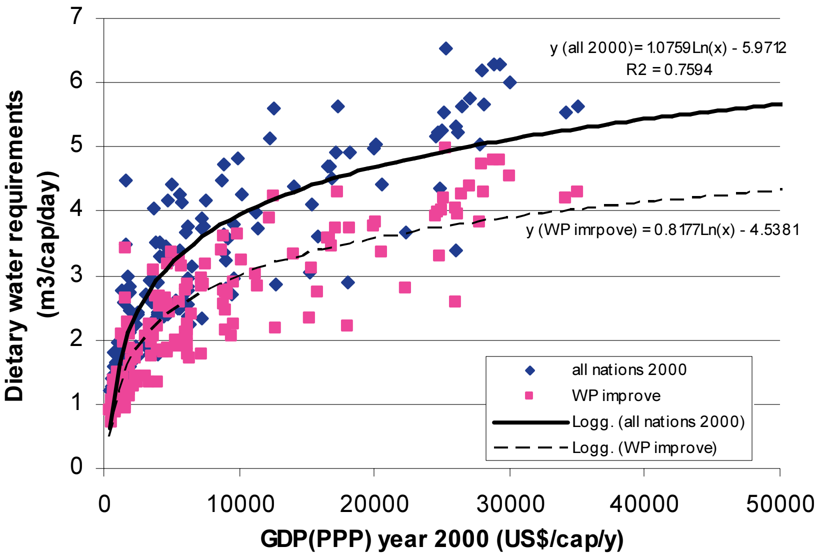
Year	*2005*	*2015*	*2030*	*2050*
Consumptive water use to produce vegetarian food items (m^3/1,000 kcal) [**a**]	0.5	0.47	0.43	0.38
Consumptive water use to produce animal food items (m^3/1,000 kcal) [**b**]	4	3.79	3.47	3.04

The values presented in Table 9 are used to modify Equation 1 (Box 1) to estimate future water requirements, which will be growing at a slower pace as compared to increases in production or yields:

$$W_{cons} = 1/1000 * (a \text{ m}^{3} * \text{ veg. kcal} + b \text{ m}^{3} * \text{ animal kcal}) \qquad \text{(Eq. 2)}$$

A modified dietary-water relationship as a function of GDP that incorporates bio-physical decoupling through water productivity improvements is illustrated in Figure 8. As shown in this figure, water productivity improvements (assuming continued progression along current dietary cultures) can result in significant long-term decoupling between economic growth and dietary freshwater requirements.

Figure 8 An illustration of water savings from an increase in water productivity (WP)



Water productivity improvements both in the case of vegetarian and animal food items translate into a 5 % decrease in water needs in 2015, 13 % in 2030, and 24 % in 2050, compared to estimates, which assume no water productivity change. As illustrated in Table 9, improvements are likely to be gradual. Parallel with changes in productivity, modifications in the demographic and economic situation should be expected. If the magnitude of productivity improvements is in the order portrayed in Table 9 and if GDP and demographic forecasts evolve in line with the projections presented in chapter 1 of this report, a substantial reduction in the growth of total dietary water requirements may be anticipated. The combined effect of the assumed trends is illustrated in Figure 9. It indicates that a considerable decoupling could be achieved over a period of a few decades. Total dietary water requirements in 2045 or 2050[8], may be at about the same level as in 2015 or slightly higher.

These figures can be compared with projections made in other studies. In the Comprehensive Assessment of Water Management in Agriculture, for instance, projected water use to meet future

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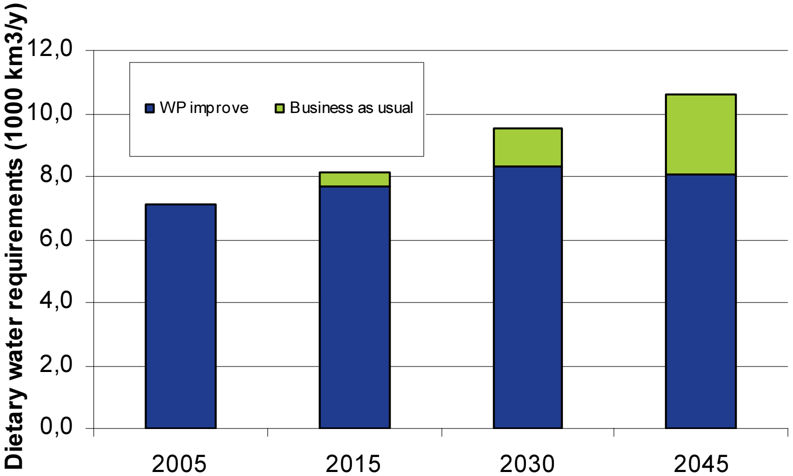
[8] The calculations in Figure 9 are based on GDP and demographic forecasts for 2045 (chapter 1) and figures on water productivity for 2050 (presented in Table 9). Since assumptions both about improvements in water productivity and economic-demographic forecasts cannot be validated, the bars shown in Figure 9 must be seen as an illustrative example of a possible future situation.

food demand in 2050 ranges between 9,200–11,400 km^3/yr for different investment scenarios (CA, forthcoming). Technologies are generally known; the challenge is to invest in human and institutional capacity.

Figure 9 Global estimates of bio-physical decoupling through water productivity improvements



3.5.2 The decoupling effect of assumed water productivity improvements.

The water productivity values presented in the Table 9 are rough estimates. For example, intensive meat production with high input of cereal or oil crop fodder means a high consumptive use of water per amount of meat produced, whereas meat and other animal products from cattle that get their feed from grazing areas with no alternative use option, implies no or little consumptive use of water that competes with other uses. Likewise, low-input smallholder farming systems in tropical and poorly developed countries are often characterized by low water productivity. Therefore, to illustrate the importance of these regional differences, disaggregated values on water productivity for different regions were used to estimate future water demands for a few selected countries, which vary in dietary composition and climate: Japan, Sweden, USA, China, Burkina Faso, Tanzania, Bangladesh and Laos.

In disaggregated calculations the equations should thus include water productivity figures for different food types and for different climatic zones. In Table 10, water productivity (WP) values for different food types for tropical and temperate climates are presented. These values were collected from literature (Zwarts and Bastiaanssen, 2004; Rockström et al 1999). For China, an average between temperate and tropical water productivity was used, as the food is produced in varying conditions and intensities. Moreover, in the estimations for China, cereal was sub-divided into a category "all cereals except rice" (WP=1400 m^3/t) and rice (WP=3500 m^3/t).

Table 10 Disaggregated water productivity for different food groups for temperate and tropical regions. In addition, water productivity for different food groups are presented separately for China

Food group	*Temperate WP (m^3/t)*	*Tropical WP (m^3/t)*	*China WP (m^3/t)*
Cereal	1300	1500	1400
Starchy roots	300	600	300
Sugar crops	130	130	10
Sugar & sweeteners	130	130	130
Pulses	2500	1700	2500
Treenuts	450	450	450
Oil crops	2000	2300	2000
Veg oil	2500	2500	2500
Vegetables	150	150	150
Fruits	300	250	300
Stimulants	4500	4500	4500
Bovine	30000	20000	25000
Mutton & goat	10000	10000	10000
Pork	10000	10000	10000
Poultry	6000	6000	6000
Meat other	10000	10000	10000
Offals, edible	30000	20000	25000
Animal fats	30000	20000	25000
Eggs	3500	3500	3500
Freshwater fish	8000	8000	8000

Each country was classified either as temperate or tropical (except China) (Table 11). Thereafter, the total water demand to produce food was calculated based on food from food groups representing the typical diet for each country, and the corresponding water productivity (Table 10). Finally, the water demands to produce food based on the simplified division water productivity into vegetable and animal foods (Eq.2 and Table 9) were estimated for each country as a comparison (denoted 'simple' below).

3.5.3 Differences between calculations

The largest difference between the simple aggregate calculation and the disaggregated calculation was found for developed countries (e.g., Japan, Sweden and USA) (Table 11). This might be because the 'simple' calculation does not adequately estimate water use for diets with large meat consumption. Therefore, it appears that there is a tendency to underestimate dietary water use for high-income countries with high animal calorie supply. For countries where the diet is based of higher proportion vegetarian items and where animal production systems are less water intensive (e.g. Burkina Faso, Tanzania, Bangladesh and Laos), the 'simple' water equation appears more appropriate.

For China, the 'simple' calculation resulted in an annual dietary water consumption of 1,283 m^3/cap/y. A disaggregated analysis resulted in annual water requirements for diets of 1,273 m^3/cap/y, i.e. almost the same. However, if water productivity for cereals had not been separated into rice and other cereals in the disaggregated approach, the estimated dietary water requirement would be 1,193 m^3/cap/y. Depending on the composition of the vegetarian part of the diet, the consumptive water use may thus vary significantly. With a population of 1,274,000,000 in year 2000 in China, separate calculations for rice and other cereals result in an additional water requirement for all China of 102 km^3 annually, as compared to estimates where there is no separation between rice and other cereals. The large uncertainties in these kinds of estimates must, of course, be taken into when interpreting the considerable differences in absolute numbers, especially when calculations refer to large population numbers.

Table 11 Examples of dietary water requirements estimated with disaggregated food groups and with 'simple' equation with parameters for share of vegetable and animal calorie supply

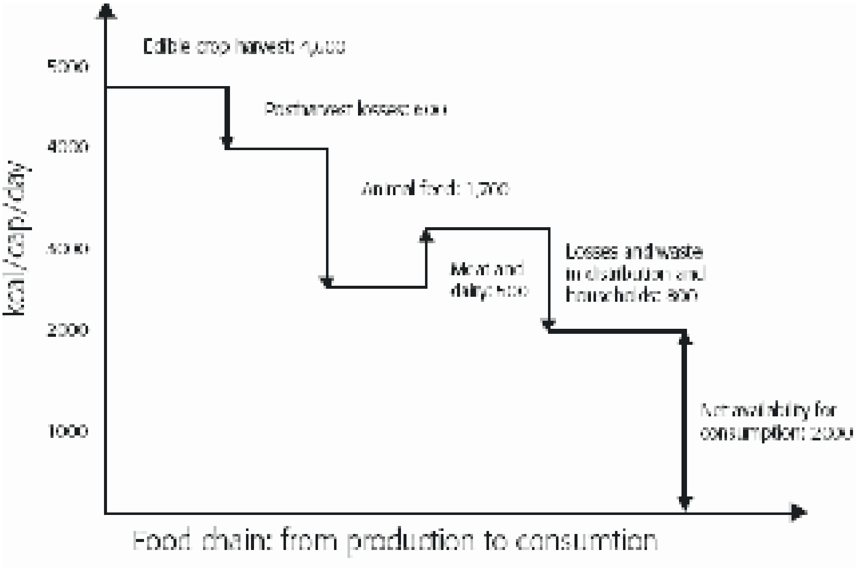
Country	*Climate category*	*Dietary water use*	
		Disaggregated WP (m^3/cap/y)	*Simple WP (m^3/cap/y)*
Japan	Temperate	1120	1243
Sweden	Temperate	1972	1885
USA	Temperate	2538	2019
China	Temperate/tropical	1273	1283
Bangladesh	Tropical	453	485
Burkina Faso	Tropical	585	580
Laos	Tropical	701	604
Tanzania	Tropical	579	509

Based on a small country sample, it appears that the 'simple' dietary water use function (for vegetable and animal calorie supply) appears to underestimate actual dietary water use, in particular for high income countries with high animal calorie supply in diets. The 'simple' dietary water use function agreed better for low-income countries with proportionally higher vegetable calories supply in diets. However, considering the large uncertainties in the estimates as illustrated in the China example, the error occurring from using the simplified compared with a disaggregated approach is small.

3.5.4 Reduction in losses and waste in the food chain from production to consumption

We have all seen examples of losses and waste of food, in the field, in stores, in restaurants and at home. For various reasons, a certain fraction of the food that has been produced and which could have been used for direct human consumption is used in other ways or is wasted. As illustrated in Figure 10, the losses and wastage can be associated with three principle sections in the food chain. The first one, losses in connection with harvest (here referred to as "postharvest" losses), occur in the field before food has reached the household or market. These losses are substantial, particularly in developing and tropical countries as compared to developed countries and the temperate region. In the case of India for example, Swaminathan (2006) mentions that the post harvest infrastructure is weak, "... even now, paddy is spread on the roads for drying in many places. The spoilage losses can be as high as 30 % in the case of vegetables and fruits". Similar levels of loss have been reported for China. Due to antiquated storage methods, losses in the order of one seventh of its cereal harvest were reported at the beginning of the 1990s (Liang et al 1993, in Smil 2000). Perishable food items are, of course, vulnerable in a hot and humid climate during transport and in the absence of cold storage.

Figure 10 Estimated global per capita averages of food harvests, losses, waste and conversions, in kcal/day. Source: Table in Smil, 2000 based on FAO statistics



Losses are also associated with transport, transactions and handling in food processing, wholesale and retail, and in restaurants and other food outlets. The third important link of the food chain refers to what is happening in the household i.e. among the consumers of food. In the rich part of the world, losses and wastage can be significant at the household level, while the postharvest losses are probably less significant, both in absolute terms and in comparison to the losses in developing countries in the tropics. For the U.S., it is noted that 40 % of the average per capita food supply is wasted (Smil, 2000). Jones (2005), who has presented detailed figures on food loss in the American food system, shows that American households throw out 1.28 pounds per day in their refuse. In addition, food goes down the garbage disposal, into compost piles, etc. In the retail segment, convenience stores have the highest loss, while supermarkets have a much lower wastage rate (ibid.). In a study about food losses in the UK, it is argued that Britons throw away 30 to 40 % of all food produced (Milmo, 2005). The reasons given are that the food items are "...deemed imperfect, out-of-date or surplus to requirements". The waste so created is worth £20bn, i.e., quite a significant amount.

Apart from losses and discarded food items, a significant part of the food that is produced is converted from vegetarian to animal calories (cf. Figure 10 which indicates that on a global basis, about 1,700 kcal out of 4,600 kcal edible crops produce are converted to about 500 kcal of meat and animal products). In calculations of the importance of this conversion, it is relevant to make a number of distinctions; between feed coming from natural grazing, from cereals/grain that could have been used for direct human consumption, what fraction of the feed that is produced with irrigation and what fraction that is produced under rainfed conditions respectively. Wild animals, which are an important source of protein and energy for segments of the rural population, are typically nourished on feed that is not directly used for human consumption whereas cattle raised for beef production get a large share of their feed through grain, alfalfa or other products that either could have been used for direct human consumption or which are grown on fields that are suitable for direct human produce, with or without irrigation and on deforested areas, e.g. in parts of all continents.

Finally, the increasing and widespread over-consumption of food must be up for scrutiny. Overweight and obesity is a growing and serious problem in the world today and is projected to be a growing challenge.

Losses and conversions in the food chain are very different in different countries. A combination of technological equipment, climatic conditions and management of food in the retail and household sectors are the prime factors behind level and type of loss. However, there is considerable scope to improve management in various segments of the food chain in order to realize opportunities for decoupling. While efficiency and productivity improvements in land and water management have been identified and discussed for some time, the policy options for progress on the consumption side are much less elaborated and scrutinised.

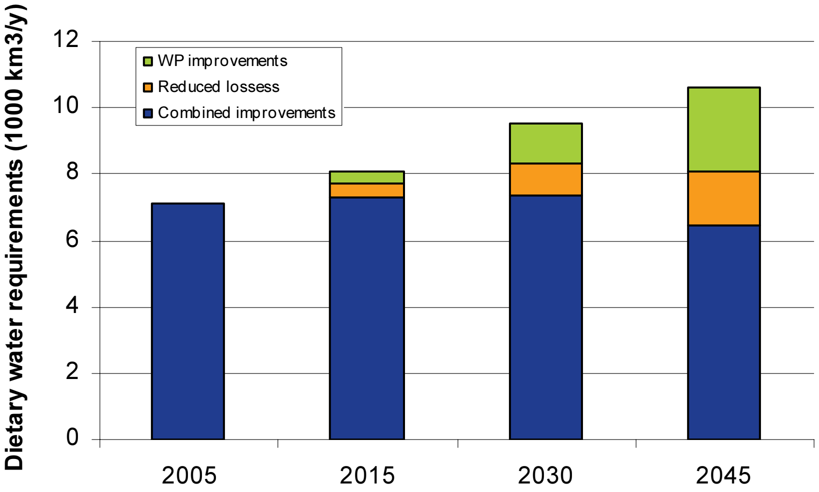
With reference to discussions in the literature (Smil, 2000; UK Vorley, 2004; Jones, 2005) it is possible and essential to reduce losses in the entire food chain, including "over consumption" of food. In the following calculations, we have assumed that food losses and waste in the entire food chain can be reduced by half over a period of a few decades. Although the time frame is different, this corresponds to the assumptions made in connection with the Millennium Development Goals, i.e. that it is possible and desirable to reduce extreme poverty and related problems by 50 % till 2015. Since losses and wastage in the food chain is in the order of 30 % of the food produced, this means a reduction of up to 15 % till the middle of this century (Table 12).

Table 12 Tentative and possible improvements in water productivity and reduction of losses in the food chain till 2045

	2005	*2015*	*2030*	*2045*
Water productivity improvements in relation to 2005 water consumption	0	-5 %	-13 %	-24 %
Reductions in losses and waste in relation to situation in 2005	0	-5 %	-10 %	-15 %

If improvements on the consumption side are combined with water productivity improvements, the implications for decoupling will be significant (Figure 11). The estimations indicate water consumption in 2045 may even be lower than the water consumption in 2005, i.e., 6,470 km^3/yr compared with 7,110 km^3/yr. Provided that both water productivity improves and that losses and wastage in the food chain are reduced, a full decoupling of future food production from GDP increase can been achieved. *It is important to note that this decoupling may be accomplished without any changes in the composition of the current, prevailing diet composition.*

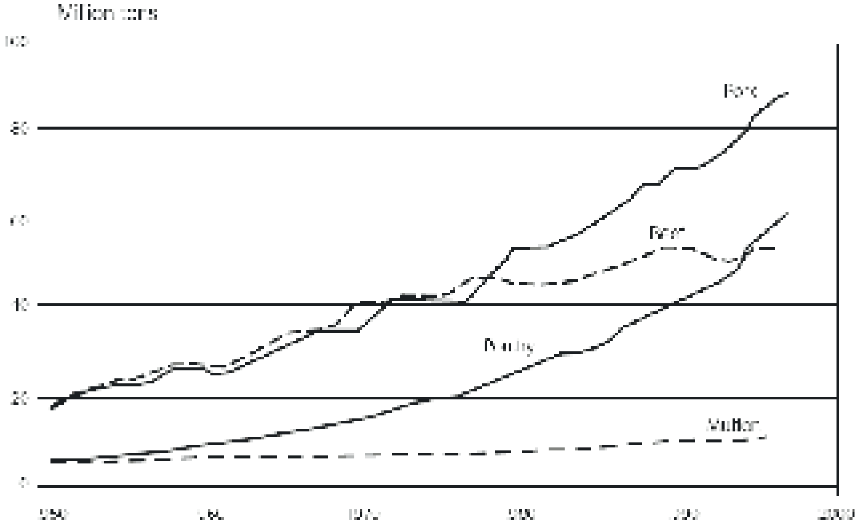
Figure 11 Reduction in water requirements through a combination of Water productivity improvements and 50 % reductions in losses and wastage. A 'break point' is assumed to be possible somewhere between 2015 and 2045



3.5.5 Changes in consumption patterns; drivers and implications

An increase in purchasing power is, of course, an important driver behind changes in food consumption patterns. Trends in both developed and developing countries show that the food demand patterns have changed significantly both in terms of composition and quantity demanded over several decades (SIWI et al 2005). As discussed in section 3.3, there is a rapid increase in food and water demand when GDP increases from very low levels to about 10,000 US$ per capita. With anticipated increases in GDP, the incremental increases in food and water demand are declining. With a progressive income, it seems that a saturation of per capita food and water demand and consumption in most developed countries is likely. But there will probably be changes in dietary composition as well as in then handling of food, in society and in households. There is obviously a market for fruits and vegetables, whereas the demand for meat and dairy products in developed parts of the world is showing a more diverse picture. There are signs of dietary changes towards demand for meat and diary products with a lower consumptive water use, e.g. a trend towards more white meat instead of read meat (Figure 12). In developing countries, where water pressure is already high, the demand for animal food products is increasing rapidly; from about 200 million tons in 1995 to about 3000 million tons in 2020 (de Haan et al 1996; Delgado, 1999). This is important from a human health point of view since current intake of animal proteins and important micro-nutrients is low. It is, however, likely to substantially increase pressure on water resources, especially since the fraction of meat production in feed lots may increase.

Figure 12 Trends in world meat consumption. Source: Vorley, 2004



Within EU, the consumption of fat dairy products, i.e., milk and butter, is to some extent kept at high levels with the help of subsidies. Subsidies stimulate production and the "surplus" is either exported or channelled into domestic consumption. The European school milk scheme, for instance, are getting higher subsidies to milk with a higher fat content (Schäfer-Elinder, 2005).

3.5.6 What nutrition level is required to lead a "healthy and productive life"?

The urgent need to stimulate an "appropriate" and sound consumption pattern cannot be overlooked in a world, where overweight and obesity are more prevalent than under nourishment. More than 1 billion are overweight and obese while the number of under nourished is about 850 million. The size of the former group is increasing fast in developed as well as in developing countries and particularly in urban settings. Too little food causes severe sufferings among individual and the costs to society are high. Similarly, too much food, and too much of energy dense food with high sugar and fat contents causes the individual and society huge sufferings and drains resources in society as well as it contributes to increase the pressure on water and land resources.

To get a more valid picture of what constitutes a "reasonable" guideline for food intake, the figures on "apparent consumption" figures derived from FBSs and used in section 3.3, should be compared with information on the food (energy) intake requirement. Information on the energy requirement can hardly be precise since it varies with age, sex, level of activity and individual characteristics. A few key figures do, however, illustrate the difference between apparent consumption and what is, or what ought to be, level of food intake.

For good nutrition, the basal metabolic rate, i.e. the energy requirement for the human body to function physiologically is in the range of 1,300–1,700 kcal/person/day in different countries, when the body is in a state of rest and depending upon age, sex, height, body weight. With increased level of activity, the requirement is naturally increasing. Figures describing the average food energy requirement in a population seem to vary between 2,000 to 2,200 kcal/person/day (Smil, 2000; Schäfer-Elinder, 2005). Substantially lower figures are, however, also reported for both OECD and less developed countries. In tables depicting the Minimum Dietary Energy Requirement (MDER), for instance, FAO presents figures for each developing country from 1969–1971 to 2001–2003. For the latter period, the figures on MDER vary from 1720 (in Ethiopia) to 2030 kcal/person/day (United Arab Emirates). A slight increase over the 30 year period is due to changing age structure of the population.

Other reports similarly show that actual energy requirements or food intake are often much below the international norm of 2,700 kcal/capita/day. For urban India, it is argued that 70 % of the 2,700 norm, i.e. 1,890 kcal/person/day is considered acceptable (M.S. Swaminathan Research Foundation, 2002) and Turkana people in rural Kenya, have an intake of 1,900 for the adult males and only 1,400 among females (Smil, 2000). More surprising, "…no U.S. food consumption survey has returned an adult female mean higher than 1,700 kcal/day during the past generation. The mean for the NHANES II was only about 1,550 kcal/day for women between twenty-five and fifty years of age" (Smil, 2000). Similar surprisingly low figures were recorded in national nutrition surveys in Canada (ibid.).

The point is that it is crucial to make a difference between food supply and the actual intake, or consumption, of food. Food supply in society must be at a level where the risk of undernourishment is low or eliminated. But if waste and losses in the food chain are considerable, if access to adequate for some people is denied due to social cleavages in society and if consumption (among some) is leading to overweight and obesity, there is an obvious need to scrutinise the linkages between supply, demand, wastage and food intake.

3.5.7 Decoupling and mitigating water competition between food and energy crop production

It is not axiomatic that an expanding energy crop production leads to negative consequences relative to land, water and other resources. Properly located, designed and managed biomass plantations can provide several benefits. Table 13 below outlines some of the beneficial effects that can be obtained from energy crop production and also indicates possible negative consequences. The table is not restricted to water-related benefits, but also includes other aspects.

Utilisation of forest and crop residues for bioenergy production is one way of achieving a decoupling between water use and bioenergy production, as previously discussed. Another possibility is to use wastelands for biomass production. The definition of wastelands varies. A common feature is that it refers to lands that are considered too dry and/or with too low fertility to be used for food or other production, and they may also be prone to erosion. Control or use rights are often vested in the state. However, it is also noted, for instance, in India, that there are traditional crops that grow well in these areas, without irrigation. These crops may not be of interest for food or other traditional purposes, but they could be suitable as energy crops, e.g., sweet sorghum. According to Dr. Suhas Wani, ICRISAT, the Government of India has embarked on a policy, through which 16 million hectares of waste land are to be used for production of bio-energy crops. Partnerships are being set up between farmers and companies that can process the biomass for energy, and assessments indicate that several hundred million hectares of degraded land could support reforestation. However, approaches other than large-scale plantation establishment are often viewed more suitable for the reclamation of degraded land. For example, protection, assisted regeneration, and agroforestry, rather than large-scale plantation establishment, were recommended for areas subject to temporary forest clearance and selective logging. The practical land availability can be expected to be limited to lower levels than indicated by assessments of technical availability, due to political and socioeconomic factors. Land reported to be degraded is often the base of subsistence for the rural population. One example is forest fallows with shortened rotation periods in shifting agriculture owing to population pressure. Reforestation attempts will likely meet strong objection unless advantages to the traditional user are secured. Implementation strategies need to integrate bioenergy production with food/feed production and rural development programs in general.

Among the water related benefits, the use of energy crops for wastewater treatment has received considerable attention. The benefits of tree plantations for water erosion control and flood prevention are extensively documented, and afforestation of deforested watersheds leads to reduced sediment load in reservoirs and irrigation channels. Large-scale planting of trees are used for salinity management on land subject to productivity losses due to soil salinity induced by rising water tables. Agroforestry systems can increase productivity in rainfed agriculture by capturing a larger proportion of the annual rainfall in areas where much of the rainfall occurs outside the normal growing season.

In-field soil evaporation and evaporating surface runoff can be redirected to energy crop transpiration, leading to increases in the productive use of evapotranspiration. Thus, since increasing demand for bioenergy allows for selection of new crop types, one strategy for water scarcity adaptation can be to use specific suitable energy crops to increase the spatial and temporal accessibility of water resources and at the same time improve the quality of freshwater flows. For example, Cynara, a perennial plant suited to the dry Mediterranean conditions, can take advantage of winter rains and produce high yields without irrigation, in contrast to crops like Miscanthus and sorghum, which require irrigation for high yields under such conditions.

Clearly, the possibilities of bioenergy in water-scarce environments need to be further investigated, both for improving the understanding of how it is possible to meet a prospective bioenergy demand without aggravating an already difficult situation, but also to provide new insights about water related limits to an increased bioenergy supply in different regions of the world.

Table 13 Alternatives for biofuel production to reduce water trade-offs

Source	*Water/land implications*	*Win or loose implications*
Residues from food and forest sectors	No additional pressure on water or land resources given careful consideration of restrictions linked to soil conservation requirements	+ will give farmer additional income + positive energy balanc e- - over – utilization may lead to erosion, soil carbon losses and reduced soil fertility
Utilisation of waste lands	No additional pressure on land and water	+ could reduce erosion + would increase value o f waste lands; more care and probably environmental benefits + with suitable policies, it could be a means for improved livelihood of the poor + could be part of an improved local/regional economy

Cultivation of energy crops in *areas where consumptive water use should increase*, i.e. water logged areas (e.g., Australia)	An increased consumptive use of water would lower a too high water table	+ reduce the detrimental effects from water logging + increase the value of degraded lands + benefits from a necessary measures
Cultivate salt *tolerant crops in salt affected areas*	Salinization is a huge problem. A number of crops can be grown, some of which can be used for energy production	+ increase value of degraded lands +/– competition with food crops that may also be salt tolerant
Blue green algae, water hyacinth, and similar	No additional water nor land required	+ presently a large part of the resource is not used today – potential logistical problems
Bioenergy plantations using traditional food crops	Currently, part of the bioenergy comes from traditional food crops such as sugarcane in Brazil and corn in USA. Implies that land and water that could be used (or have been used) for food production will be allocated to energy production	+/– net energy contribution and climate benefits vary from good to only marginal – increases the pressure on water and land and competes with food production – implies monocultures; loss of biodiversity – risk that big companies will take over land and management; social effects questionable
Agroforestry systems	Increases productivity in rain-fed agriculture by	+/– beneficial effects for

	capturing a larger proportion of the annual rainfall in areas where much of the rainfall occurs outside the normal growing season	under-storey food crops is sometimes unclear
Multifunctional bioenergy plantations	Plantations of lignocellulosic tree and grass species that are located, designed and managed so as to provide additional benefits besides the biomass harvest. Improves soils /reduces soil degrading processes	+ improves local acceptance due to additional local benefits + soil phytoremediation (e.g. cadmium removal from cropland) + reduction of nutrient leaching and soil erosion + flood mitigation + treatment of nutrient-rich drainage water and pre-treated municipal wastewater and sludge + provision of habitats and enhancing biodiversity and game potential

3.5.8 Total water demand for food and bioenergy production after accounting for decoupling effects

To conclude, it seems that there is a large window of opportunity for decoupling future water needs for food and bioenergy production from increases food and bioenergy demands. If improvements on the food consumption side are combined with water productivity improvements on the production side, the estimated water need for food production in 2045 is estimated to be 6,470 km^3/yr as shown in Figure 11. The illustrative calculations of water need for bioenergy in 2050 (4,000–12,000 km^3/yr) give a clear indication of the difficulties to give an estimate of the total water need for future bioenergy production. The calculation does, however, show that the consumptive water requirements to produce biofuels are quite significant. As such, they indicate that we may expect a heavy competition for the same water that farmers and society in general have assumed should be for food production. As shown in Table 13, bioenergy can be generated from a wide range of sources. The text in the table also points at opportunities for decoupling in connection with energy production from bio-sources.

Climate change will further add to the uncertainties of estimates of water for food and bioenergy, especially at a regional level. Nonetheless, it is clear that the total water demand would become very high, and far beyond what can be considered as a realistic water withdrawal, if current levels of water productivity and efficiencies in the chain from production to consumption were to prevail in the future.

3.6 Land requirements for future food and bioenergy production

3.6.1 Horizontal expansion of croplands for food production

Recent assessments of agricultural production and food demand (FAO/IAASA, 2001; FAO, 2003), as well as the Global Millennium Ecosystem Assessment (MA, 2005a) point out that past agricultural production increase has been dominated by area expansion up until the 1950's. Thereafter, a substantial productivity increase (i.e., higher yields or more produce per unit area) has made it possible to produce much more food without a corresponding increase in cropland. The MA chapter on 'Cultivated systems' (MA, 2005b) concludes that although cultivated land has been increasing with 11 % globally, the per capita area to support food demand has decreased with 40 % between 1960 and late 1990. In view of the considerable increase in the demand for food and also for other produce that require land and water resources, it is important to estimate the likely horizontal expansion of land requirements in the future.

3.6.2 Estimation of future land requirements for food production

Based on projections of increased water demand for food as a result of increasing GDP and demographic change until 2045 presented above (section 3.3), future crop land requirements are estimated for two different land productivity scenarios:

- No improvements in land productivity, but improvements in water productivity and efficiency in the food chain as described in sections 3.5.2 and 3.6.4 (Appendix 2).
- Regions, which today have low or very low land productivity, will reach the same level of land productivity as regions with high levels of productivity. Water productivity and efficiency in the food chain are the same as described in sections 3.5.2 and 3.5.4. (Appendix 2).

The assumed land productivity improvement in scenario 2 means that yields will be increased to the same level as regional averages in other areas with similar climatic conditions. Agricultural research and experiments show that the potential improvements are well beyond the average yield improvements assumed in this calculation. Obviously, different paths and strategies are required. Moreover, it should be noted that there is a close link between land and water productivity; if water productivity improves, yields will also improve.

The estimates include demand for main crop types, i.e. cereals, oil crops, vegetables and sugar beet and sugar cane. Additional land is used for cultivation of other crops, like fruits, cotton and other commercial crops. In terms of area, these crops are not significant on a global basis although they could be quite important for an individual country and also for livelihood. About half of the cereal production is converted to feed for animals. Thus, the calculations estimate the total land area requirements for the vegetable part of the future diet, as well as part of the animal based food. Estimates of land requirement for total animal food products require thorough calculations, since feed for animals also comes from “permanent grazing lands” and crop and household residues.

The total area of agricultural land required to produce the assumed food supply in 2045 without any improvements in land productivity is estimated to be in the order of 1,900 million ha (Table 14). This means that an additional 600 million ha of land will be required to meet the expected food demand in 2045, even if water productivity improvements and reduction of losses (as discussed in section 3.5) are accounted for. However, with land productivity improvements in regions where productivity currently is low (scenario 2), the required permanently cropped area will be approximately 1,600 million ha (FAOStat, 2006). Thus, in this scenario an additional 300 million ha must be converted to crop land for production of food demand in 2045. The effect on land area requirements from improvements in land productivity in sub-Sahara Africa, North Africa and West Asia explains the largest part of the difference between the two scenarios.

Table 14 Estimates of land required in 2045 to produce selected food groups. Estimates are based on growth in GDP, population and the associated assumed increase in the demand for food water. Values are compared with land use data for year 2000 (FAOStat, 2006)

Food group	*Estimated food demand by 2045*		*Land used for food prod.*
	Scenario 1 Year 2045 (10^6 ha)	*Scenario 2 Year 2045 (10^6 ha)*	*Year 2000 (10^6 ha)*
Cereal (human consumption)	568	482	310
Cereal (other uses)	568	482	364
Starchy roots	82	77	53
Sugar, cane + beet (human consumption)	12	14	
Sugar, cane + beet (other uses)	(?)	(?)	20
Pulses	83	60	66
Oil crops (human consumption	90	71	89
Oil crops (other uses)	135	107	133
Vegetables +20 % waste	36	32	45
Total area for selected food groups	1890	1590	1300[9]

Cereals constitute by far the largest food group in terms of land area requirements. The land area needed for cereal production is expected to almost double by 2045, assuming no changes in land productivity. The other commodities included in Table 14, i.e., starchy roots, pulses, sugar cane and beets, oil crops and vegetables

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[9] In 2000, FAO estimated the total permanent crop land area to 1,533 million ha. The area of selected food groups is equivalent to 84 % of the total permanent crop land. This relation may alter, but here such land use change is not included. The scenario here only estimate land required for the projected diets in 2045.

only constitute about a third of the total land area requirements. Today, there are no comprehensive data on human consumption versus other uses of oil crops. Rough estimates indicate that approximately 60 % of total oil crop production is used for non-human consumption, and it is estimated to increase further (FAO, 2003; FAOStat, 2006).

The second scenario, i.e., effects of improved productivity per land area, takes accounts of the fact that current average crop yields are well below the potential yield. In crop production research and experiments, an increase in yields with 5–10 % in high-intensive crop production is regarded as a significant improvement. In currently low-yielding regions such as sub-Sahara Africa, the margins for improvements are wider. Here, relatively well-known management strategies, such as timely coordination of land, water and nutrient management, and improved crop varieties, can increase production with 30–50 %, or even doubling yields in currently low-intensity rainfed systems. Thus, there seems to be a large scope for reducing future land area requirements by increasing land productivity in low-yielding regions such as sub-Saharan Africa, South Asia, South East Asia and North Africa.

These estimates on future land area requirements (an additional 300–600 million ha by 2045) can be compared to recent estimates for different investment scenarios, in which the figures range between 90–490 million ha by 2050 (CA, forthcoming). It can be concluded that, although reduction of losses and improvements in agricultural and water productivity have been accounted for, food production to meet expected increase in demand will *not be possible without the addition of new cropland.* The annual cropland expansion needed was estimated to be 0.48 % on average from now until the year 2045, which corresponds rather well to the figure estimated in a similar assessment (Box 3).

BOX 3: Future land requirements differ depending on scenario basis.

Different approaches in the estimation of future natural resource use result in quite diverse numbers of required resources. For example, an alternative approach, which uses the current global fresh water availability as the basis for estimates, suggests that fresh water resource may ultimately limit agricultural expansion rather than land resources (Falkenmark and Rockström, 2004;

Falkenmark et al. 2007). In Falkenmark et al. (2007), the overall *water requirements for food self-sufficiency are calculated for 92 developing countries* on the level projected by FAO by 2030 (3,000 kcal/p.d. out of which 20 % is animal-based). The same diet-related assumptions of consumptive use of water per 1,000 kcal were made as in the present study, resulting in a yearly per capita requirement of 1,300 m^3. This represents a rather low water requirement when comparing with the current study, where it corresponds to a GDP level in figure 1 of only 5,000 US dollar per capita.

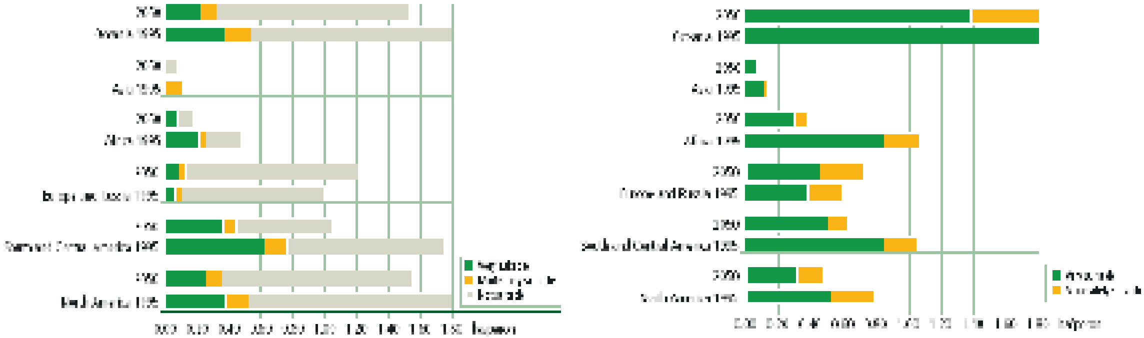
Besides the total water requirements, the study also tried to assess *from what sources these water requirements could be met* (e.g. loss reduction by water productivity increase; irrigation; rainfed fodder from grazing lands; and increased rain capture for upgrading rainfed agriculture). It was concluded that, although attention had been paid to realistic increases in land and water productivity, *food self-sufficiency will not be possible without the addition of new cropland of the order of 0.8 % per year over the coming 50 years as compared to 0.65 % per year the last 50 years.* This figure corresponds well with the estimates presented in this study.

3.6.3 Comparing estimated land use requirement with available land resources

Key findings from the FAO/IIASA (2001) agro-ecological zoning show that ca 75 % of global land surface are unsuitable for crops due to adverse climatic conditions (too cold, too dry) or physical constraints (too steep, poor soils). On a regional scale, South America and sub-Sahara Africa were identified as holding ca 80 % of the currently unused potentially suitable crop lands (Figure 13) However, these areas are already providing other ecosystems goods and services (ex forests, wild food, habitat for fauna, etc). Thus, what is sometimes seen as potential croplands are already serving humans and part of a wider ecosystem. Climate change scenarios may seriously hamper the current crop land potential, more so for developing countries than developed countries (FAO/IAASA, 2001).

In view of the FAO/IAASA report and the MA conclusions on human activities affecting ecosystems services and produce in different scales, it appears that there is little scope for expanding the agricultural area without affecting ecosystem services negatively. In the four MA scenarios with different levels of technology, socio economic and demographic settings, land use is continued to change with 9–20 % addition of today's cropland until 2025 (MA, 2005a). This expectations of land use conversion resulted in sufficient food production in all scenarios except one, the 'adapting mosaic' strategy, which implicitly should reflect an environmental sustainable and socio-economic fair development path.

Figure 13 Per capita land availability potentially suitable for crop production (left), and per capita land availability with crop potential in forest ecosystems (right). Due to expected population growth, the per capita land resource decrease, especially in Asia. From FAO/IAASA 2001



3.6.4 Prospects of land requirements for future food supply

From the above estimates on land required to support food supply in 2045 the following conclusions can be drawn:

- To meet future dietary demands, it is necessary and inevitable that productivity both in water (m^3/t) and land (t/ha) is improved.
- There is large scope for improvements of water and land productivity in currently low efficient production systems in different regions, such as large parts of Africa. Substantial improvements can be done with known agricultural technologies and water management.
- There is a potential to enhance land productivity and water productivity in currently so-called permanent grazing lands of 3,400 million ha. These areas may support a greater animal production and specific crop production system.

- Expansion of crop land in the permanent grazing lands may be possible in some regions, but not in others. Any expansion of crop land implies trade-offs between a set of benefits from various land-uses. Permanent grazing areas, for instance, are important in terms of provision of ecosystems goods and services other than food items and other biomass intended for direct human consumption/usage.
- Even with considerable productivity improvements in current low producing systems, additional land may have to be appropriated into permanent crop production.
- The calculations suggest that even with considerable improvements on the production side, it will still be necessary to consider what efficiency gains that can be achieved in terms of changes on the consumption side.

3.6.5 Land requirements for bioenergy production

In order to complement the above assessment of land requirements for food production, the earlier calculated regional demand for biomass from dedicated plantations is used to indicate the land requirements for bioenergy. The numbers in Table 15 corresponds to the cases where regional average yield levels are 200 GJ per hectare and year (about 10 Mg DM/ha/yr) and 400 GJ per hectare and year (about 20 Mg DM/ha/yr). It is estimated that the future land requirements for bioenergy production will be in the order of 400–800 million ha.

As for the case of water demand for bioenergy, we refrain from more refined approaches such as using regional-specific yields due to the uncertainty of crucial parameters such as climate change, crop choice, biotechnology development, land use practices and relative cost of land, water and other inputs. One could argue that at least a distinction between tropical areas (and C4 crops) and the rest of the globe should be made, acknowledging the possibility for reaching higher yields. On the other hand, if mostly degraded and marginal land areas are targeted in tropical areas, and more extensive production dominates, yields may be similar or even lower than in temperate areas.

Table 15 Land requirements for energy crop production to supply the biomass demand from dedicated plantations calculated earlier

	Energy crop demand (EJ/year)	*Corresponding land requirements given regional-average yields at 200 GJ/ha/yr (million hectares)*	*Corresponding land requirements given regional-average yields at 400 GJ/ha/yr (million hectares)*
Canada	11	55	28
USA	18	90	45
C America	7	35	18
S America	12	60	30
N Africa	1	5	3
W Africa	14	68	34
E Africa	12	62	31
S Africa	4	21	10
W Europe	3	15	8
E Europe	7	35	18
Former USSR	21	107	53
Middle East	0	0	0
S Asia	12	60	30
E Asia	16	80	40
SE Asia	9	45	23
Oceania	9	46	23
Japan	0	0	0
World	157	783	392

3.7 Implications from urban expansion and industrialisation

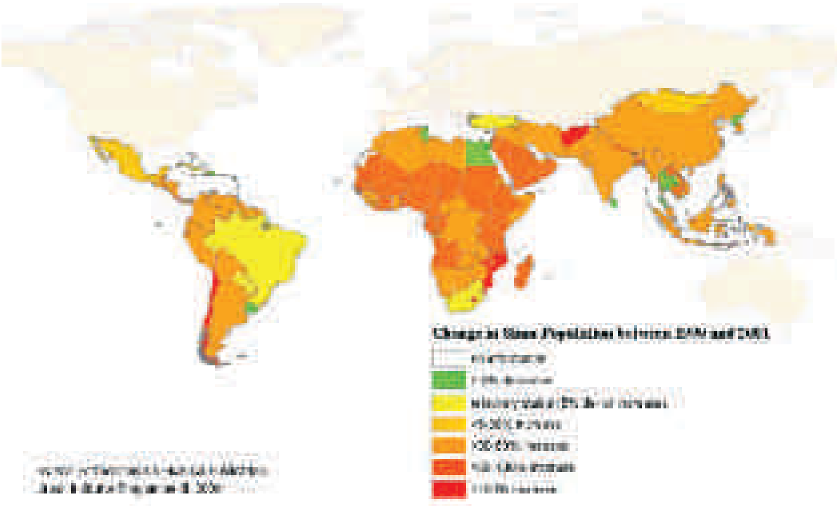
3.7.1 Urbanisation as a driver in economic development and social transformations

Rapid growth of urban centres is one of the most significant features of change today and in the foreseeable future. Within a generation, it is projected that some 2 billion people, or about 95 % of the total population increase, will be added to the urban population, primarily in Asia and sub-Saharan Africa. By 2030, it is expected that 60 % of the world population will live in urban areas. This massive expansion is equivalent to the combined total national populations of China and India at the turn of the century. But in developed countries, the urban population is expected to increase very slowly, from 0.9 billion in 2000 to 1 billion in 2030 (UN-Habitat, 2006).

The new demographic situation will have far-reaching consequences. For instance, the contribution to GDP and government revenues from urban sectors is generally quite high. In India, for instance, it is calculated that the contribution from urban sector to GDP increased from about 29 % in 1951 to more than 50 % in 2001, while the share of urban population was 17 % and 29 % respectively (Lundqvist et al. 2003). Official sources claim that more than 90 % of central government revenues emanate from the urban sector at the turn of the century. At the same time, the share of water allocated to the urban sector was around 17 % in 2001 (ibid.).

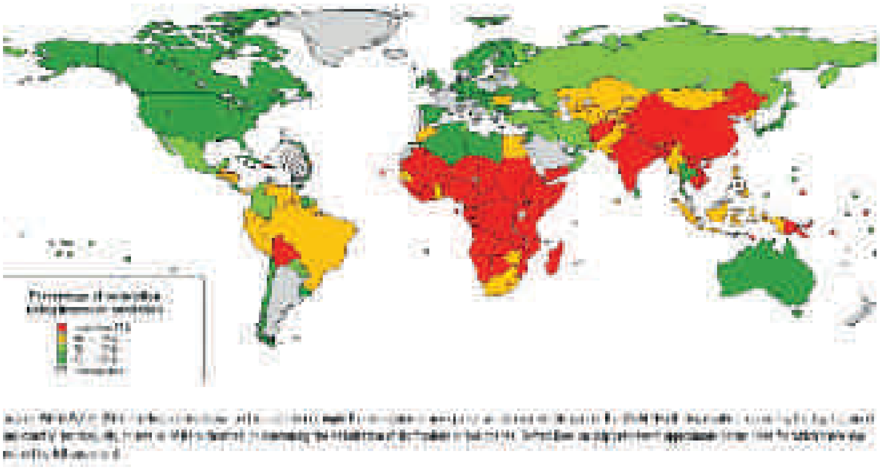
In 2000, more than 900 million urban dwellers (nearly a third of all urban dwellers worldwide) lived in slums (Figure 14). A slum dweller may only have 5 to 10 litres per day at his or her disposal. A middle- or high-income household in the same city, however, may use some 50 to 150 litres per day, or more (UN-Habitat, 2006). In highly industrialised countries, almost 100 % of households are connected to piped water. The average water consumption for these households is 215 litres per person daily. Less than 20 % of households in Africa are connected to piped water and only 40 % have access to water within 200 meters of their house. Treatment of sewage will remain to be a huge challenge, resulting in a worsened pollution of the remaining water resources.

Figure 14 Change in global slum population, 1990–2001. Source: World Water Development report, 2006



Human population growth and the expansion of economic activities are collectively placing huge demands on coastal and freshwater ecosystems. Water withdrawals, for instance, have increased six fold since the 1900s, which is twice the rate of population growth. Losses of water in distribution systems are often as high as 40 %, sometimes up to 60–70 %. Less than 35 % of cities in the developing world have their wastewater treated. Sewage and treatment costs are estimated to be 5 times higher than cost of providing water. Many countries still lack access to improved sanitation (Figure 15), (UN-Habitat, 2006).

Figure 15 Coverage of improved sanitation, 2002. Source: World Water Development Report, 2006

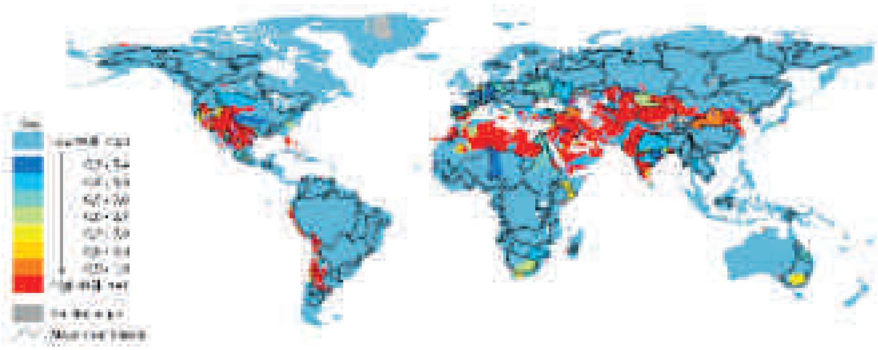


Urban expansion will continue to increase in developing countries. The urban population will also raise their income, faster than other segments of their society. The net result will be an increased demand for water for use in the cities, both per capita and in total (due to the increasing population). In the context of this report, it is most relevant to recognise that an increasing share of the water that is used to produce food is actually indirectly consumed by the urban population.

3.7.2 Competition and trade-offs between sectors

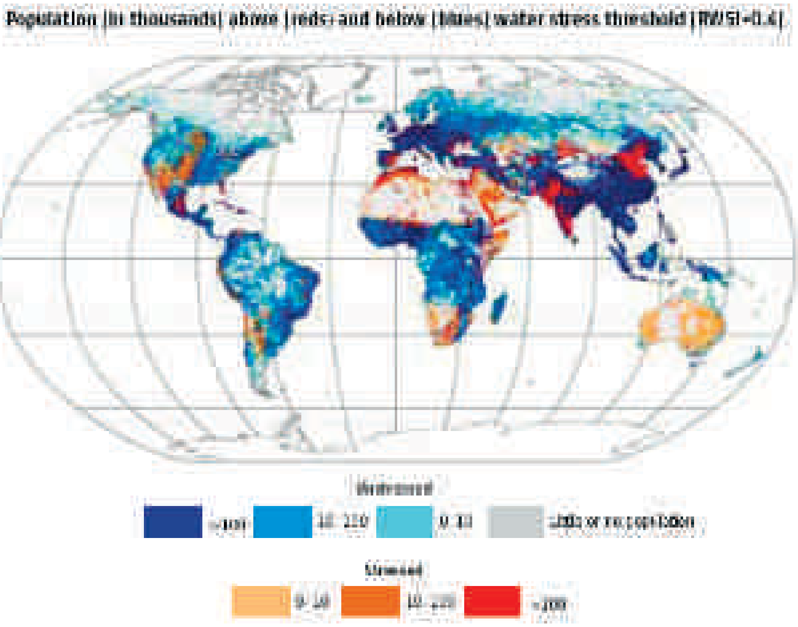
About 1.4 billion people, mostly impoverished, live in river basins where all the blue water is already committed or overcommitted (Figure16). Climate change and variability compounds the risks of such over-commitment in many parts of the world. With current levels of water productivity, the additional consumptive use of water linked to food security by 2025 and 2050 is estimated at 3,800 and 5,600 km^3/year, respectively (Shiklomanov, 2000). Currently, the total annual withdrawals of blue water are between 3,500 to 4,000 km^3.

Figure 16 Water withdrawal in relation to blue water availability. Beyond a water withdrawal level of 0.7, the environmental flow has already been over-appropriated (yellow and red areas). Source: Smakthin et al., 2004



Water requirements in households, industry and service sectors will increase with city size. Even if direct requirements are comparatively small in the urban sector, growing demands still pose a significant problem in cases where all accessible water is already allocated or committed (Figures 16 and 17). Already today, there are several examples in various parts of the world where some of the water that used to be delivered to the agriculture sector is now being diverted to urban areas. Severe tensions and conflicts have resulted. Farmers, who have been accustomed to liberal supplies with virtually no fees have now to face reduced supplies and must often pay for water services. In some areas this has resulted in demonstrations and riots, including casualties.

Figure 17 Population experiencing blue water stress. Source: World Water Development Report, 2006



Big cities are expanding their search for water to the surrounding areas, increasingly distant from the city itself. Examples from India are: Chennai, pumping 235 km and planning for 300 km; Bangalore: 95 km; Delhi: 450 to 500 km (from Tehri dam) (Sunita Narain, CSE, India. Pers. Com.). In some countries, governments can decide on the allocation of water from one sector to another, depending on how the water rights are defined. In other countries, where land and water rights might be private, urban water service providers can buy water from the surrounding land-owners, for example by compensating for reduced abstraction for irrigation or even to give up farming. These examples are so far primarily from developed countries such as North America and Australia.

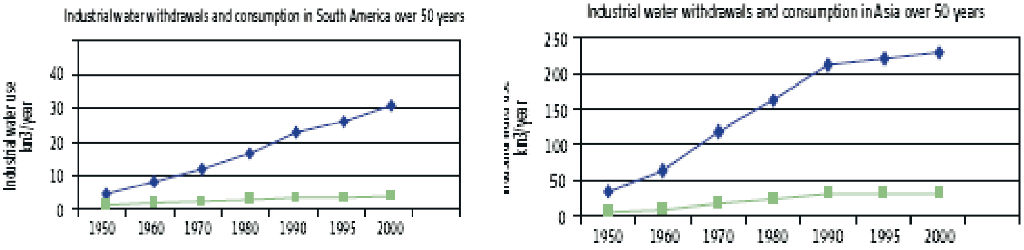
Over-appropriation of ground- and surface water will continue to increase, due to increased food-production and increased use by industry and cities, with the consequence that freshwater ecosystems will deteriorate. Cities and industries will secure their water supply on the expense of other sectors, such as agriculture and other rural uses, due to the fact that water has a much higher economic value in industry and in cities, but also because the political and media voice of a growing urban population is significant.

3.7.3 Urbanisation, industrialisation and environmental implications

Water pollution worldwide is of huge concern, but has not received adequate attention. Vast amounts of water are today used to dilute and transport waste. Dilution is not a viable solution to manage pollution. The world's sinks for pollution are filling up fast – rivers, seas and atmosphere. The water sector has done little long-term forecasting or scenario development, but what has been done suggests that 'the problem of water is the most important global scale issue of the present century (Simonovic, 2002). In particular, the current use of clean water for the dilution and transport of wastes is not sustainable.

As described in section 3.7.1, urbanisation and industrialisation will continue to increase, with worsened pollution as a result. Water withdrawals for industrial purposes have continuously grown over the last 50 years (Figure 18). The lack of sewage treatment in cities will remain to be a concern. Steps are taken to find less polluting industrial processes in many countries, but especially developing countries will continue to use old and polluting techniques for some time yet.

Figure 18 **Industrial water withdrawal (diamonds) and consumption (squares) in Asia (left) and South America (right) over 50 years. The demand for water by industries increases rapidly in many regions. Bad water quality can hamper industrial development. Source: World Water Development report, 2006**



Aquatic ecosystems and species are deteriorating rapidly in many areas. This is having an immediate impact on the livelihoods of some of the world's most vulnerable human communities by reducing protein sources for food, availability of clean water, and potential for income generation.

The UNEP program GIWA (Global International Waters Assessment) has conducted studies over the state of the environment in 66 regions of the world (Figure 19). Agricultural run-off and industrial and domestic discharges are in general the main causes of pollution. Microbiological pollution is widespread in densely populated areas.

Figure 19 Future environmental pollution trends. Source: GIWA, 2006

The total supply of the world's renewable water resources is estimated to be 42,650 km^3/year. Production of wastewater was in excess of 1,400 km^3/year in 1995. Estimating that each litre of wastewater pollutes at least 9 litres of freshwater, some 12,600 km^3/year, approximately 30 % of world's water resources, are not available for use due to pollution. With foreseeable population growth, industrial development, agricultural production, use of non-renewable resources and persistent pollution, the situation will get worse before it gets better (Simonovic, 2002). There are however indications that there is a strong relationship between world's water resources and future global industrial growth. Industries need clean water for their production, and Business is less inclined to invest in areas that are much polluted. The use of clean water for dilution and transport of wastewater, imposes a major stress on the global world water balance. If not dealt with, the pollution of the world's water resources will have a dramatic impact on the world population in the 21st Century.

3.8 Suggestions for policy makers

Experience suggests that economic development will involve both rising per capita food demands and an increase of the animal protein component. With present water productivity and with a projected increase in the average per capita dietary energy supply, global water requirements may be expected to grow by 50 % by 2045. Such huge additional water requirements cannot possibly be met by irrigation expansion, since blue water resources are already over appropriated in large parts of the world (Figures 16 and 17). A combination of measures both on the production side and throughout the food chain must be pursued through a mix of policy interventions to achieve food security in the future. On the production side, the role of rain fed agriculture must be enhanced by a more efficient utilisation of the rainfall. Rainwater harvesting could increase the availability of water for supplementary irrigation and also replenish the water resource available as soil moisture, i.e. the green water resource. For the farmer, it is crucial to be able to better cope with drought and dry spell incidents.

Studies of the impacts of anticipated climate change, at the regional level, indicate that present tropical semi-arid and Mediterranean climate zones may be severely affected by decreased rainfall, increased temperatures or both (IIASA, 2002). Both these factors may hamper yield potential and subsequent possibilities to produce food and biomass. In addition, the expected 'fertilizer effect' i.e., improved water productivity caused by higher levels of atmospheric CO_2, may not have the same impact on water use as hitherto believed (Long et al. 2006). This may have contributed to a slower development of policy actions to adapt crop production systems to the expected effects from climate change, since the urgency of the matter was previously underestimated. Thus, on regional scale, climate change may be a key driver for change in biomass production for food and energy, both affecting and being affected by available water and land resources.[10]

Future water requirements will radically increase also in response to the increased demand for energy and the reduced importance of fossil fuels after the "oil peak". Additional water requirements to meet the needs for bio-energy production are estimated to be of a similar order of magnitude as the agricultural sector requirements (Berndes, 2002).

A decoupling is absolutely necessary but it will not be realised in the absence of concerted policy interventions. Improvements in water productivity in irrigation systems require one set of interventions while improvements in the rainfed systems will need other measures. A principal difference is that interventions in blue water systems, in terms of building of dams and conveyance structures, require a heavy involvement from government agencies, financial institutions and similar. The success of a green water strategy hinges very much on efforts of the farmers and communities. The green water strategy presumes an integrated land and water management systems. Also in this case, the support of formal and informal institutions is of paramount importance. Financial and advisory support in terms of loan schemes and revised extension services are required for the development of supplementary and small scale irrigation systems and co-management of land and water resources. Efforts must be made to replicate successful rain water harvesting programs and improved land husbandry. Together, they could give a boost to food production in areas where the yield is currently very low.

For countries at low levels of GDP/capita, the losses and wastage are to large extent due to poor and antiquated post harvest infrastructure which result in high losses at field level and before food reaches the household or market. With increasing levels of GDP, policy interventions will gradually have to be directed to the consumption side of food or nutrition security.

It is important to realise that a modification in consumers' behaviour is a complicated and thus lengthy and continuous process. Basically, it has to be recognised that increased income will motivate the consumer to buy more and it is impossible to give firm figures on what is a "reasonable" and "acceptable" level of consumption. For the consumers as well as for society at large,

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[10] A comprehensive review of recent scientific material on consequences on water resources and food production of regional climate change was recently presented by Stern (2006).

healthy dietary habits are economically well motivated (Livsmedelsverket and Statens Folkhälsoinsitut, 2005). In the case of dietary habits, important pieces of information could be further elaborated to influence consumer behaviour. It is, for instance, relevant to increase awareness of the fact that food production is associated with a huge water requirement, something that few consumers are aware of. It is also relevant to know more about the fact that price on food can not only be judged by the price tag at the supermarket. A considerable payment is made over the tax bill, which is used to pay about 350 billion US$/year in subsidies to the agricultural sector in OECD countries. Another price tag refers to environmental cost. It should be equally important for the consumers to know more about the links between an increasingly alarming over consumption of food and the individual and social cost in terms of public health risks.

Changes on the consumption side are as important for decoupling as improvements in productivity on the production side and they are crucial for the possibilities to lead a healthy and productive life.

3.8.1 Actions in Sweden

Sweden can lead the way in a number of policy and governance actions for future sustainable and sound development strategies. Key areas identified at the national scale are to:

- Explicitly include green water management strategies into its work related to the European Water Framework Directive, in terms of the consumptive water use involved in food production and production of bioenergy.
- Act as a role model by creating broad public awareness of the consumptive use of water in food production, for example through:
  - making better use of grazing lands for national meat production to reduce import from regions where scarce water can find more efficient uses,
  - introduce water marking on food items, especially imported meat (“nutrition per drop”), in cooperation with the food-industry,
  - modify the curriculum in schools so that they include important information about water / environment /

  sustainability and the linkages to economic growth and societal wellbeing,
  - procurement of food in the public sector should be guided by a rule that, say, 25 % of the food purchase by 2015 must be "water efficient",
  - bonus / rewards should be given to companies (farmers) who reduces losses in the food chain (from production to consumption) according to a jointly agreed schedule,
  - define "sustainable vices" concerning the connections between food-water-health-environment (elaborations could relate to proposals presented in: SOU 2005:51).
- Develop a national strategy for curbing the outflow of nutrients to rivers, lakes and surrounding seas to reduce the already serious eutrophication.

3.8.2 Sweden as an actor on the international scene

Sweden is also a global actor and partner. On the international scene, it is recommended that Sweden contributes in the following areas:

- Carefully considers the promotion of an International Food Security Panel to analyse implications for water resources, further eutrophication of freshwater systems and coastal waters, for food trade, and for securing a safe food supply system globally.
- Work for international agreements regarding the development of national strategies for food and nutritional security and for agricultural improvement. They should include.
  - land and water rights,
  - incentives for efficient water use and conservation of vital ecosystems,
  - assessment of virtual water export/import,
  - identification of river basin targets for residual stream flow, i.e. so called "environmental flow",
  - basin wide pollution treatment and abatement plans for all main sources of pollution.
- Initiate incorporation of green water for both food and bioenergy production as a component of national plans for IWRM and increased water efficiency.

- Strengthen research for water productivity increases in both rainfed and irrigated agriculture.
- Analysing the economic and financial aspects in terms of:
  - investments required to stimulate an upgrading of rainfed agriculture in semiarid tropics and subtropics,
  - improved opportunities for international trade on food and bioenergy, and evaluating it's consequences for water,
  - effects of current trade barriers and subsidies within the agricultural sector in terms of water use efficiency and negative environmental impacts,
  - Initiate international awareness raising campaigns designed to increase knowledge of the consumptive water use of different food products (in collaboration with the international food-industry), including:
  - labelling of food products based on their nutritional value per drop of water consumed,
  - develop and market food products of high nutritional value per drop of water,
  - support decoupling by encouraging loss reduction also on the consumption side of the food chain (especially in developed countries).

In development co-operation, Sweden could:

- increase the attention in its technical assistance to poor tropical countries in the development of suitable technologies for rainwater harvesting and strategies for integrated land and water management within the contexts of (micro-) basins to the consumptive water use linked to the production of food and bioenergy,
- facilitate decoupling by purposeful strategies for loss reduction in agriculture in countries under economic development by securing adequate investments and extension services,
- strengthen capacities on all levels (farmers, water user groups, governmental agencies and advisors) particularly for rainfed agriculture and its contribution to improved livelihoods through,
- enable an integrative approach on food production, water, social, environmental and economic aspects (including legal, economic and regulatory mechanisms),

- foster a better understanding of the different roles and values of water (including to sustain terrestrial and aquatic ecosystems and biodiversity),
- share knowledge of innovative management approaches and tools (social, economic, ecological),
- strengthen research, management practices, extension services and technical know-how.

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Appendix 1. Estimating future water requirements for the eleven regional groups of countries

All trend lines used the equation:

y = constant a * LN (x) + constant b

where y is dietary water requirements according to formula consisting of vegetable and animal supply in kcal per cap per day, and x is annual average national GDP per cap. National values were sorted according to commonly used UN geographical regions.

Regional trends were developed for national data year 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995 and 2000 (Table A1). Min and max trend lines for global data only use OECD country data 1990, 1995 and 2000. Data for diets and GDP was obtained from FAO Country food balance sheets (FAOStat, 2006) and the World Bank (2006). Future projections on dietary water requirements used projections of national populations and national average GDP per cap from Malmberg and Lindh (2004).

In order to limit the future cases of excessive dietary water requirements, functions for two regions (OECD, East Asia) were forced, i.e., the constants in the functions were limited to reduce water requirements. These two regions currently have high dietary water requirements, and it would be unrealistic to have future increases exceeding 5.5 m^3/cap/y.

Table A1: Trend equation coefficients for regional data

	Constant a constant br 2		
GLOBAL	1 0449	-5 3439	0.6638
DEVD	0.5441	-0.6931	0.1364
EA	0.453	-0.1742	forced
EURA	0.7906	-3 1881	0.5317
LAC	0.9218	-4.6229	0.3755
NAF	0.3935	-0.7754	0.7589
OECD	0.63	-1.6	forced
SA	0.2426	0.0074	0.1408
SEA	0.5951	-2.4824	0.6028
Sislands	0.8022	-3.3207	0.543
SSAF	0.4205	-1.1923	0.472
WA	0.4956	-1.0441	0.2978

The following text contains the countries used in each region.

Regional code	Country	Country code
DEVD	Albania	ALB
DEVD	Belarus	BLR
DEVD	Bosnia and Herzeg	BIH
DEVD	Bulgaria	BGR
DEVD	Croatia	HRV
DEVD	Estonia	EST
DEVD	Latvia	LVA
DEVD	Lithuania	LTU
DEVD	Macedonia, FYR {	MKD
DEVD	Romania	ROU
DEVD	Serbia and Monter	YUG
DEVD	Slovenia	SVN

Regional code	Country	Country code
EA	China {3}	CHN
EA	Hong Kon	HKG
EA	Korea, Der	PRK
EA	Mongolia	MNG

Regional code	Country	Country code
EURA	Armenia	ARM
EURA	Azerbaijan	AZE
EURA	Georgia	GEO
EURA	Kazakhsta	KAZ
EURA	Kyrgyzstan	KGZ
EURA	Moldova, F	MDA
EURA	Russian Fe	RUS
EURA	Tajikistan	TJK
EURA	Turkmenis	TKM
EURA	Ukraine	UKR
EURA	Uzbekistan	UZB

Regional code	Country	Country code
NAF	Algeria	DZA
NAF	Egypt	EGY
NAF	Libyan Ara	LBY
NAF	Morocco	MAR
NAF	Tunisia	TUN
NAF	Western Sahara	

Regional code	Country	Country code
LAC	Argentina	ARG
LAC	Bahamas	BHS
LAC	Belize	BLZ
LAC	Bermuda	BMU
LAC	Bolivia	BOL
LAC	Brazil	BRA
LAC	Chile	CHL
LAC	Colombia	COL
LAC	Costa Rica	CRI
LAC	Cuba	CUB
LAC	Dominica	DMA
LAC	Dominican Rep	DOM
LAC	Ecuador	ECU
LAC	El Salvador	SLV
LAC	Guatemala	GTM
LAC	Guyana	GUY
LAC	Haiti	HTI
LAC	Honduras	HND
LAC	Jamaica	JAM
LAC	Nicaragua	NIC
LAC	Panama	PAN
LAC	Paraguay	PRY
LAC	Peru	PER
LAC	Puerto Rico	PRI
LAC	Suriname	SUR
LAC	Trinidad and Toba	TTO
LAC	Uruguay	URY
LAC	Venezuela	VEN

Regional code	Country	Country code
OECD	Australia {	AUS
OECD	Austria	AUT
OECD	Belgium	BEL
OECD	Canada	CAN
OECD	Czech Rep	CZE
OECD	Denmark	DNK
OECD	Finland {5}	FIN
OECD	France	FRA
OECD	Germany	DEU
OECD	Greece	GRC
OECD	Hungary	HUN
OECD	Iceland	ISL
OECD	Ireland	IRL
OECD	Italy	ITA
OECD	Japan	JPN
OECD	Korea, Re	KOR
OECD	Luxembou	LUX
OECD	Mexico	MEX
OECD	Netherland	NLD
OECD	New Zeala	NZL
OECD	Norway {1	NOR
OECD	Poland	POL
OECD	Portugal	PRT
OECD	Slovakia	SVK
OECD	Spain	ESP
OECD	Sweden	SWE
OECD	Switzerlan	CHE
OECD	Turkey	TUR
OECD	United Kin	GBR
OECD	United Sta	USA

Regional code	Country	Country code
SSAF	Angola	AGO
SSAF	Benin	BEN
SSAF	Botswana	BWA
SSAF	Burkina Fa	BFA
SSAF	Burundi	BDI
SSAF	CÃ´te d'Ivo	CIV
SSAF	Cameroon	CMR
SSAF	Cape Verd	CPV
SSAF	Central Afr	CAF
SSAF	Chad	TCD
SSAF	Congo	COG
SSAF	Congo, De	COD
SSAF	Djibouti	DJI
SSAF	Equatorial	GNQ
SSAF	Eritrea	ERI
SSAF	Ethiopia	ETH
SSAF	Gabon	GAB
SSAF	Gambia	GMB
SSAF	Ghana	GHA
SSAF	Guinea	GIN
SSAF	Guinea-Bis	GNB
SSAF	Kenya	KEN
SSAF	Lesotho	LSO
SSAF	Liberia	LBR
SSAF	Madagasc	MDG
SSAF	Malawi	MWI
SSAF	Maldives	MDV
SSAF	Mali	MLI
SSAF	Mauritania	MRT
SSAF	Mauritius {	MUS
SSAF	Mozambiq	MOZ
SSAF	Namibia	NAM
SSAF	Niger	NER
SSAF	Nigeria	NGA
SSAF	Rwanda	RWA
SSAF	Senegal	SEN
SSAF	Seychelles	SYC
SSAF	Sierra Leo	SLE
SSAF	Somalia	SOM
SSAF	South Afric	ZAF
SSAF	Sudan	SDN
SSAF	Swaziland	SWZ
SSAF	Tanzania	TZA
SSAF	Togo	TGO
SSAF	Uganda	UGA
SSAF	Zambia	ZMB
SSAF	Zimbabwe	ZWE

Regional code	Country	Country code
SEA	Cambodia	KHM
SEA	Indonesia	IDN
SEA	Lao People	LAO
SEA	Malaysia	MYS
SEA	Myanmar	MMR
SEA	Philippines	PHL
SEA	Singapore	SGP
SEA	Thailand	THA
SEA	Viet Nam	VNM

Regional code	Country	Country code
others	Antigua and Barbu	ATG
others	Aruba	ABW
others	Barbados	BRB
others	Brunei Darussalan	BRN
others	Comoros	COM
others	Cyprus	CYP
others	Fiji	FJI
others	French Polynesia	PYF
others	Grenada	GRD
others	Kiribati	KIR
others	Malta	MLT
others	Netherlands Antille	ANT
others	New Caledonia	NCL
others	Saint Kitts and Nev	KNA
others	Samoa	WSM
others	Sao Tome & Princi	STP
others	St. Lucia	LCA
others	St. Vincent & Gren	VCT
others	Timor-Leste	TMP
others	U.S.S.R. (former)	
others	Vanuatu	VUT

Regional code	Country	Country code
SA	Afghanista	AFG
SA	Banglades	BGD
SA	India	IND
SA	Nepal	NPL
SA	Pakistan	PAK
SA	Sri Lanka	LKA

Regional code	Country	Country code
WA	Bahrain	BHR
WA	Iran, Islam	IRN
WA	Iraq	IRQ
WA	Israel	ISR
WA	Jordan	JOR
WA	Kuwait	KWT
WA	Lebanon	LBN
WA	Oman	OMN
WA	Palestinian Territories	
WA	Qatar	QAT
WA	Saudi Arab	SAU
WA	Syrian Ara	SYR
WA	United Ara	ARE
WA	Yemen	YEM

Appendix 2. Estimation of crop land requirement for key food groups year 2045

Question: How much additional crop land would the estimated increased diets require year 2045?

Method: Regional estimates of dietary calorie demand and populations year 2045 were used. It was assumed that each food group (cereal, oilcrop, sugarcane and beet, vegetables etc) contains same amount of kcal as today's produce (global average). Global yield productivities for different food groups were extracted from FAOStat in t/ha for respective regions (Table A2).

Table A2 Crop productivity as t/ha year 2000 from FAOStat, 2006

	Current productivity (yields that) according to FAO for regions year 2000								
	Cereal	*Starchy roots*	*Sugar-crop*	*Sugar-cane*	*Sugarbeet weeterner*	*Pulses*	*Oli-crop*	*Veg. oil*	*Veg*
DEVD	2.3	10				2	0.39		13.9
EA	4..2	7.3	23.6	58.4	23.6	1.5	0.8		16.5
EURA	1.6	7	24.5		24.5	1..2	0.34		13.9
LAC	2.9	5.5	13.7	64.3	13.7	2.6	0.5		14.6
NAF	1.8	5.4	62.2	100	62.2	1	0.2		19.9
OECD	4.4	20.4	51.9	78.7	51.9	2.1	0.5		25.3
SA	2.4	5.5	55	64.9	55	1	0.26		12
SEA	3.4	5.5	26.2	58.4	26.2	1	0.5		14
Sislands									
SSAF	1	7.4		49.1		0.5	0.26		6.1
WA	1.8	5.4	41 %	78.8 %	41 %	1	0.47		19.9
			sugar	sugar	sugar				
			15	12	15				
Improved 2045	2	6.5	20	60	20	1.3	0.35		14

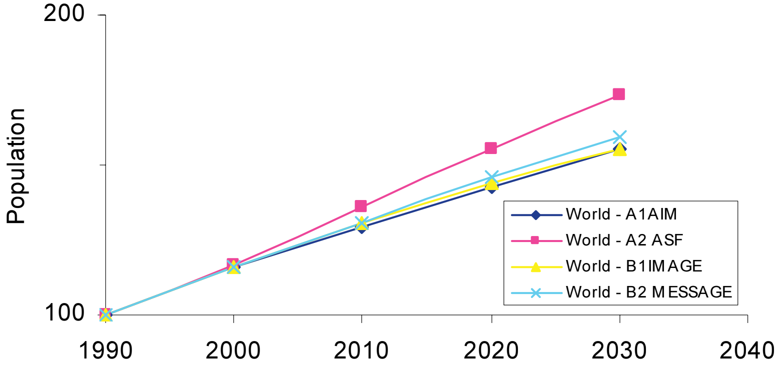
Only key food groups are used as calculation example. Additional non-human consumption is represented as a percentage of total area demand. For cereals this is approximately 46 % non-human consumption uses (feed, fodder, biofuels, etc.) and 54 % for direct human consumption. For oil crops, an approximate 40 % is currently used for human consumption and 60 % for non-human consumption. For oil crops the non-human consumption is rising fast and is expected to increase even further in the future (FAO, 2003). Similarly, for sugar cane, data was not readily available into human consumption and non human consumption. Thus, in this estimate, feed and fodder requirements in 2045 are partly included, although not from an animal dietary perspective, but rather as a share similar to current share of the group item production.

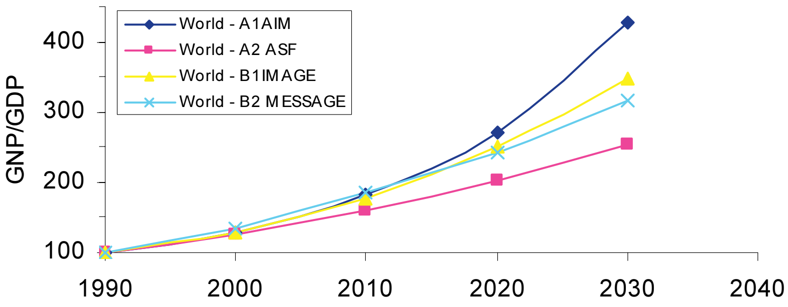
Two scenarios of land use requirements were tested. Firstly, the same regional productivity is used for year 2045 food demand. Secondly, crop productivity (t/ha) was improved for certain regions with currently low productivity in different food groups. The second scenario is assuming that crop productivity is increased more in some regions and not at all in others. The proposed productivity increases are possible from an agricultural technology (biophysical and plant-yield) perspective and have been achieved in numerous documented research experiments. However, to obtain them in farmers fields require a socio-economical, policy and market enabling environment for the farm enterprise, which is not represented here.

Trade of commodities between regions is not accounted for. As data is based on estimated consumption demand, the land resources in current scenarios assumes that al regional demand is to be satisfied within the region. This is most likely not appropriate as we trade significantly between regions. Thus, the results in Table 6, focus will be on global level, and not on regional level.

Appendix 3. The IPCC SRES scenarios

The development in the four SRES Illustrative Marker Scenarios[11] along selected crucial parameters is presented in graphs below.





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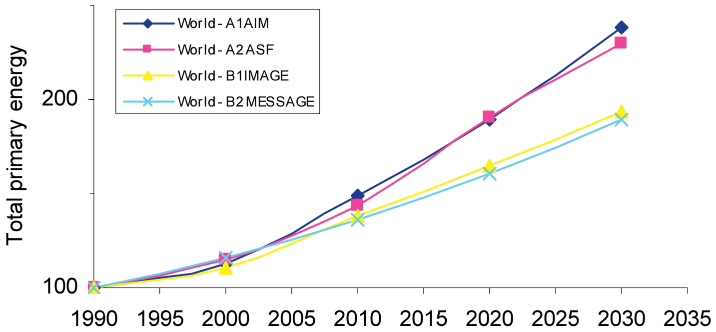
[11] According to information provided via the SRES homepage (http://sres.ciesin.org/): "For the purposes of the SRES for each scenario family (A1, A2, B1 or B2) one quantification governed by the associated template is provided as marker. These markers represent one quantified interpretation of the scenario family concerned, no more and no less. They cannot be viewed as the best or most likely outcome within the boundaries of the scenario families, but only as one representative example selected for illustrative reasons".


Total primary energy
200
100
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
World - A1AIM
World - A2ASF
World - B1IMAGE
World - B2MESSAGE

4 Bioenergy – may satisfy many energy requirements but far from all of them!

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4.1 Summary

In this short report we summarise some important observations as regards bioenergy. It is clear that bioenergy can play an important role in the efforts to achieve low CO_2targets. Bioenergy has considerable potential and the costs of certain uses – especially solid fuels use for heating – are low. This implies that even relatively modest carbon dioxide taxes will create strong incentives for the production and use of bioenergy.

On the other hand, however, the potential of bioenergy is limited if we compare it to the world's total energy system. The following rough estimates aim to illustrate this fact:

- One hectare of land on which energy forest is grown provides about 10 tonnes of dry substance (DS) per year. Energy-wise, this is equivalent to approximately 50 MWh/year, which roughly speaking is equal to the primary energy supply per capita in the OECD area. If everyone were to have the same living standards as the industrialised countries using bioenergy from plantations as their energy source, a total of 10 billion hectares would be required. The Earth's total land area amounts to just over 13 billion hectares, but this figure includes deserts, mountain ranges, permafrost areas, etc. The total amount of arable land in the world amounts to about 1.5 billion hectares. Even if residues and organic waste products would be able to

- contribute, it is obvious that bioenergy cannot satisfy everyone's energy needs.
- Even if we "only" satisfy 10 % of the above-mentioned energy requirements using bioenergy, we are talking about huge volumes – one billion hectares of land with 10 tonnes of DS as an annual yield corresponds to about 20 billion m^3 of forest wood, or about 10 times the current extent of the world's forestry activities!. Perhaps this is possible to achieve – and roughly speaking it is equivalent to the entire world's oil use – but we must remember that we are talking about very large biomass volumes.
- A similar rough estimate can also be made for vehicles. Converted to fuel, one hectare of land provides about 30 MWh GJ/ha/year, which in round figures corresponds to 4 000 litres of gasoline equivalents. These figures apply to sugar-cane ethanol or to advanced techniques in which the biomass is gasified and then converted to e.g. methanol, FT diesel or DME. If we assume that a vehicle uses 1 000 litres per year (driving 20 000 kilometres per year and using 0.05 litres per kilometre), that gives us 4 vehicles per hectare. If the world, with a population of 10 billion, resembles Europe (i.e. one vehicle for every two inhabitants), that gives us nearly 5 billion vehicles and about 1 billion hectares of land. It might be technically possible to accommodate such an expansion, but the question is whether it is desirable. One billion hectares of land is about 10 times the size of the entire EU's arable land area or the same size as the whole of the United States.

Our assessment is that bioenergy can be important and the volumes substantial, but not large enough to satisfy the global requirement for electricity, transport fuel or domestic/industrial heating on its own. Since bioenergy is a relatively cheap energy source compared to other climate-friendly alternatives, demand for it is likely to be high, leading to a high price level. High bioenergy prices can tempt farmers to cultivate crops for energy instead of for food and animal feed– this is how the market functions – with the risk of price increases for food (and land). This is not necessarily a problem – higher food prices can be beneficial to poor third world farmers, but it is a question of ensuring that the demand for bioenergy does not lead to poor people being forced from their land or rain forests and other valuable ecosystems being impoverished or totally destroyed in the hunt for bioenergy.

4.2 Introduction

Is there enough bioenergy? This question is often asked and the answer depends on our frame of reference: is there enough bioenergy in Sweden, in Europe or in the world? This depends on if we are asking ourselves whether biomass will suffice for global heating requirements, electricity, transport requirements, plastics or maybe all these put together. But it also depends on how ambitious our carbon dioxide policies are, to what point in time we are referring when we ask whether there will be enough bioenergy (2010 or 2050?), and not least what consequences of an ever-greater bioenergy use we are prepared to accept.

In this short summary, we will try to give concise answers to these questions. We would like to emphasise to the reader even at this early stage that it is not possible to say exactly how large the bioenergy potential is. It all depends on the choices we make as regards land use: how much land is it desirable for us to use for cultivating energy crops and how do we wish to shape our forests are important social, ecological, cultural and aesthetic questions. It is not just a question of technology and economics.

We will not commit ourselves as regards the potential of bioenergy. Our aim is instead to make it clear to the reader, using easy-to-understand estimates and examples, what sizes we are talking about when we discuss bioenergy as a climate measure and energy security solution, compared to other land and biomass use and also in relation to future energy use. We also want to highlight the decisive factors in relation to bioenergy potentials and the uncertainty surrounding them.

We wish to stress at this early stage (and this can be seen as a main conclusion) that even if very large land areas are utilised for bioenergy plantations globally, bioenergy will perhaps still only satisfy 20–30 % of the global energy requirement over the next 50 to 100 years. Bioenergy will therefore not suffice as a replacement for all fossil fuels in a world in which energy demand is continuing to grow. This means that questions such as: *in what sectors is the use of bioenergy strategic, optimal or cost-efficient*, will become very relevant.

Some interpret this as bioenergy not being able to play a particularly significant role. Such a conclusion is incorrect, however. Bioenergy could well play an important role in the future – not just in Sweden, which has such large areas of forest, but also in the world as a whole – something which we aim to prove in this report. Biomass use for energy could increase to an extent that corresponds to current global oil consumption.

Policies aimed at reducing carbon dioxide emissions (e.g. CO_2 taxes or emissions trading) will make biofuel very interesting from a commercial point of view. The costs are relatively low compared with other alternatives, especially regarding biomass use for heat production.

Furthermore, bioenergy is the only renewable energy form that inherently generates carbon-based fuels, which is the basis for much of present-day energy technology. This makes bioenergy very suitable for use in the transport sector. If hydrogen or electric vehicles show themselves to be technically complicated, expensive or just incapable of satisfying the demands for technical performance which we want from our vehicles – and at the same time we want to achieve zero emissions of CO_2 due to the climate problem – the only remaining option is to rely on biofuels. The issue of whether biomass will be sufficient to satisfy the future fuel requirements of the transport system is therefore of central importance, and we will specifically address this question later on.

4.3 How much bioenergy can we produce?

Bioenergy has two main raw material sources: residues and waste products generated in agriculture and forestry (plus subsequent biomass processing and use of the products), and biomass produced specifically for energy purposes in forests and on agricultural land.

4.3.1 Residues and waste products in Sweden, the EU and globally

Today, most of Sweden's and the industrialised world's[1] bioenergy use is based on residues and waste products from agriculture (e.g. straw) and the forestry sector (branches and treetops, pulping liquor, wood chips, bark, damaged timber). Waste flows are also obtained from other business activities and households (paper, wood waste, food waste, etc.)

Sweden has access to large amounts of biomass (per capita) in the form of waste products generated in the forest industry. This is because a large proportion of forest industry products are exported and production is therefore not limited by domestic consumption. We already use about 100 TWh/year, or just over 10 MWh/person/year, of bioenergy in Sweden (of which just over 90 TWh comes from the forest and the forest industry). This is the equivalent of about one fifth of Sweden's energy supply. Findings from studies performed recently (e.g. by Swedish University of Agricultural Sciences, SLU, and Svebio) provide a rather varied picture of the scope for increasing biomass extraction from the forest. An optimistic estimate is that we could double extraction from the forest in the longer term, through efficient thinning and management, improved plant material and optimised fertilisation of parts of the forest.

It is important to remember, however, that Sweden and a few other countries are unique in that the flows of waste products in the forest industry can make up a considerable proportion of the energy supply. This is clearly indicated in Figure 1, in which the industrial wood production gives an indication of the size of the biomass flows in the forest sector in different countries which might be available for energy purposes (the waste product flows are of the same magnitude as the biomass flow in the form of products). Global industrial wood production provides roughly 4 500 TWh/year, or about 0.7 MWh/person/year, which can be compared to the global use of fossil fuels – nearly 108 000 TWh, or just under 17 MWh/person in 2005 (BP 2006).

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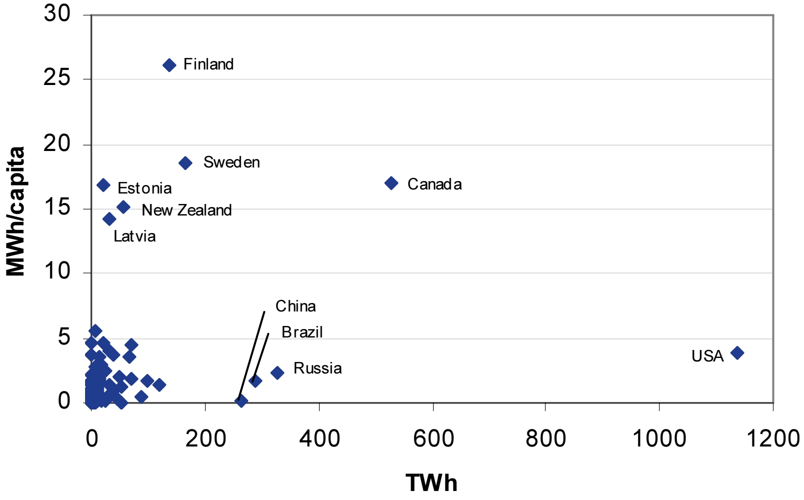
[1] Things are different in developing countries, where biomass often plays an important role in energy supply, but in the form of wood and charcoal for cooking and heating. The raw material base is mostly made up of wood from the forest and in the agricultural landscape. In some countries – notably Brazil and USA – there is a substantial cultivation of crops (mainly sugarcane and corn) for the purpose of ethanol production.

If we take a closer look at the EU and also compare with current energy use, it is clear that the preconditions vary considerably from one Member State to the next (Figure 2). Sweden and Finland have the largest forest extraction relative to their own energy use. The three Baltic States also have a fairly large forest extraction relative to their own energy use. The Figure also shows that extraction relative to forest growth is less in the Baltic States: countries closer to the dotted diagonal have a net annual increment (NAI)[2] that is approximately twice the extraction rate. For the entire EU, forest extraction is equal to about half the net annual increment and is, as can be seen from the figure, rather modest compared to the energy use (about 7 %).

Figure 1 **Industrial wood production in the countries of the world: average for 2000–2003, converted to energy in the form of biomass based on an assumed energy content of 2.8 MWh/m^3 of wood. The figure shows the dominant industrial wood producers in the world and the production per capita in different countries. Based on data from the UN Food and Agriculture Organization, FAO (FAOSTAT 2006)**



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[2] Net annual increment (NAI) = total forest growth - natural losses. The NAI in Figure 2 applies to parts of a country's forest that is earmarked as available for forest extraction. In many European countries, the NAI in the entire forest stand is close to this level, but in Italy, for example, NAI in the available forest is only about 60% of the NAI in the total forest stand.

Considerable residue and waste flows are also generated in agriculture. Straw, particularly from cereal production, is one of the residue products that is already used to a certain extent for energy purposes. Global cereal production lays claim to about half the world's harvested arable land and makes up 60–70 % of the global production of food and animal feed crops (measured in energy terms). Usually, less than half the biomass production above ground consists of seed, the rest is straw[3]. Far from all the straw can be used for energy purposes, however: some must be left on the fields and some is utilised for other purposes such as bedding in livestock production. On the other hand, waste products are generated that might be used for energy when cereals are processed in the food industry and other residues can also be utilised, such as the straw in oil-seed production and bagasse, which is obtained when making sugar (or ethanol) from sugar cane.

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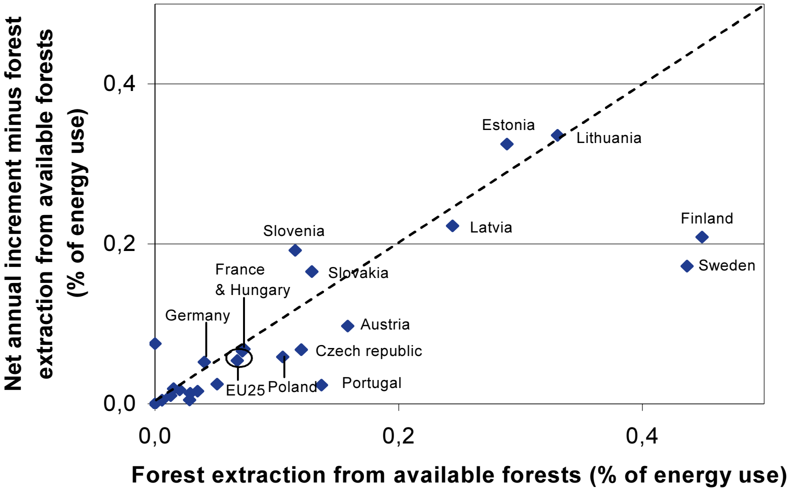
[3] The harvest index, which indicates what proportion of the aboveground biomass consists of seed, varies between different cereal types and between different regions in the world. In western Europe, we achieve a harvest index of 0.5 for wheat, but for many other cereal types and for wheat in other regions, the index is lower.

Figure 2 Comparison between energy use and forest wood extraction, and the balance between net annual increment and forest wood extraction in EU Member States. The forest wood extraction and balance are converted to bioenergy based on assumed energy content of 2.8 MWh/m^3 of wood and then divided by each country's energy use. The net annual increment applies to the part of a country's forest that is designated as available for forest wood extraction. Based on data from Eurostat (Eurostat 2006).



Cereal production can therefore – in addition to giving an indication of straw production in different countries – provide a rough picture of the amount of residues and waste products generated within agriculture that might be used for energy purposes[4] in the countries of the world (Figure 3). Global cereal production is equivalent to about 9 200 TWh, or approximately 1.5 MWh/person, which can be compared to the global use of fossil fuels, which was just under 108 000 TWh hours in 2005 (BP 2006).

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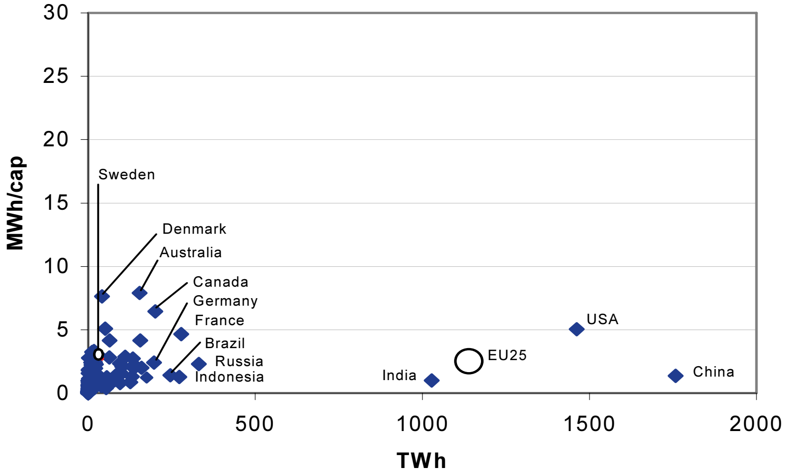
[4] We can also produce biogas by anaerobically digesting manure from livestock production. Model-based analyses indicate that the volume of manure that could be utilised for energy purposes in 2030 or so is equivalent to roughly 0.5 MWh/person (Wirsenius et al, 2004).

Figure 3 **Cereal production in the countries of the world: average for 2000–2003, converted to bioenergy based on an assumed energy content of 4.4 MWh/tonne of cereal. The figure shows the dominant cereal producers in the world and the production per capita in different countries**



We will discuss the possible future demand for bioenergy in a later Section in this report. We can however establish that if bioenergy is to become a major force on the global level, it will require more than just using residues and waste products from forestry and agriculture, which have until now dominated bioenergy use in the industrialised world. This also applies to a future scenario in which average global consumption is about the same as it currently is in the western world.

Assume, for example, that the world's population reaches 10 billion at some time this century and that its food consumption generates on average the same amount of waste products in agriculture and the food industry as is currently the case in the west. Assume also that the average world citizen consumes paper and other forest-based products to the same extent as we currently do in the west. Let us then assume that a waste flow of 30 kg per year is available for bioenergy (this is a very rough estimate): This gives us approximately 15 000 TWh/year or 1.5 MWh/person/year. This is naturally an unreliable figure and does not apply to the present-day but only when/if the developing countries reach consumption levels that are similar to those in the west (the billion poorest people in the world currently consume an average of 2 kg of paper per person per year, in contrast to the richest people who consume 200 kg). In any case, we will return to this figure later in the report when we discuss the future demand for bioenergy.

4.3.2 Energy crops in Sweden, the EU and globally

The possible contribution made by energy crops depends on two central factors: how much land that can be used and what the average yield might be.

In the 1940s, Swedish arable land covered about 3.7 Mha. Today, we are down to about 2.7 Mha, 280 000 of which is unutilised arable land or fallow land. How much land that might be available for bioenergy purposes depends on agricultural development, which in turn depends to a great extent on EU agricultural policy and on the prices of food and bioenergy. Let us assume that half a million hectares become available for the cultivation of energy crops, which is in line with the figure given by the Federation of Swedish Farmers (LRF) in its most recent scenario for 2020. Assume further that we reach an average harvesting level of 10 tonnes of dry substance (DS) per hectare and year (the average cereal yield is just over 5 tonnes/ha + approximately the same volumes of straw; the willow (Salix) yield is perhaps 7–8 tonnes DS/ha, which can be expected to rise as a result of improved grades and better cultivation techniques). If we assume an energy content of 5 MWh/tonnes DS, this gives 25 TWh/year or nearly 3 MWh/person/year. We can perhaps double this through a combination of increased harvests and further expansion of energy crops. The production of energy crops can hence make a significant contribution in Sweden, but the forest will probably still constitute the country's largest raw material base.

Arable land in EU-25 covers about 110 Mha, roughly a quarter of a hectare per person. With a yield of 10 tonnes DS (or 50 MWh) per ha and year and assuming *all the arable land* is used for energy crops, this gives about 12 MWh/person/year. *This corresponds approximately to the current Swedish level of bioenergy supply per capita, which is another reminder of the unique prerequisites of our forests.* If energy crops are also grown on pastureland, to the extent that all the farmland in EU-25 (about 200 Mha) is utilised for bioenergy and assume the same average yield (a very optimistic assumption!), we would reach 10 000 TWh/year, or 22

MWh/person/year, corresponding to about 60 % of the current fossil fuel consumption in EU-25.

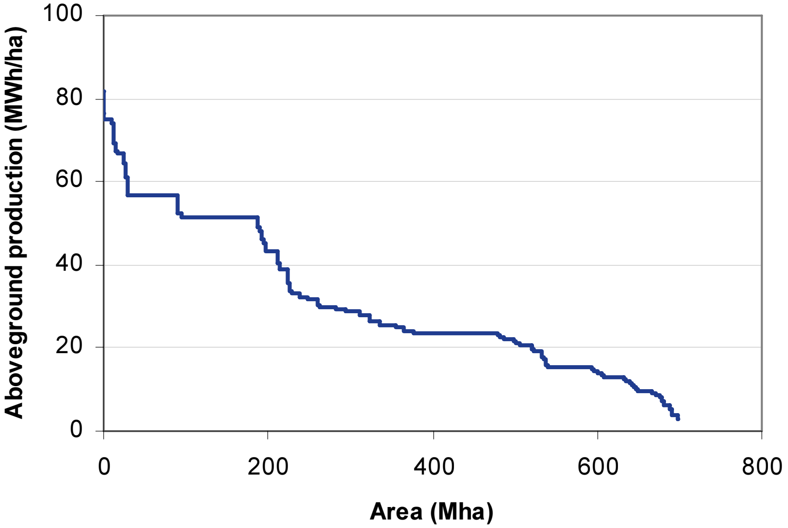
Such a level of bioenergy cultivation is of course unrealistic, but the above figures do give us an idea of the potential of bioenergy cultivation in EU-25: if, for example, 10 % of farmland is utilised, perhaps about 5–10 % of fossil fuels could be replaced (depending on the average yield achieved).

In other parts of the world, the conditions for energy crop production vary considerably, both with regard to the land that might be available and the potential yield. The total amount of arable land in the world amounts to about 1 500 million hectares, and pastureland covers about double that. There are "optimists" who believe that productivity gains in agriculture and livestock farming will free up large areas of land. Others believe that it will be difficult enough to feed a world population of 10 billion. They point to the limited availability of water as a problem in many parts of the world even when it comes to food supply. There are groups against plantations on the grounds that they are yet another example of monocultures that uglify the landscape and requires artificial fertilisers and pesticides. What is desirable as regards forms of production and volumes goes beyond the scope of this report. We do not forecast how much land we might be able to lay claim to. The figure stated below should instead be seen as a starting-point for discussion.

We assume here that 700 million hectares of land is set aside for plantations – the equivalent of about half the world's total arable land or seven times the arable land in the EU. Allow us again to assume that we can achieve an average yield of 50 MWh/ha/year. This will give us 35 000 TWh/year of bioenergy from plantations. The observant reader might now think of Brazil, and a number of other places, where much higher yields of eucalyptus and sugar cane have been ashieved. Indeed, very impressive yield levels are quite clearly achievable, especially on good soils in tropical regions with a suitable climate. At the same time, however, plantations are also established in drier areas and on poorer quality soils. According to the UN Food and Agriculture Organization (FAO), Eucalyptus and Pinus, which are the dominant plantation species, grow on average 10–20 cubic metres/ha/year, corresponding to roughly 25–50 MWh/ha/year.

A comparison with global cereal production levels is perhaps in order: it is easy to be inspired by high harvest levels achieved in certain countries (e.g. in Europe), but we must remember that yields in many other countries are much lower. Figure 4 gives a rough description of the above-ground biomass production (seed and straw) from the world's cereal fields, based on the assumption that the seed harvest makes up 50 % of total above-ground production. Cereals are normally grown on relatively good-quality soils, or at least on the best available soils in the region.

Figure 4 A rough description of biomass production above-ground (seed and straw) in the world's cereal fields. Based on data from FAO (FAOSTAT 2006)



It is important to bear in mind that 35 000 TWh is a very large figure. It is equivalent to a biomass production that is about ten times greater than the total industrial wood production in the world today! Some say *impossible*, others claim that we should be able to obtain double this figure (there are energy scenarios in which one billion hectares of land are brought under cultivation and where the yield is 15 tonnes DS/hectare/year, on average). We cannot categorically dismiss such a future scenario as impossible, but conversely, it is not altogether easy to claim that it is particularly desirable.

If we assume that we obtain 15 000 TWh/year in the form of waste products from agriculture and forestry and that we obtain 35 000 TWh/year from energy crops, we achieve a bioenergy supply of 50 000 TWh/year. This is about the same amount of energy currently generated from oil on a global scale.

4.4 How great is the need?

We have already drawn comparisons between the volume of possible future biomass production and current energy use in Sweden and the EU. The size of the future bioenergy demand in different parts of the world naturally depends on how much energy we use in total, what restrictions we place on fossil fuel consumption (determined by e.g. climate targets and scope for carbon dioxide sequestration and storage) and what other energy alternatives we might have access to in the future. Here, the conditions vary considerably between different countries, but in general we can say that bioenergy is considered in many countries to be the most important renewable energy source, at least over the forthcoming decades.

Sweden

The picture for Sweden looks reasonably optimistic. Estimates of the bioenergy potential are around 200 TWh, or one third to just under one half of current energy supply (depending on how heat losses in nuclear power plants are calculated). With greater energy efficiency, bioenergy could be responsible for a considerable share of energy supply. It is however not altogether obvious that Sweden will use Swedish bioenergy. It may well be the case that Swedish-produced biofuels, such as pellets, are sold to the continent at the same time as we import sugar-cane ethanol.

Globally

How far will our estimated contribution of bioenergy on the global level (50 000 TWh/year) suffice if we compare it to the expected demand for CO_2-free energy?

The world currently uses just over 100 000 TWh/year, 80 % of which is fossil fuel. Energy use increases with an increasing population and economic growth – not just in China ad India, as is often stressed, but also in the United States, EU and Japan. If 10 billion people in the world were to use as much energy as the average OECD citizen uses today, that would require 500 000 TWh/year, about five times the current level. Employing extensive efficiency measures, we might be able to reduce the need to half this level, but CO_2 emission levels must also decrease to almost zero over the next 100 years.

In other words, bioenergy could be responsible for a fifth of the need for CO_2-free energy in 50–100 years. There is considerable uncertainty here and perhaps we can force the bioenergy share up to one third but it might also be only one tenth.

What we can say with a little more certainty is that biomass can become a very sought-after energy raw material in the future. As has already been mentioned, bioenergy is the only renewable form of energy that inherently provides climate neutral carbon and this makes it very suitable in a variety of contexts. Compared to many other energy technologies, which could make a significant contribution to the future energy system, bioenergy is also relatively cheap to produce. This, in combination with a possible scarcity in relation to demand, means that biomass production for energy purposes can make excellent business sense for farmers and forest-owners. We will return to the possible consequences of this later on.

4.5 The transport sector

Should we use bioenergy for transport? There are two opposing and seemingly irreconcilable positions in the debate on vehicle biofuel, but both of them are worth taking seriously. One position is based on the fact that it is cheaper to use biomass for heating or combined heat and power production. The main reason is that it is costly to convert bioenergy into liquid fuels, and it is associated with substantial energy losses. There should not therefore be any specific policy aimed at directing biomass towards the transport sector.

The main counter-arguments are as follows: *Firstly*: emissions from the transport sector are rising, the current situation is not sustainable, it will take time to reverse the trend and it is therefore reasonable to start the transition now even if it is more expensive than implementing measures in other sectors. *Secondly*: The transport sector uses oil and there are other problems associated with the oil economy (prices will rise even further due to scarcity, it causes military conflicts, reduces our energy security). *Thirdly*: Sweden has a more ambitious climate policy than many other countries. An introduction of high carbon taxes, or similar, for industrial enterprises, will negatively affect their competitiveness and is therefore difficult to implement. One area where tougher policies are possible is the transport sector. Why not use this possibility? *Fourthly*: In the longer term, say in 50 to 100 years time, CO_2 emissions must be reduced to very low levels. This will present the transport sector with three options; electricity, hydrogen gas or biofuels[5]. If the first two options fail, biofuels will be the cost-effective solution (even if it is not so today).

Below, we will use some calculations to show how big the potential is for different types of biofuels. These types are: cereal ethanol, sugar-cane ethanol, cellulose-based ethanol and gasification-based biofuels.

4.5.1 Cereal ethanol and first-generation vehicle biofuel

The major part of the present Swedish ethanol production is using cereals as feedstock. According to the producer Agroetanol, about 2.65 kg of cereal grain is needed to produce one litre of ethanol. If we assume a cereal harvest of just over 5 tonnes/ha/year, we reach a yield of about 2 000 litres of ethanol/ha/year, the equivalent of 12 MWh/ha/year. A high-protein by-product containing about the same amount of energy as the ethanol is also produced in the production plant. However, basically the same amount of energy is used during the processes. The Norrköping plant uses biomass-based energy for this, which gives the plant a good CO_2 balance compared to plants that use oil or coal.

In principle, the by-product from the process, could be used to satisfy internal process energy requirements. But it is presently more profitable to convert it to a protein-rich animal feed and buy energy instead. If we were to invest heavily in cereal ethanol, we would saturate the protein feed market relatively quickly, and the most profitable area of use might then be to use the waste products for additional bioenergy production (biogas) for subsequent sale – or to satisfy internal process energy requirements.

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[5] It is technically possible to sequestrate carbon dioxide directly from the atmosphere and use it in the production of climate-friendly transport fuel. But it is very expensive.

Energy (e.g. diesel and energy embodied in fertilizers) is also used in the cereal production. Roughly, this energy use corresponds to 500 litres of ethanol. Thus, we have a net supply of ethanol equivalent to about 1 500 litres/ha/year. This corresponds to about 7.5 MWh/ha/year.

Two comparisons are illustrative:

- Producing ethanol corresponding to 10 % of Sweden's total vehicle fuel consumption (about 100 TWh) would require the use of 1 Mha of arable land (if we use cereal ethanol). This is obviously not a feasible route to take.
- Considering the current vehicle fleet and distance driven, a total of 2 000 x 0.8 x 3/2 = 2 400 litres of ethanol/vehicle/year would be required. If we assume that the vehicles instead consume 0.05 litres of gasoline per kilometre, 1 ha per vehicle (if we use cereal ethanol) would be required. In Sweden, however, there are about four million vehicles and about 2.7 Mha of arable land.

The ratios look approximately similar at the European level, i.e. 250 million vehicles and roughly 100 Mha of arable land.

It is clear that cereal ethanol is not sufficiently area-efficient to be able to play a significant role. Furthermore, cereal ethanol production in many parts of Europe and the United States uses significant amounts of fossil fuels, which leads to CO_2 emissions per kilometre being much the same as from gasoline.

Moreover, cereal ethanol is relative expensive (about EUR 0.61/litre compared to Brazilian ethanol which costs around EUR 0.39 a litre, including import costs into Sweden).

A reasonable conclusion is that cereal ethanol, which is a "first-generation" vehicle fuel, is not efficient enough from an energy, area and cost point of view to be able to compete with other biofuels in the long term. When sugar beets are used for ethanol production, higher ethanol production per hectare is achieved, but this alternative is implausible from a cost perspective. Furthermore, CO_2 emissions can be just as high as they are for cereal ethanol. Rapeseed methyl ester (RME) leads to lower CO_2 emissions but the area efficiency is lower than for cereal ethanol.

The construction of factories for the production of first-generation biofuels could however be justified as part of a strategy to initiate a domestic Swedish fuel market (interest in the issue, evidence that it works, construction of ethanol vehicles and knowledge build-up). At the same time, however, there is a risk that this would hinder the development of second-generation biofuel (based on lignocellulosic raw materials – more on this later). Not least as it would lead to strong groups being established who would endeavour to keep the status quo in which first-generation fuel would dominate. In all likelihood, fewer farmers would also be interested in the production of new lignocellulosic plant types if extensive production of e.g. cereal ethanol meant that it would be possible to continue to produce cereal at an acceptable profit.

4.5.2 Ethanol from sugar cane

Ethanol production based on sugar cane has a much better yield, is more energy-efficient and – as mentioned previously – is more economically viable. An estimated 6 000 to 8 000 litres of ethanol can be produced per hectare. Energy is needed in the ethanol plants, but that can be obtained from the bagasse (waste fibres left after the juices have been squeezed out of the sugar cane). It is even the case that when the internal process energy requirement has been satisfied, electricity can be produced and sold, so that the net contribution will be even greater. If we assume an average production of 6 000 litres of ethanol/ha/year, one hectare would support 4 energy-efficient vehicles.

Even if the sugar-cane alternative offers higher yield, the use of ethanol in Europe and the United States will lead to a scarcity of sugar-cane ethanol relatively quickly. The following calculations illustrate this: assume that there are 250 million vehicles in the EU, that everyone drives on ethanol and that they consume 2 500 litres per year. This gives us a total consumption of 625 billion litres. This is approximately 50 times Brazil's total current ethanol production and would require a surface area of 625 billion/6 000 litres = 100 million hectares, the equivalent of about 20 times the current sugar-cane growing area in Brazil (about half the sugar-cane production is used for sugar, the rest for ethanol production). It is therefore undoubtedly the case that a massive import of sugar-cane ethanol into the EU would require expansion far beyond Brazil's borders.

There are several countries which, like Brazil, would be able to produce ethanol based on sugar cane and export it to e.g. the EU. But it is also the case that if several densely populated countries and regions were to introduce ambitious biofuel goals, it would be difficult to meet the total import demand for ethanol (and other biofuels such as biodiesel) even if more countries established themselves as exporters on an international market. And – once again – the excellent potential for profitability in raw material production, should biofuel become a commodity in short supply, gives cause for reflection.

4.5.3 Ethanol and gasification-based biofuels from lignocellulosic raw material

So-called "second-generation" fuels include lignocellulose-based ethanol and biofuels such as methanol, FT-diesel or DME that are produced via biomass gasification and subsequent synthesis. Since they are produced from lignocellulosic feedstocks, these biofuels can utilize a much larger resource base. They also offer a higher area efficiency than most first-generation biofuels. If we assume 10 tonnes of DS/ha/year, 60 % conversion efficiency and a vehicle that consumes 1000 litres of gasoline equivalent per year, one hectare would support 4 vehicles – approximately the same level as ethanol from sugar-cane.

4.5.4 The total potential

Let us assume that one hectare of land provides about 4 000 litres of gasoline equivalents per year. These figures apply, as mentioned above, to sugar-cane ethanol or to biofuels based on biomass gasification and subsequent synthesis. If we assume that one hectare supports 4 vehicles, and that the world, with a population of 10 billion, resembles Europe (one vehicle for every two inhabitants), this gives us nearly five billion vehicles and about 1 billion hectares of land. It is technically possible to imagine such an expansion, but the question is whether it is desirable. One billion hectares of land is about 10 times the size of the entire EU's arable land or the same size as the whole of the United States.

A main conclusion is that we have to invest in other parallel solutions; efficiency improvements and hybrids, electric batteries, plug-in hybrids or hydrogen combined with fuel cells.

4.6 Policy instruments for bioenergy

Our presentation above shows that bioenergy has the potential to make a contribution similar to today's oil supply. But this would require laying claim to extensive land areas (the equivalent of almost half the present-day amount of agricultural land on a global level) for the benefit of a relatively limited contribution compared to what might be needed in the future.

For bioenergy, and for policy instruments associated with bioenergy, this will have the following consequences:

Firstly:

The central instrument as regards the climate is to make it more expensive to emit CO_2, which will lead to bioenergy becoming more profitable, especially for heating and combined heat and power. This is what we have experienced in Sweden: the use of biomass in district heating plants has increased dramatically. At the current high oil prices, sugar-cane ethanol will also be profitable (at least with the level of CO_2 tax we have in Sweden).

Secondly:

As the world starts to reduce CO_2 emissions – as a result of tax or emissions trading – incentives are created for the greater use of bioenergy, and hence increased supply. Producing biomass for energy will be good business and there is a risk that bioenergy plantations will:

- Expand in valuable rain forest areas (we have already witnessed how oil palm plantations destroy the rain forests in Malaysia).
- Spread out over such large areas that they meet with considerable local resistance (we have already witnessed the state of Espirito Santo, north of Rio de Janeiro, Brazil, forbidding further expansion of eucalyptus plantations).

- Crowd out poor farmers who do not have sufficient ownership rights to the land, which is common in developing countries (we have already witnessed what happened when sugarcane plantations expanded in north-east Brazil).

It is therefore important that policy instruments are introduced in parallel in order to prevent such negative consequences from occurring. It is a question of domestic policy in developing countries, e.g. protection of rain forests and poor farmers, as well as in the industrialised nations – who will import bioenergy initially – imposing demands on how bioenergy is to be produced, e.g. by means of a certification system.

Parallel to this, projects should be established to show (and learn more about) how bioenergy cultivation can be expanded in a responsible way. Sweden has a possible role in this: being a pioneer in bioenergy need not be restricted to domestic production and technical development. There is an equal need for best practice examples regarding biofuel production in developing countries, for domestic consumption or export to industrialised countries.

It is also important to remember that the expected growing demand for bioenergy can lead to problems in Sweden as well. Constantly high bioenergy prices can leave their mark on the Swedish forestry sector and we must ensure that the extraction of e.g. branches and tree tops does not reach a level that threatens to damage the long-term forest productivity. Exempting ecologically valuable forest areas from evermore intensified forestry activities also risks being considered too expensive.

The central question we must ask ourselves is not how much bioenergy can be produced from a purely technical point of view but rather what level is desirable. On how large land areas do we wish to see eucalyptus, willow and other fast-growing crops? What is acceptable? How much land do we want/should we set aside for the preservation of biodiversity and natural ecosystems? To what extent can extensive biomass production for energy purposes be reconciled with the preservation of life-essential ecosystem services?

Thirdly:

The food-bioenergy conflict. Bioenergy enthusiasts have a tendency to say that we can avoid competition between food and bioenergy by setting aside special areas of land – that are not suitable for food production – for bioenergy. We are convinced that they are wrong. If we implement an ambitious carbon dioxide policy, cultivating for bioenergy on agricultural land will also become attractive and this can be expected to drive land and food prices upwards. Cereals are already cultivated to satisfy many Swedish farms' own heating requirements and U.S. farmers are now considering the development of corn ethanol when they plan what to grow.[6] We have performed studies in which we show that the land value may increase by factor 10 and cereal prices by a factor of 2–3 over the next 100 years (see Azar 2005, or Johansson & Azar, 2006).

This is often seen as something negative for the world's farmers, but it can be both positive and negative. For a farmer with proper ownership rights to his land, it will mean higher revenue. For a poor urban-dweller, it may represent a problem.

Fourthly:

A common subject of discussion in the Swedish forest industry is whether Swedish forest raw materials should be sawn, burnt or boiled. Bioenergy enthusiasts usually say that we can increase growth in the forest so that it "suffices for all". But on a basic level, this is an odd debate and a strange notion. The debate is odd because forest raw materials will in all likelihood be used by the sector that is prepared to pay the best price for them and this is true even if we increase the harvest by means of growth-promotion measures.

But on a practical level, it is possible to understand the debate, at least if Sweden and the EU embrace considerably more ambitious climate measures than other countries. Electricity and heating prices in the EU will then be higher than in the rest of the world, whilst paper prices are set by the global market. The energy sector will be able to pay more for pulpwood than the pulp-mills, putting

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[6] http://www.nytimes.com/2006/01/16/national/16ethanol.html?ex=1295067600&en=0c5651f9be1414dd&ei=5088&partner=rssnyt&emc=rss..

the latter in a difficult position. This type of competition is more problematic and we should give more careful consideration to which measures are reasonable.

Fifthly:

The scarcity of bioenergy makes surface-efficient systems more interesting. We currently have policy instruments that encourage surface-inefficient systems, such as cereal ethanol and RME. Energy tax exemption on ethanol and RME is equivalent to a subsidy of SEK 0.30 per KWh! If we have decided to go for biofuels, subsidies may be justified for a transitional period – in order to establish a market for new vehicle fuels. But then these subsidies should gradually be phased out and the government should send clear signals that this is what is going to happen.

Sixthly:

The reasoning about surface-efficiency means that cereal ethanol and RME will hardly be successful on an unsubsidised market, but there are some biofuel critics who believe that it has been a hopeless project from beginning to end (since the conversion to biofuels implies considerable energy losses). But if hydrogen gas or electricity become too expensive or technically complicated, biofuels will be the only remaining option. There is hence reason to continue to invest in the development of second-generation biofuels. At the same time, the fact that biomass may become a scarce resource means that incentives should be introduced to spur on energy efficiency improvement in the vehicle fleet. For example, one of the requirements for the environmental classification of vehicles could be that they don't consume more than, say, 0.06 litres of gasoline equivalents per km. This level should of course be gradually reduced.

Seventhly:

It is common in Sweden to discuss whether Swedish bioenergy resources suffice to satisfy the Swedish demand for heating, electricity and transport. It is naturally reasonable to estimate

Swedish biomass resources now and again and compare them to the possible demand in our country, but there is far too much focus on this issue. If Sweden and the EU (or even the entire world) pursue tough climate policies, it is reasonable to expect that we will export a fair amount of biomass (e.g. chips and pellets for combustion in district heating plants on the continent) whilst at the same time we will perhaps import ethanol from the tropics. We currently trade in cereals and paper (including biomass), oil and coal. It is strange to assume that bioenergy use in Sweden should be based on Swedish biomass and that biomass produced in Sweden should necessarily be used in Sweden.

The EU currently imposes customs duty on the import of ethanol from Brazil and other more advanced developing countries. This is not only uneconomic but also immoral: It seems we can demand that Brazil buy Swedish trucks without any customs duty being imposed whilst we tax the import of fuels for the trucks of the future!

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The Swedish Environmental Advisory Council (SEAC) advises the Government since 1968 on issues of environmental concerns.

This is a background report to the main report by the SEAC (Memorandum 2007:1) on growth and the environment in a long term global perspective. The main report deals with three important challenges: climate change, with a focus on energy efficiency, sustainable use and management of natural resources, and sustainable global production and consumption chains.

In this background report scenarios are outlined for future demand on energy, bioenergy, forest products and freshwater given that current trends prevail. The aim is not to make forecasts about the future but to create a basis for discussion on the need of breaking present trends.

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