Exploring Technology Scenarios with an Input-Output Model

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Abstract
The dynamic IO model DIMITRI will be used for explorations of long-term scenarios on technology and demand. The model describes at a sectoral level the relationships between consumption, production and emissions. Technology per sector is described by the inputs from other sectors (represented by IO coefficients) and capital, labour and emission coefficients. Since these coefficients are not stable over time, they have to be constructed for future years. The paper will present a methodology for projecting these coefficients for different scenarios. The methodology combines trend analysis with detailed information of specific technologies per sector, which differentiates between scenarios. The adjustment of coefficients influences model outcomes such as production, balance of trade and emissions. The paper outlines the methodology and presents the main outcomes for four scenarios for the period 2000-2030.

1 Introduction

Nearly all of the main environmental problems are related to current non-sustainable production systems and consumption patterns. The Netherlands Environmental Assessment Agency (MNP) uses several models in the search for more sustainable production and consumption systems. One of these models is the dynamic input-output model DIMITRI (Wilting et al., 2001; Idenburg and Wilting, 2005) that describes at a sectoral level the relationships between consumption, production and emissions. The scope of the model is the economy in the Netherlands and the consumption of the Dutch in relation to the environment in the Netherlands and abroad (footprint). The model is used for long-term explorations of economic activities, technological change, and the related pressure on the environment.

The Netherlands has a long history in scenario planning. Environmental policy plans are often supported by scenario studies by the MNP. Recent MNP scenario's are based on the scenarios framework developed by the International Panel on Climate Change (IPCC, 2000) for the period 2000-2030. In a sequence of projects these global IPCC scenario's have been specified into Dutch scenario's on several issues (RIVM, 2000, 2002; Hilderink, 2004; van Egmond et al., forthcoming). This paper outlines the methodology used to draw up four technology scenario's and presents - as a first exercise - some of the outcomes of DIMITRI computations with these scenario's. The technology scenarios only diverge in the extent of technological change.

2 Input-output modelling and technology

The DIMITRI model is a demand-driven input-output model, similar to most input-output models. Production per sector is determined on the basis of the Leontief inverse matrix and final demand, as is usual in input-output modelling. Final demand consists of household and government consumption, exports and (endogenous) investments. Changes in household demand are based on demographic changes, household income growth and changes in lifestyle. On the basis of production per sector other outcomes are determined, like value added and emissions per sector, GDP, employment and balance of trade (see figure 1).

In a Leontief input-output model technology is presented by so-called technical coefficients (or input-output coefficients), primary input coefficients and, in the case of DIMITRI, by emission coefficients. Primary inputs are costs of sectors like taxes and subsidies, wages (employee compensations), depreciation (in the form of interest on capital and land), and profits. In the model, environmental pressure is expressed in so-called emission coefficients describing emissions per unit of production. Furthermore, the model uses labour and capital coefficients.

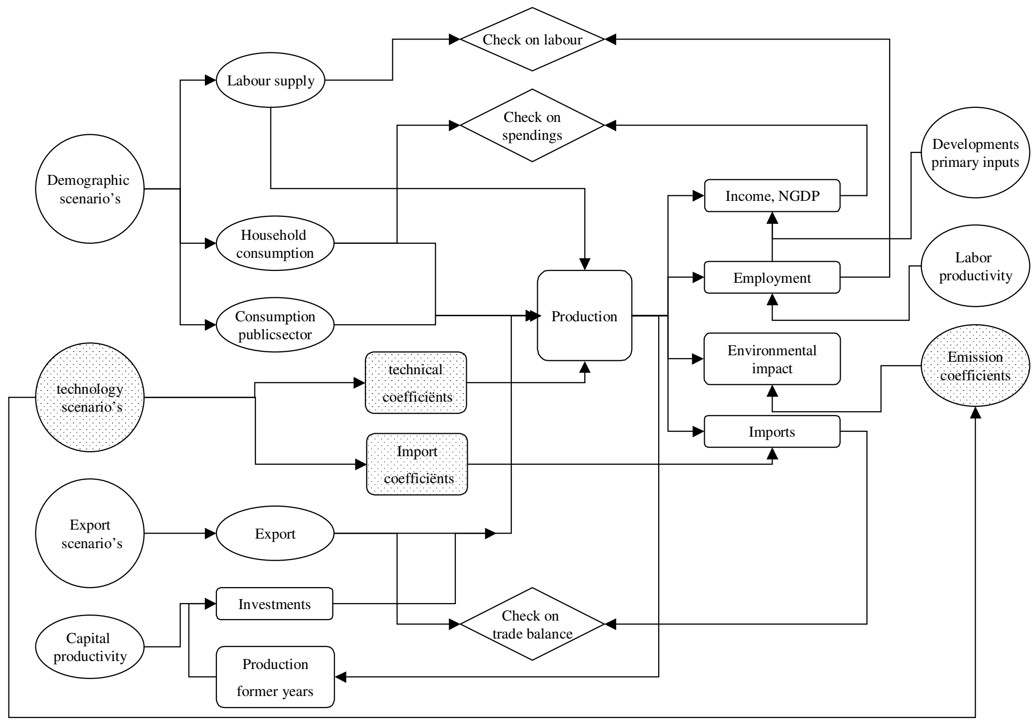


Figure 1 Outline of DIMITRI

The technical coefficients describe the inputs from other sectors per unit of production of the receiving sector. Leontief compared the list of technical coefficients and primary input coefficients with the list of ingredients that are required to bake a cake (Leontief, 1966, 1987). In most empirical studies, the technical coefficients are derived from the input-output table. These tables are generally based on statistical surveys. The technical coefficients therefore reflect the costs of production rather than the physical requirements for production. It is possible to derive the technical coefficients from engineering data. This is shown by a number of input-output studies on the potential impact of new or alternative technologies (Idenburg, 1993; van den Broek, 2000). The definition of technical coefficients from engineering data, however, is not an easy task. In most cases, technical data are not published in a form that can be easily translated into required inputs per unit of output. In case of the cake, they might describe the volume of flour and number of eggs, and required temperature of the oven, but not the amount of gas or electricity required for heating the oven. Moreover the technical description also does not mention how many cakes could be baked in an oven to give an indication of the 'amount' of oven required for one cake and neither it tells the hours of labour required to clean the oven afterwards. This means that technical data are often used in combination with statistical data from input-output tables.

Besides the fact that statistical data describe the cost structure of a sector rather than the physical requirements of a sector, there is another aspect of technical coefficients based on input-output tables that should be mentioned here. Because input-output tables are based on statistical surveys they represent the average input structure over a group of companies and technologies. This notion is important when projecting future technologies as will be shown in section 4.

3 Input-output modelling and technical change

It is said that the input-output production function does not allow substitution among inputs, and, because of this lack of substitution possibilities, the input-output production function is only valid for short-run studies. This argument confuses two different contrasts between short-run and long-run. The first is the difference between short-run and long-run studies. If a model is used for a long-run study it is often desirable that the model should incorporate technological changes, which is quite possible in an input-output model, as will be demonstrated. Secondly there is a difference between short-run *options* and long-run *options* for a production technology. Short-run options are often limited, because each industry has a particular technology installed which probably does not allow significant substitutions of input in the short-run. In the long-run, an industry will have the opportunity to choose among several technologies with different input structures. The difference between short-run and long-run options in this case is then the difference between production with a technology that is already installed, described as an ex-post production function, and the choice among several technologies which could be installed. The latter choice is described as an ex-ante production function (Idenburg, 1993). If a model in which the choice of technology is endogenous is used for long-run studies, the model should have such an ex-ante production function. However, when the long-run options are described with exogenous technology scenarios, as is the case in this paper, the input-output production function suffices.

There are roughly two manners to project technological change within an input-output context. The first way is a modelling approach based on trend analysis. The second approach is the construction of future technical coefficients based on expert judgement (see also Rose, 1984).

A simple way to use trend analysis is an extrapolation of the trends in coefficients in the past to the future. Studies carried out for the Netherlands and the UK showed that trend extrapolations for the short term did not lead to better results than using the original coefficients of the base year. The same holds for the use of so-called marginal input coefficients (Miller and Blair, 1985). This approach can also be used in a more sophisticated manner, for instance, by using a logistic growth curve. This method is e.g. applied in the INFORUM models (INterindustry FORecasting at the University of Maryland). For each row, the future coefficients are estimated on the basis of logistic curves based on the changes in the coefficients in the past. It is assumed that the penetration of new technologies can be described with an S-curve with a certain saturation level. A similar approach can be carried out for each cell in the input coefficient matrix.

Basing future technologies on past trends has some clear advantages. It is easy to use and there are, in most cases, no real data problems. The major disadvantage is that it is impossible to project innovative technological changes from a past trend. This is especially a problem for studies that deal with environmental issues because much is expected from this type of changes in solving environmental problems.

There are different manners of using expert judgements to construct future technical coefficients. On way is to define the technical coefficients from an engineering description of future technologies, as has been discussed in section 2. Examples of this type of studies are Just (1973), Edler (1993), Proops et al. (1994), Meade (1995) and Blom (1999). There are many sources of data on future technologies which could be used for this purpose (Idenburg and Nagelhout, 2001). A method that is often used in projecting a future production technology within an input-output context is based on the assumption that today's 'best practice technology' will become tomorrows 'average technology'. More often, however, future studies with input-output models are based on the expert judgements on the change in technical coefficients. In this case the technical coefficients for a base year are used as a point of departure for the construction of the future technical coefficients. Leontief and Duchin (1986), Veeneklaas (1990), and Duchin et al. (1994) used this method. Drawbacks of using expert judgement in projecting future production technology are the high data- and labour intensities of this method. The advantage is, of course, a more realistic description of future production. Using this method makes it also possible to assess innovative technological changes.

A combination of trend analysis and expert judgement is used for the construction of the technology scenarios in this paper. This will be described in the next section.

4 Method

As seen above, there are several methods for projecting the input-output coefficients. This paper presents a method that combines an extrapolation method with more specific knowledge on technologies. The extrapolation method generates a reference path, independent of the scenarios. This reference path can be seen as a more or less autonomous path to the future, based on the trends from the past. The scenarios on their turn are variations based on this reference path. For the specific technology scenarios, detailed information on the rise and fall of technologies is implemented. However, in filling in the technology scenarios, one should keep in mind the course of the reference path.

In the reference scenario, technical coefficients are based on historical trends. Projecting these trends from the base year 2000 to the future leads to the 2030 technical coefficients. These coefficients can then be written as a function of the coefficients in the base year 2000:

$$a(R)_{30} = a_{00} + \Delta a(R) \tag{1a}$$

or

$$a(R)_{30} = a_{00} + \delta(R) * a_{00} \tag{1b}$$

with:

$a(R)_{30}$ technical coefficient in 2030 according to the reference scenario R;

a_{00} technical coefficient in 2000;

$\Delta a(R)$ absolute change in technical coefficient between 2000 and 2030 according to the reference scenario R;

$\delta(R)$ relative change in technical coefficient between 2000 and 2030 according to the reference scenario R;

In modelling specific information on technological change in scenarios two types of change are distinguished:

1. changes in primary production processes, e.g. common production versus organic production in agriculture; this may result in lower input coefficients, e.g. for herbicides;
2. more general changes, independent of the primary production process; examples are a more efficient use of inputs due to an increase in information and

communication technologies (ICT) or substitutions between inputs (materials, means of transport, etc.).

Both types of technological change lead to changes in the technical and other coefficients. Before the actual modelling of specific technologies per scenario, two steps are carried out on the technology-related input. First, per sector a survey of alternative process technologies is made. These technologies apply for the primary production process. For all technologies, estimations are made for their shares in total production. Second, for these alternative technologies, the differences in coefficients compared to the regular technology are estimated. On the basis of these estimations, new coefficients can be derived describing the new mix of technologies. After that, more general technology changes, independent of the primary process technology, are modelled.

The first step concerns the alternative technologies for the primary production process in a sector. The input column describes the mix of installed technologies in that sector. A column coefficient in the matrix of technical coefficients represents the average of the coefficients of the separate technologies, e.g. electricity production based on fossil fuels versus wind and solar energy, weighed to the share of each technology in the mix. So the average coefficients can be determined per sector in case information is available over the input structure and share in total production per technology. E.g., the following relation holds for the input coefficients for 2000:

$$a_{00} = \sum_i \alpha_{00}^i * a_{00}^i \text{ , with } \sum_i \alpha_{00}^i = 1 \qquad (2)$$

with:

a_{00} technical coefficient based on the input-output table in 2000;

a_{00}^i technical coefficient for technology i in 2000;

α_{00}^i the share of technology i in total production of a sector in 2000 (sum of the alphas is 1).

One of the alternative technologies is now defined as the regular or common technology for the sector. The coefficients of all technologies can be related to the regular technology (per definition the regular technology has index 1):

$$a_{00}^i = \gamma^i * a_{00}^1 \qquad (3)$$

with:

γ^i ratio of technical coefficient for technology i and technical coefficient for technology 1 (γ^i = 1);

a_{00}^1 technical coefficient for regular technology in 2000;

Equations (2) and (3) result in:

$$a_{00} = \sum_i \alpha_{00}^i * \gamma^i * a_{00}^1 \qquad (4a)$$

This leads to the following equation for the coefficients of the regular technology:

$$a_{00}^1 = a_{00} \Big/ \sum_i \alpha_{00}^i * \gamma^i \qquad (4b)$$

Before projecting the coefficients for 2030 for a specific scenario some further assumptions are made:

Assumption 1: the ratio in the coefficients of technologies i and 1, γ^i, is unchanged over time for all technologies.

Assumption 2: the shares of technologies in total production are constant over time in the reference scenario.

Assumption 1 states that the pace of technological development in all technologies is the same. It means, for example, that the relative change in inputs from chemistry to agriculture (e.g. herbicides) is the same for all technologies. This means that for alternative technologies, the ratios per coefficient in 2030 are the same as in 2000. So, equation (2) also holds for 2030:

$$a_{30}^{i} = \gamma^{i} * a_{30}^{1} \qquad (5)$$

with a_{30}^{1} is the technical coefficient of the regular technology in 2030.

Assumption 2 relates to the reference scenario. It states, for example, that the share of organic agriculture in total agriculture does not change in the reference scenario for the period 2000-2030. The reference path is based on the past in which the shares did change. However, for most alternative technologies, the shares were near zero in the period 1995-2000.

The next step is the modelling of generic technological changes, which are not related to a certain specific technology. Such technological changes are usually independent from the main process and they differ per scenario. These generic technologies are characterised with the factor φ, which indicates improvements in the efficiency of all technologies in a sector. Substitution between inputs is modelled with the factor φ as well. Technical coefficients in scenario S_1 can be written as a combination of the coefficient in the reference path and the factor φ:

$$a(S_1)_{30}^{i} = \varphi(S_1) * a(R)_{30}^{i}\text{, for all technologies i} \qquad (6)$$

with:

$\varphi(S_1)$ a factor representing the more general change per coefficient for scenario S_1 with respect to the coefficient in the reference scenario irrespective the production technologies.

The change in a specific scenario modelled with φ is thus in addition to the autonomous change in the reference path. This change can be lower or higher than the change in the reference path.

On the basis of the given equations the equation for the coefficients in 2030 for a certain scenario, e.g. S_1, can be worked out. Applying equations (2) for 2030, (6), (5) and (4), subsequently gives the result:

$$a(S_1)_{30} = \sum_i \alpha(S_1)_{30}^{i} * a(S_1)_{30}^{i}$$

$$= \sum_i \alpha(S_1)^i_{30} * \varphi(S_1) * a(R)^i_{30}$$
$$= \sum_i \alpha(S_1)^i_{30} * \varphi(S_1) * \gamma^i * a(R)^1_{30}$$
$$= \sum_i \alpha(S_1)^i_{30} * \varphi(S_1) * \gamma^i * \left[\delta(R) * a^1_{00} + a^1_{00}\right] \quad (7)$$

with

$\alpha(S_1)^i_{30}$ the estimated share of technology i in total production of a sector in 2030 in scenario S_1 (sum of the alpha's is 1).

Equation (7) describes the coefficients in a future year as a result of technological changes for scenario S_1. Rewriting the equation gives:

$$a(S_1)_{30} = \varphi(S_1) * \left[\delta(R) * a^1_{00} + a^1_{00}\right] * \sum_i \alpha(S_1)^i_{30} * \gamma^i \quad (7a)$$

So, the projection of the coefficients for a future year is carried out with equation (4b) and (7a). The projections of other coefficients in the model, like labour, capital and emissions coefficients, can be done out in a similar way.

5 Application of the method for four scenarios

In order to illustrate the method for the projection of coefficients, the method was applied in a scenario context, with the year 2030 as a time horizon. First, coefficients were derived for the reference path on the basis of historical data. After that, technologies were in more detail incorporated in the model calculations depending on the scenario descriptions.

5.1 Reference path

The projection of the input-output coefficients in the reference path is based on the input-output tables in real prices for the Netherlands for the period 1995-2000. The changes in the input-output coefficients (including both domestic and imported inputs) are used as a starting-point for the projection for the 2030 coefficients. As mentioned before, extrapolation of coefficients does not lead to better results than taking the base-year coefficients as departure. Therefore, a middle course can be adapted by applying a weakening of the extrapolation. It was assumed that the annual change per coefficient (derived from the 1995-2000 period) decreased with 10% every year. So, the change between 2001 and 2002 is 0.9 times the change in 2000-01. Each coefficient converges to a specific saturation value as in an S-curve. The total change over 30 years is about 9.6 times the change in 1999-2000. This approach is in line with an extrapolation method based on logistic growth curves. In order to restrict the changes in coefficients a maximum change of 0.05 is assumed.

The reference paths for other coefficients, such as the emission coefficients, were determined in a similar way. However, for emissions related to transport, expert information was used about the estimations of the emission coefficients in 2020.

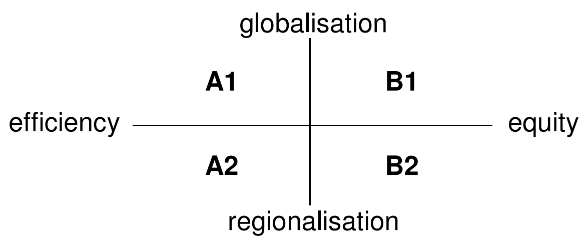
5.2 Scenarios

Framework

The method was applied for four scenarios, which are based on the framework developed by the International Panel on Climate Change (IPCC, 2000). In the SRES-studies, a large number of climate change scenarios are clustered into four scenario families, which are referred to as A1, B1, A2 and B2. These scenarios are descriptive in nature, distinguished from each other along two lines (describing opposite driving forces):

1. From *efficiency* to *equity*;
2. From *globalisation* to *regionalisation*.

If these two lines for argument are posed cross-sectional to each other, the four scenarios come forward, each incorporating their own story-line or narrative (see figure):



It should be noted that the two dimensions yield a simplistic overview, to which developments in e.g. technology or population are not considered as a separate driving force. Also, the main driving forces were originally analysed for greenhouse gas emissions, but this framework will be applied in a broader context. The basic idea however remains the same: each story-line assumes a distinctly different direction for future developments, such that the four story-lines differ in increasingly irreversible ways (IPCC, 2000).

At the ends of the first line of driving forces it is conceivable that efficiency leads towards market oriented story-lines (the A-scenarios), while equity translates much more to resilience and robustness (the B-scenarios). This line of driving forces is often associated with the terms *economy* versus *ecology*. These two terms are often juxtaposed to each other in common discussions, although there is not necessarily a gap between these two (see e.g. eco-efficiency production). In the scenario framework, this line should be seen not only as a driving force but also as indicative for the line of solutions that a society will seek. In the A-scenarios, these are much more market oriented, while in the B-scenarios government takes a much larger role.

The other line distinguishes a globalised and interactive world on the one end (the 1-scenarios) to a much more fragmented and polarised world on the other end (the 2-scenarios). The 1-scenarios describe a convergent world with often rapid changes and increased interactions. The 2-scenarios are not necessarily fragmented in the negative sense, but much more heterogeneous, with a focus on local solutions, preservations of local identities and self-reliance.

It should be noted that the SRES-scenarios are qualitative descriptions (story-lines) rather than quantifications. The original methodology is rather the other way around; the SRES-scenarios are collections of quantitative modelling results, based on their descriptive similarities.

Scenario description

The **A1-scenario** is a market-oriented scenario of globalisation, following principles of liberal and international markets. International hedges and market disturbances such as protective measures and subsidies are phased out in favour of free trade mechanisms and institutions. The competitive market is seen as the best substrate for environmental, economic and social solutions. The allocation of the appropriate production functions is done internationally rather than national or regional. With the argument of perfect and global markets for the most efficient and effective allocation of consumption and production, governments will withdraw from many themes and areas in favour of those markets. Therefore, many issues are brought to the market and international liberalisation is a key element of this scenario. *Technology* and *innovation* will be largely dependent on the private sector and their R&D-investments. Chances are considerable that in many sectors large monopolists will eventually determine the markets. This does not necessarily inhibit chances for innovations, but these will be incremental rather than radical, since the monopolist will strive to maintain the existing technological regime. The large size of the market will make it hard for small-scale entrepreneurs to enter and take over (niches of) that market. The nature of the innovations will be to contribute to the solution of perceived problems. In the application in DIMITRI, this implies a relatively large focus on technological development and market-based innovations in the A1-scenario.

The **B1-scenario** also takes stock from the drivers and consequences of globalisation, but includes equity rather than efficiency as the second line of argument. This scenario does not as such *exclude* market principles from the global village, but it tends to bend these towards a more equitable and global distribution of welfare, costs and benefits. Collectivity and equity are important drivers, also in technological innovations. Strong innovation networks emerge as coalitions of knowledge and know-how. Distribution and exchange of knowledge is key in this scenario, but also more generally a key driver of technological development (Shapiro, 2002). This implies a relatively good substrate for transfer and distribution of innovations. The equity principle implies a relatively strong role for government and public knowledge. Innovation is not necessarily targeted towards technology, but also takes institutional and organisational changes into account. System innovations are therefore much more conceivable than in the market based A-scenarios.

The **A2-scenario** departs from protectionist measures in favour of regional or national markets. To a large extent this can be seen as a counter force of globalisation, relapsing to local and regional structures (regionalisation) as a reaction to the construction of abstract and large-scale global trade networks. Nations or nation blocks do not just yield themselves to the emerging global order, but rather organise trade and economic institutions among themselves. For technological development two major effects are key here:

1. protected markets serve as *niches*, allowing for small business initiatives and experiments, leading to a relatively high diversity of technological systems;

2. Strong competitiveness forces businesses to be innovative, since they would otherwise loose their market shares. The size of the competitive market is however much smaller than in the A1-scenario.

Chances for technological innovations are fairly large in this scenario, even though the innovations will not easily proliferate on a global scale. World-wide standards are not easily implemented. Arguments for equity, environment and collectivity are not of high priority in this scenario, although some niches are conceivable.

In a **B2-scenario** the argument on niche markets is shared with the A2-scenario, but competitiveness and innovative environment will now be much lower. The *direction* of technological development (i.e. the types of innovations) is on the other hand much more influenced by government, who will strive for equity in chances and opportunities for all. The focus on the benefits of knowledge produces chances for broad and high level public education, exceeding mere technological innovations and including focus on e.g. culture, organisation and social development. In this scenario, the ties between public knowledge institutes and business enterprises will not mature very much, barring the proliferation of public knowledge to private profits. This undeveloped tie obviously also blocks the diffusion of innovations. The somewhat fragmented economic layout of the world in this scenario enables the existence of separate technological systems and regimes. Technologies will not easily mature due to scale advantages. Radical innovations are on the other hand most conceivable in this scenario, since the existing technological regime is much less strict than in other scenarios. Also, governmental policy focuses on system changes, enabling the creation of niche markets.

5.3 Survey of technologies per scenario

The technological survey of the project incorporates a longlist of 134 technologies in the fields of agriculture, transport, industry, households and energy. Technologies were selected broadly from a variety of literature sources (see e.g. RIVM, 2000; Weterings et al., 1997) and expert judgements. The survey excludes very small scale technologies and/or technologies with no or negligible estimated environmental or economic impact. Also, technologies with e.g. medical impact, space science and impact on attitude or behaviour were mostly excluded, since their impacts either go beyond the scope of this study or are for now too hard to grasp in the scenario context. Finally, technologies related to hydrogen economic systems were treated separately and not in their systems perspective, although it is realised that significant impact may be reached here.

Assessments were made on all these technologies, which were clustered in the following phase (see table at the end of this section). The assessments include descriptions and background information on the technologies, the sectors on which it links, and a qualitative estimate of the development of the technologies per scenario. These latter estimates were quantified for the model runs, mainly by making use of expert judgements. The clustered and quantified technologies were then included in the model runs in the already described manner (exogenous).

The methodology acknowledges differences in the nature of the technologies considered, as it distinguished changes in primary production processes and more general changes independent of the primary production processes (see description in section 4). Technologies are then judged on their economic impacts, in terms of sectoral implications: what are the changes in intersectoral deliveries following the introduction of a technology or technological cluster?

Environmental coefficients were introduced for each technology, in order to calculate their environmental impacts. Impacts were calculated for emissions to air (CO_2, CH_4, N_2O, NH_3, NO_x, SO_2, PM_{10}, and non-methane VOC), and soil and water (N and P). For the emissions to air, a distinction was made for emissions related to combustion, processes and transport. The reference path for transport emission coefficients was based on the 2020 figures obtained from a forecast study on emissions in traffic and transport (van den Brink, 2003). The emission coefficients related to combustion and processes develop according to a trend based on the 1990-2000 period for the reference scenario. Deviations in respect of the reference path were made for each of the scenarios. These deviations were mainly based on expert judgements.

For each scenario, a matrix of technical coefficients for 2030 was projected. The total change in coefficients in the period 2000-30 was derived from the matrices for these two years. For the intermediate years, matrices of input-output coefficients were determined on interpolating the coefficients linearly over these 30 years. The DIMITRI model uses these matrices for all these years to calculate production per sector for the period 2000-30. Other coefficients, e.g. concerning labour and emissions, were modelled similarly by projecting them for 2030 and interpolating them linearly for the intermediate years. However, the outcomes related to the primary input coefficients (labour, depreciation, value added, etc.) are beyond the scope of this paper.

Technological clusters	sphere[1]	includes (among others):	general development in scenario[2]				Main line of argument (in short)
			A1	A2	B1	B2	
Genetic modification techniques	AG	Modification in agricultural production	++	++	+	-	Market driven in A-scenarios, ethic restraint in B2. Possible food security argument in B1 (hunger).
Use of biofuels and cultivation of biomass	AG,EN	Biomass growth, biofuel use, combustion or gasification of biomass/biofuel	0	-	++	+	Climate policy argument in B1 only. Lower in B2 also due to space shortages, but some local air quality arguments. No major arguments for A-scen.
Organic agriculture techniques	AG	Organic growth, incl. mechanistic techniques replacing e.g. chemicals	-	-	+	++	Efficient chemical techniques in A-scenarios; env. argument in B-scen, stronger in regional scenario (B2)
Alternative agricultural production chains	AG	Novel protein foods	+	0	++	+	Replaces meat in B-scen., used in cheap ready made bulk products in A-scen.
Efficient use of energy and resources[3]	AG,EN,IN	includes CO_2-storage, super conduction, etc.	0	0	+	+	Driven by environment argument for B-scenarios; trend for A-scenarios, driven by relatively low market prices
Alternative energy production: nuclear	EN	Nuclear fusion energy production	-	+	-	-	Too expensive for private parties (A1) or too risky (B). Chances in A2 due to diversification in energy production
Alternative energy production: other non-fossil	EN	Wind, solar, incl. decentralised applications	0	-	++	+	Very much driven by env. argument (B), reinforced by climate policy for B1.
ICT-cluster[3]	AG,TR,IN	Sensor technology, precision instruments, intelligent systems, etc.	++	+	++	-	Relates to globalisation[4] and general efficiency improvements (which is no issue in B2 especially)
Fertiliser and manure policy induced technologies	AG	Processing and fermentation, low emission stalls	0	0	++	+	No fertiliser policy in A; larger livestock in B! induces higher innovation than in B2
Transport innovations	TR	High-speed trains, maglev trains, developments in electric cars,	various				Driven by fuel prices, market demand (A) and regulations (B)
Integrating transport modalities	TR	Intermodalities in person and goods carriers	-	-	+	0	Govt. is much larger driver than market (B>A), but B2 may lack the large funds that are needed
Environmental innovations	all	wide variety of mainly *production* innovations	0	0	+	+	Opportunity if in line with market (A), but generally driven by stricter regulations (B)

1. *Spheres: AG – agriculture; EN- energy; TR – transport; IN – industry; EV – environment*
2. *Scenario developments are scored in relation to the reference scenario developments.*
3. *Efficiency improvement and ICT developments due to general technological developments are largely included in the reference scenario, but some specific efficiency improvements are included in the scenarios*
4. *Note that the actual causality with globalisation is very much the other way around: ICT enhances globalisation.*

6 Results

This section shows the differences in production and emissions due to differences in technological development for the four scenarios presented above. The DIMITRI model calculates sectoral production on the basis of the matrix of technical coefficients and final demand. In order to show the effects of technological development only, for all technology scenarios, production is kept to the same final demand, derived from the reference scenario. All other factors were kept constant.

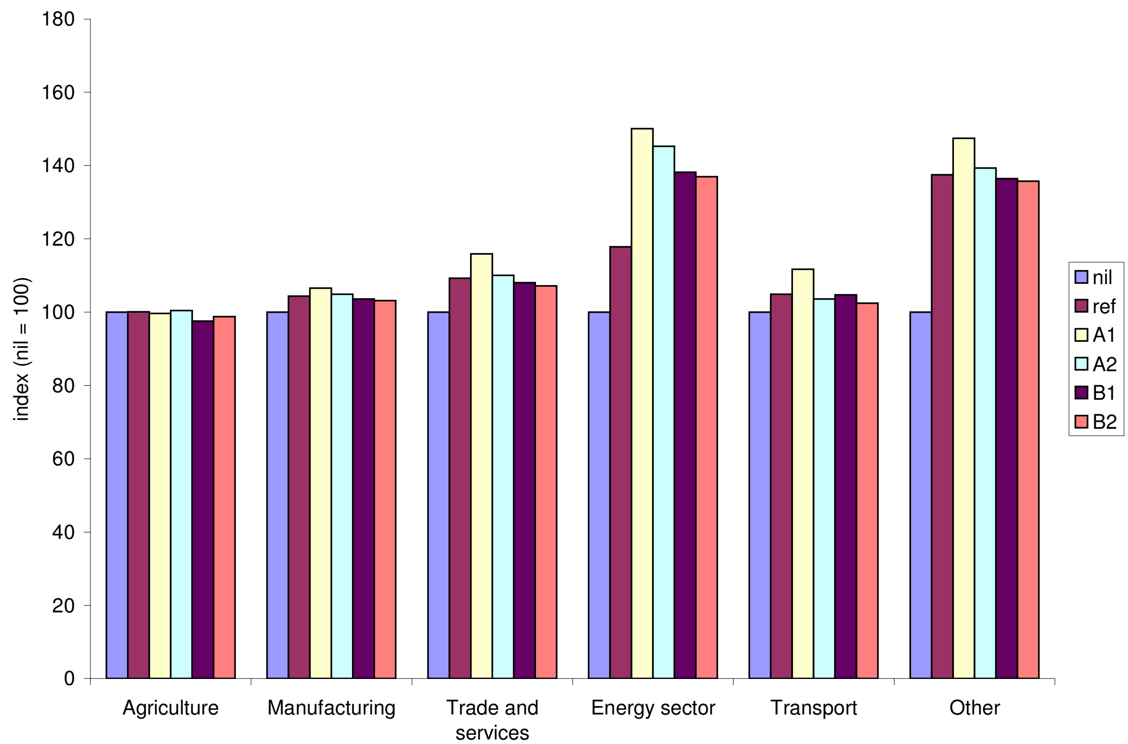


Figure 2 Production per sector in the Netherlands in 2030 for five scenarios in relation to the nil scenario.

Figure 2 shows production for five scenarios for 2030 calculated with the DIMITRI model based on changes in production technology only. The nil scenario is the scenario in which the 2000 input-output coefficients are used for the whole period 2000-30. In this scenario no technological changes are assumed. The differences between the reference and nil scenario are due to the extrapolated (but weakened) trends derived for the period 1995-2000. For the six sectors shown, 2030 production based on the extrapolated coefficients is higher than production based on the 2000 coefficients. Especially the inputs from computer services, construction and telecommunication into other sectors displayed a high increase in the historic period. The production calculated for the four IPCC scenarios fluctuates around the values in the reference scenario. For almost all sectors the production in the A1-scenario is the highest. This scenario shows a further increase in production in business services, which leads to an increase of production in other sectors. Furthermore, in all scenarios electricity production (energy sector) increases due to a higher rate of electrification in the future.

Figure 3 presents an overview of the differences in CO_2 emissions in the Netherlands over the scenarios. The outcomes are the result of changes in both technical coefficients and emission coefficients. The differences between the nil scenario (based on the 2000 technical and emission coefficients) and the reference scenario are obvious. The CO_2 emissions in the energy sector, which occur for more than 95% in electricity production, show the largest variations over the scenarios. First, electricity production is higher in the scenarios A1, A2, and B1 compared to the reference scenario, mainly due to a further increase in the application of ICT systems in these scenarios. In the B-scenarios the share of non-fossil electricity production technologies, like wind and solar, is higher. Furthermore, CO_2 emissions related to electricity production are lower in the B-scenarios than in the trend (and A-scenarios) because of a higher share of technologies, like CO_2-storage and underground coal gasification. In scenario A2, electricity production in 2030 is for 20% based on nuclear energy. The CO_2 emissions in transport only concern the emissions of Dutch production sectors in the Netherlands. So, emissions of freight transport of Dutch companies abroad (road, sea and air) are not included in the figure.

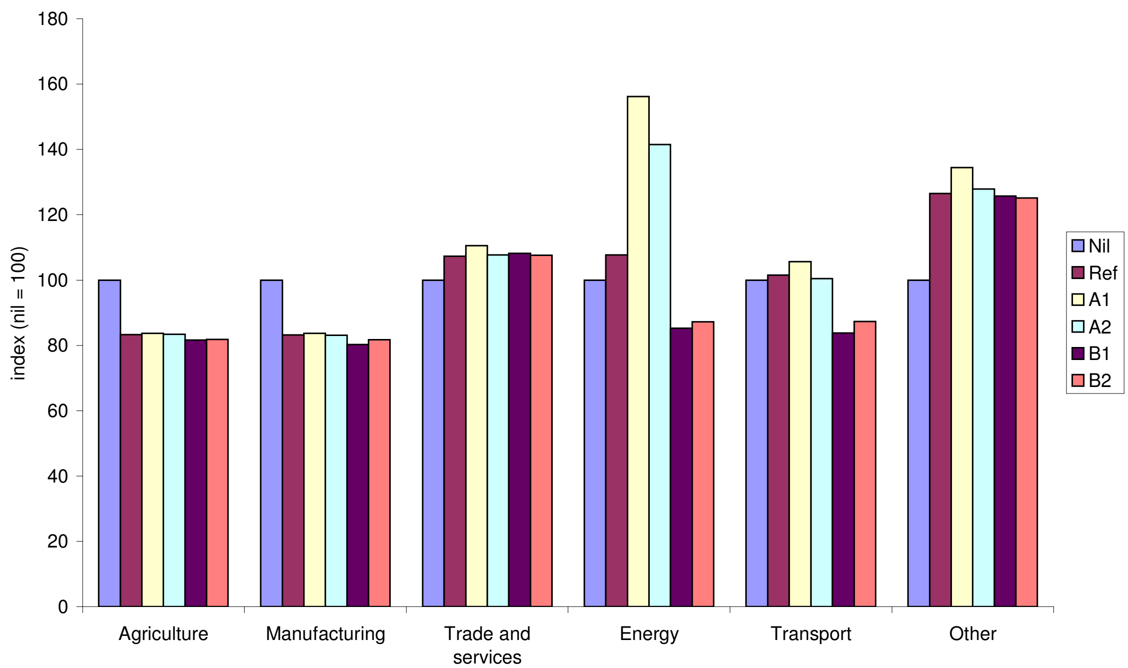


Figure 3 CO_2 emissions per sector in the Netherlands in 2030 for five scenarios in relation to the nil scenario.

Figure 4 shows the emissions of nitrogen to soil in agriculture for the scenarios distinguished. The decrease in emissions between the nil scenario (based on 2000 technologies) and the reference scenario is the result of the extrapolated trend of the period 1995-2000. The amount of emissions in the four IPCC scenarios, which is lower than in the reference scenario, is the combined effect of the introduction of specific technologies. Both genetic modification techniques and organic agriculture techniques show lower nitrogen emissions per unit of product (due to a decrease in the use of fertilisers) in arable, cattle and dairy farming, and non-greenhouse horticulture. The emissions in the A-scenarios are lower due to a relative high share of genetic modification techniques (see table 1). Organic agricultural techniques will be partly applied in the B2-scenario (and to a lesser extent in the B1 scenario) in 2030. In the scenarios A1, A2 and B1, a further decrease in nitrogen emissions is achieved resulting from some general efficiency improvements (ICT cluster in table 1). Finally, the introduction of alternative agricultural production chains, e.g. novel protein foods, lead to lower meat consumption and as a consequence lower production in livestock breeding. This results in fewer emissions especially in B1 and to a lesser extent in A1 and B2.

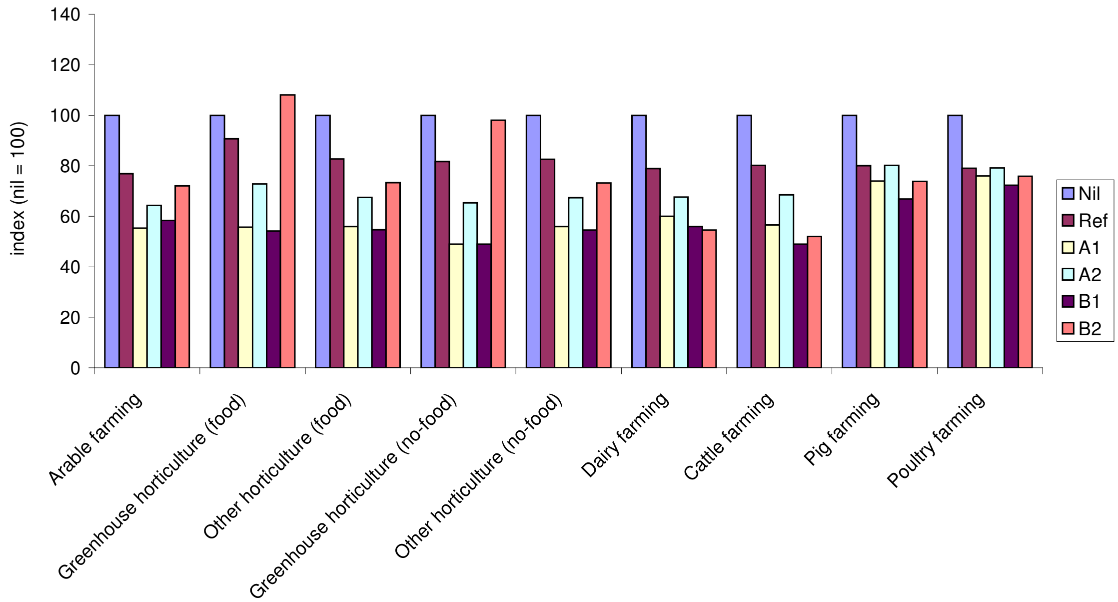


Figure 4 Nitrogen emissions to soil in agriculture in the Netherlands in 2030 for five technology scenarios in relation to the nil scenario.

Figure 5 shows the calculated NO_x emissions related to transport in the Netherlands for the five scenarios compared to the nil scenario. As said before, the reference emission coefficients for transport are based on the 2020 figures obtained from a forecast study on emissions in traffic and transport. Especially, the NO_x emission factors for road transport show a sharp decrease in the period 2000-2020. The variations in emissions in the A- and B-scenarios with respect to the reference scenario are relatively small. Different shares of new transport technologies mainly cause these variations. The B1-scenario shows the highest share of new technologies, like fuel cell and hybrid cars, instead of the internal combustion engines with which the fleet of cars is fitted for almost 100% in 2000. Other scenarios have a lower share of new technologies. Furthermore, the more efficient use of materials in the B-scenarios leads to less heavy cars which are more energy efficient. The same holds for ships and planes. In the A1-scenario (globalisation) the demand of production sectors on international transport (air and sea shipping) is higher than in the reference scenario, In the regional scenarios (A2 and B2) the demand on international transport is just lower than in the reference scenario.

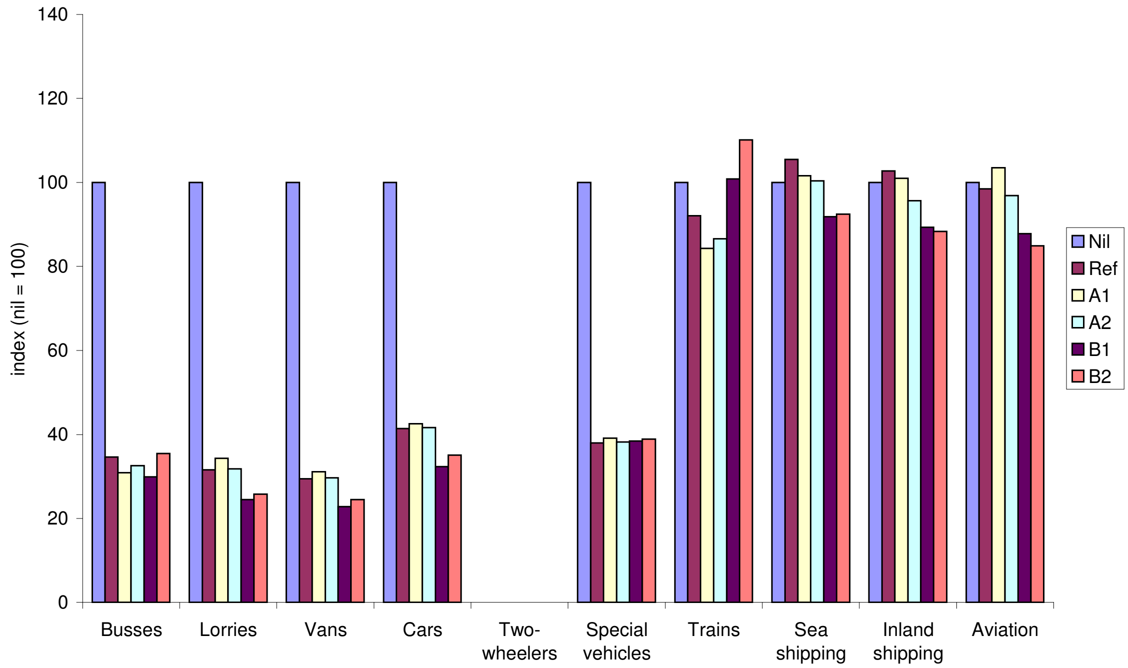


Figure 5 NO_x emissions related to ten means of transport used in production in the Netherlands in 2030 for five scenarios in relation to the nil scenario (there is no use of two-wheelers in production sectors).

7 Discussion

The presented methodology and calculations are part of a larger project in which the IPCC scenarios will be quantified more comprehensively. An important aspect that will be included is the modelling of final demand (including changes in consumption) and related technology. Differences in consumption due to differences in income and population growth will have a huge impact on the outcomes per scenario. Furthermore, consumption patterns differ per scenario as a result of different lifestyles and technological development. Technological change, of course, not only appears in production sectors, but also in consumption. This may lead to less energy use by consumers or the purchase of more advanced products. E.g. more efficient internal combustion engines lead to a decrease in the purchase of motor fuels. As a result, these developments may have their repercussions on the input-mix of the producing sectors. The presented calculations do not include changes in consumption as a result of technological change yet.

The paper only presented the effects of technological change on Dutch production and emissions. The input-output coefficients describing technology per sector partly concern inputs produced domestically and partly inputs produced abroad. So, the matrix of technical coefficients consists of a domestic and a foreign part. In the model, just changes in the domestic part have effect on production in the Netherlands. Production in the Netherlands and changes in the foreign part have effect on the imports, and therefore on the balance of trade. So, technological changes that influence only the import part are not visible in Dutch production and related emissions. However, in case of substitution between inputs, e.g. materials, a part of

production (and GDP) may be shifted to abroad if the new input is mainly produced in other countries.
The share of domestic inputs in total differs per technical coefficient. The calculation of the effects of technology assumes no change in this share, e.g. due to changes in competitiveness. However, this aspect will be considered in the integrated calculations, which are planned. The competitiveness will then vary per scenario and per sector.

The reference path is based on historic changes in the technical coefficients in the period 1995-2000. These measured changes concern both changes in the share of the specific technologies, e.g. organic farming and usual farming, as changes in the technologies themselves. Since these factors cannot be distinguished, it is assumed that all changes are related to the regular technology. The share of the alternative technologies is almost zero for all technologies investigated. Other factors also influenced the technical coefficients in the past, e.g.:

- changes in the product mix of sectoral output;
- changes in the composition of products;
- changes in the location or region of production (competitiveness).

It is assumed that these changes will continue in the future in the reference path.

The period for the determination of the coefficients in the reference path was, due to a lack of data availability, only 5 years. The reference path constructed for the environmental coefficients of the production sectors was also on the basis of trends in the past. It is doubtful wether these trends will continue in the future.

The chosen approach consists of a major role for the reference scenario. In some sectors, the difference between nil and reference scenario is much higher than the variation on the basis of the scenarios. Furthermore, the boundaries between the reference path and specific technologies are not sharp and it is difficult to separate them. Furthermore, in estimating the coefficients, it was difficult to let experts make the distinction between an autonomous path and the implementation of specific technologies. So, further research has to be directed at the separation of the reference scenario and the specific scenarios according to the story-lines. However, it must be remembered that the research presented takes part in a broader context of integrative scenario calculations.

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