Expected demand for resources in the Netherlands

A consumption and production view

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July 2018

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1 Background

The Dutch government has formulated targets for a circular economy: in 2030, the economy should be circular for 50% and in 2050 for 100%. What that means exactly is as yet unspecified. This will be clarified over the coming years. Whatever that specification will be, it is at least clear that the use of primary resources must be reduced as far as possible, and should be replaced by secondary resources.

To estimate the policy effort that is required, it is important to have an insight in business as usual development: how would the demand for resources, primary as well as secondary, develop without any additional policies? This then could be compared to alternative developments where specific policies are included. This question could be approached best by a scenario study, comparing a Business as Usual (BAU) scenario to a number of policy rich scenarios to establish which policy measures could be successful.

In this report, we aim at developing a BAU scenario: what is the expected demand for resources in the Netherlands without any specific policies? We approach this BAU scenario from a consumption as well as a production perspective. It is a follow-up of the earlier report “Trends in production and consumption of resources in the Netherlands and in the World”, where past trends of resource use are specified.

2 Starting points for the Business as Usual scenario

On the following topics, specifications need to be made for a BAU scenario:

- Selection of resources
- Relevant scale level and time horizon
- Production and consumption perspective
- Expected developments in the Dutch society.

Selection of resources

The selection of resources is identical to those from the previous report “Trends in production and consumption …”:

- Agricultural crops (food and fodder)
- Animal products
- Phosphorus
- Iron and steel
- Major metals, non-ferro: aluminium, copper, zinc, lead
- Minor metals, non-ferro: rare earth elements, gold and silver, platinum group metals
- Plastics
- Cement and concrete.

An analysis at the material level is possible for analysing past trends. To estimate future demand, however, we have to take the applications of the materials as the starting point. Ideally this would be done in a bottom-up manner, being as specific as possible. For this project, in view of the limited time, we have to take a top-down approach using the EXIOBASE database, an environmentally extended input output model containing information on broad classes of applications. For some product groups and some of the major resources, this may lead to acceptable results. For others, such as minor metals and plastics, additional information must be found as no extraction data are linked to EXIOBASE and the translation via monetary units will probably lead to results that are less than adequate. We add some bottom-up estimates for the major metals, to allow for more detail and to provide a check on the EXIOBASE results.

Scale level and time horizon

The expected demand for resources will be specified for the Netherlands. The driving forces behind the demand will not necessarily operate at the Dutch level. In some cases, they will, for example in the housing and construction sector. But in other cases, driving forces will be international, even global, such as the demand for metals by the Dutch manufacturing industry. For each of the resources, we specify the most relevant driving force to estimate future demand.

Regarding the time horizon, we will use the future target years of the Dutch circular economy policy: 2030 and 2050.

Production and consumption perspective

The Dutch circular economy policy seems to start from the point of view of Dutch industry, and from the motivation of the continuing availability of (not too expensive) resources for industrial production. From that point of view, we should be looking at the materials used in the producing sectors. However, a circular economy refers to closing cycles: keeping resources in the use phase for as long as possible, via reuse, repair, refurbishing, remanufacturing or recycling. From such a point of view, the end-use of resources in all kinds of products is relevant, and the way such products become waste. That would imply a consumption based system would be the more appropriate choice. The difference between inflows and outflows of our economic system also has a temporal aspect: the delay factor related to the life span of applications, the stock dynamics that are essential information for a circular economy policy. However relevant, this last issue is not covered in this report as it would be too time consuming. We do specify future trend information in the BAU scenario from both the production and the consumption perspective.

Expected developments in the Dutch society

The future demand for resources will depend on all kinds of developments in society, related to demographics, economics, and policies in different areas and at different scale levels. A BAU is policy-poor by definition. We interpret this as: only policy that is already in place is taken into account.

As the starting point for our BAU resource demand scenario, we take the Welvaart en Leefomgeving (WLO) scenarios, two scenarios (a “high” and a “low” development scenario) composed by PBL and CPB, with the aim of offering a basis for policy decisions regarding the physical environment. The WLO scenarios do not contain specific information on resources. They do have specific “cahiers” that can be used, specifying developments in demographics, macro-economics, agriculture, mobility, urbanization, energy and climate. With the exception of the energy and climate cahier, the WLO scenarios can be interpreted as BAU scenarios. The energy and climate cahier contains very strict policies on energy and climate, with the aim to meet the Paris climate goals. As these policies are not yet decided on, we will not take them up in our BAU resource demand scenario. Instead, we will used the Nederlandse Energieverkenning (NEV), an annual report compiled by ECN, PBL and CBS on the Dutch energy production and use, including forecasts based on policy-in-place only.

The WLO scenarios have a time horizon that runs until 2050. The NEVscenario only runs until 2035, which implies we have to extrapolate to be able to estimate resource demand for energy unitl 2050.

3 Approach to the estimation of future resource demand

The approach, in general terms, is as follows:

- Identifying driving forces for the demand for resources
- Correlating past trends of these driving forces with past trends of demand for specific resources
- Extrapolate this correlation into the future: calculate future resource demand for 2030 and 2050 based on the expected developments in the driving forces.

Past trends for resource use are taken from EXIOBASE, both for the consumption and the production perspective. Past trends of the driving forces will be taken from statistical sources, as WLO seldom specifies this. Future developments related to driving forces will, as far as possible, be taken from the WLO/NEV scenarios.

3.1 Driving forces for the different resources

Specifying driving forces for the different resources requires a careful statistical approach. Such an approach will not be applied to the full extent in this exploratory project. Instead, we will select the (according to our information) most appropriate driving force and make straightforward correlations between past trends in driving force development and past trends in resource use, and use these to extrapolate into the future.

Agricultural crops and animal products

In many studies, it has been shown that the population is the most important driver for food consumption. Just the basic need for calories determines food consumption to a large extent. GDP plays a smaller role and is especially important for the diet, the choice of food products to consume. Generally, richer societies consume a larger share of meat products. In the Netherlands such a trend is not visible. Rather we see a trend in the opposite direction: a shift towards a more vegetarian life style. The WLO does not contain dietary information, so for a BAU scenario we'll assume no dietary changes.

With regard to the production system, the WLO contains detailed information on expected future development of the agricultural areas used by the Dutch agricultural sector. These will be used to estimate future production.

Phosphorus

Phosphorus is not an end product but is part of all biomass flows, especially food. We therefore identify food consumption and production as the relevant driver (see above). Phosphorus and P-fertilizer production does not take place in the Netherlands anymore.

Iron and steel

The use of iron and steel is driven by its main applications: the built environment, transportation, and infrastructure. Developments in these sectors for the future will be taken from WLO. For past trends, we'll establish a correlation between the use of iron and steel and the developments in these major consumption categories as reported in various statistics[1].

With regard to production, there is one major steel production plant in the Netherlands. Past trends in production of this single operation may not be very relevant for the future. This is in fact a problem for many of the resource production systems. We will ignore this and take global GDP as a driving force, from the perspective of steel being a global level market.

Non-ferrous metals: Al, Cu, Zn, Pb and Ni

We'll treat the major non-ferrous metals similar to steel. The major applications are similar. Production of these metals does not take place anymore in the Netherlands, but the metals are used widely in the manufacturing industry. We take global GDP as the driver, as for these metals, too, the world market is leading.

Minor metals: REE, Au, Ag, Pt group

These metals are applied in electronics and in specific technologies such as renewable energy technologies. The WLO scenarios offer very little information; the NEV scenarios a little more but still very partly. In fact, for these metals it is very hard to make forecasts at any scale level. Developments go very rapidly and markets are volatile. Nevertheless, we include them in our assessment and use Dutch GDP as a driver for consumption, and global GDP for production.

Plastics

Plastics are used in countless applications throughout the whole economic system. Therefore, we use Dutch GDP as a driver for the consumption system, and global GDP for the production system.

Cement and concrete

Cement and concrete are closely related to the built environment. The WLO scenarios contain some information on future construction plans. We will use the past correlation between construction activities and the use of construction materials to estimate the future use of these materials. Due to the mainly regional nature of construction, there will be little difference between consumption and production.

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[1] In practice we found that the number of new cars bought in the Netherlands was the best correlated with the final consumption of iron ore.

3.2 Top down approach using EXIOBASE

3.2.1 Introduction

The top down approach using EXIOBASE utilizes a simple model to extrapolate past resource use trends towards 2030 and 2050. The approach will be illustrated for the case of primary crops as shown in Figure 3.1.

3.2.2 Past trends primary resource use

The resource use related to the activities in the Dutch economy is analysed from two different points of view. One point of view is resource use extraction that may happen anywhere in the world along the supply chain as a result of Dutch final consumption, i.e. the products consumed by households, government, stock formation and investments. The other point of view is resource use extraction that may happen anywhere in the world along the supply chain as a result of production happening in the Netherlands.

We start explaining how the resource use extraction related to Dutch final consumption is calculated. In Figure 3.1 these are the open ochre colored squares that give the total use of primary crops associated with Dutch final consumption from 1995 until 2011. The data are indexed (2010 = 100). Resource use associated with final consumption ($\boldsymbol{M}$) is calculated using the EXIOBASE version 3.3 product by product table (according industry technology assumption) following the familiar Leontief equation:

$$\boldsymbol{M} = \boldsymbol{B}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y} + \boldsymbol{H}$$

In which $\boldsymbol{Y}$ is the final demand table, $\boldsymbol{A}$ is the technology matrix, $\boldsymbol{B}$ are the resource use extension coefficients, $\boldsymbol{H}$ is the direct resource extraction by private households and $\boldsymbol{I}$ is the identity matrix. In practice private households do not mine their own metals or clay and sand or grow to an appreciable amount their own crops. Therefore matrix $\boldsymbol{H}$ contains zeros only and can be disregarded.

Because EXIOBASE is a multi-regional input-output table the previous equation, assuming two regions only, can be expressed as:

$$\boldsymbol{M} = (\boldsymbol{B}_1 \quad \boldsymbol{B}_2)\left(\boldsymbol{I} - \begin{pmatrix} \boldsymbol{A}_{11} & \boldsymbol{A}_{12} \\ \boldsymbol{A}_{21} & \boldsymbol{A}_{22} \end{pmatrix}\right)^{-1} \begin{pmatrix} \boldsymbol{Y}_{11} & \boldsymbol{Y}_{12} \\ \boldsymbol{Y}_{21} & \boldsymbol{Y}_{22} \end{pmatrix}$$

where $\boldsymbol{B}_1$ and $\boldsymbol{B}_2$ are direct resource use coefficients in region 1 and 2. $\boldsymbol{A}_{11}$ and $\boldsymbol{A}_{22}$ are the input-output coefficients of domestic products. $\boldsymbol{A}_{12}$ and $\boldsymbol{A}_{21}$ are input-output coefficients of imported products. The final demand of region 1 is given by $\boldsymbol{Y}_{11}$ and $\boldsymbol{Y}_{21}$ which are the final demand for domestically produced products and imported products respectively. We are only interested in the resource use associated with total Dutch final demand and thus can disregard final demand by other regions. Assuming that in our two region model the Dutch region is the first of the two regions the Dutch final demand can be expressed as:

$$\boldsymbol{y_{NL}} = \begin{pmatrix} \boldsymbol{Y_{11}} & 0 \\ \boldsymbol{Y_{21}} & 0 \end{pmatrix} \boldsymbol{i}$$

in which $\boldsymbol{i}$ is a column vector of ones of appropriate size. The resource use related to Dutch final consumption ($\boldsymbol{m_{C,NL}}$) can thus be expressed as:

$$\boldsymbol{m_{C,NL}} = \boldsymbol{B}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{y_{NL}}$$

If one would calculate resource use related to final consumption for every country in the world according above equations and some up all the values, the sum values would be equal to total global resource use.

The second point of view on resource use is resource use related to production in the Netherlands. The analysis starts by calculating, the total output of all Dutch sectors. This produced output is either domestically used or exported. The output of the Dutch sectors is calculated by first creating a total final demand vector. For our two region global example:

$$\boldsymbol{y_{glo}} = \begin{pmatrix} \boldsymbol{Y_{11}} & \boldsymbol{Y_{12}} \\ \boldsymbol{Y_{21}} & \boldsymbol{Y_{22}} \end{pmatrix} \boldsymbol{i}$$

The total output of each sector anywhere in the world ($\boldsymbol{x_{tot}}$) is calculated using:

$$\boldsymbol{x_{tot}} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{y_{glo}}$$

Assuming that $\boldsymbol{x_{tot}}$ was calculated for the two region global example and the Netherlands is the first region, total output of products in the Netherlands is given by:

$$\boldsymbol{x_{NL}} = \begin{pmatrix} \boldsymbol{x_1} \\ \boldsymbol{0} \end{pmatrix}$$

Resource use by Dutch production ($\boldsymbol{m_{P,NL}}$) is subsequently calculated as:

$$\boldsymbol{m_{P,NL}} = \boldsymbol{B}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{x_{NL}}$$

Please notice that the values of $\boldsymbol{m_{P,NL}}$ are “double” counting resource use. The production in a particular country relies on production in other countries creating overlapping supply chains. If one would calculate resource use related to production in each country in the world according the equations above and sum up all these values, total resource use is overestimated. The sum values would not even be near the values for global resource use. Comparing the values in $\boldsymbol{m}_{\boldsymbol{P},\boldsymbol{NL}}$ with global resources use (or any other country) is not allowed[2].

The use of plastics by Dutch final consumers or by production happening in the Netherlands is of special concern. Plastics are a product that is either incorporated into other products such as televisions or cars,or used as packaging material and going ito intermediate consumers and final consumers. Plastics are not a raw material taken from the enviroment and incorporated into products such as the the other resource use items analysed in this report. Therefore the calculation of the use of “plastic and rubber products” was carried out slightly different. The total monetary “rubber and plastic products” output everywhere in the world related to Dutch final consumption and production happening in the Netherlands was calculated. This gives the monetary ouput in 49 countries/regions for “rubber and plastic products”. This monetary input is affected by price changes through the years and cannot be used for time series analysis. Therefore the hybrid version of EXIOBASE was utilized to calulate prices of rubber and plastic products in each country and each year. These prices were used to transform monetary outputs into physical outputs not affected by price changes.

EXIOBASE v3.3, a multi-regional input-output database was used to calculate resource use associated with Dutch final consumption and the resource use in the Netherlands related to Dutch production. The monetary tables available in EXIOBASE v3.3 provides us with a time series of annual resource use from 1995 – 2011, i.e. 17 data points. For the calculation of plastic use the hybrid version of EXIOBASE v3.3. was needed as well. Because the hybrid tables are only available for the period 2000 – 2011, the past trends for plastics are only available for the year 2000 – 2011, i.e. 12 data points. The relatively short time period for which the trends can be calculated will affect the strenght of the model fitted to these data as we will see later.

3.2.3 Past trends drivers

For the drivers identified in Section 3.1.2 and for which quantified data were available in the WLO or at global level, historical data spanning the years 1995 – 2011 were collected. Most of these data are taken from CBS. An overview of data sources is given in Table 3.1and Table 3.2 below.

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[2] Although frequently done, even in “scientific” articles.

Table 3.1: Past trends in drivers for resource use related to Dutch final consumption: sources of information.

Driver	Source
GDP - NL	CBS, Statline. Opbouw binnenlands product, 23 juni 2017
Population - NL	CBS, Statline, Kerncijfers van diverse bevolkingsprognoses en waarneming, 23 maart 2018
Agricultural area - NL	CBS, Statline, Akkerbouwgewassen; productie naar regio
Built houses – NL	CBS, Statline, Voorraad woningen; standen en mutaties vanaf 1921, 26 januari 2018
Cars - NL	Autoweek. 1995 – 1999 CBS statline , 2000 – 2011 Ministry of Economic Affairs, number of BEV and PHEV.
Car kilometer - NL	Compendium voor de Leefomgeving, Wegverkeer: volumeontwikkeling en milieudruk, 1990-2016
Electricity use - NL	Compendium voor de Leefomgeving, Aanbod en verbruik van elektriciteit, 1995-2016

Table 3.2: Past trends in drivers for resource use in the Netherlands related to production in the Netherlands: sources of information.

Driver	Source
GDP - global	World Bank. Data converted from constant 2010 US$ to 2010 EU €
Agricultural area - NL	CBS, Statline, Akkerbouwgewassen; productie naar regio
Built houses – NL	CBS, Statline, Voorraad woningen; standen en mutaties vanaf 1921, 26 januari 2018

For primary crop use the driver is the Dutch population development from 1995 – 2011. These are given in Figure 3.1 by the red open circles. The data are indexed (2010 = 100). A quick comparison between primary crop use in the years 1995 – 2011 and population developments shows that primary crop use follows an inverted U shape and that population is monotonously growing. This already shows that population development is probably not well correlated with primary crop use.

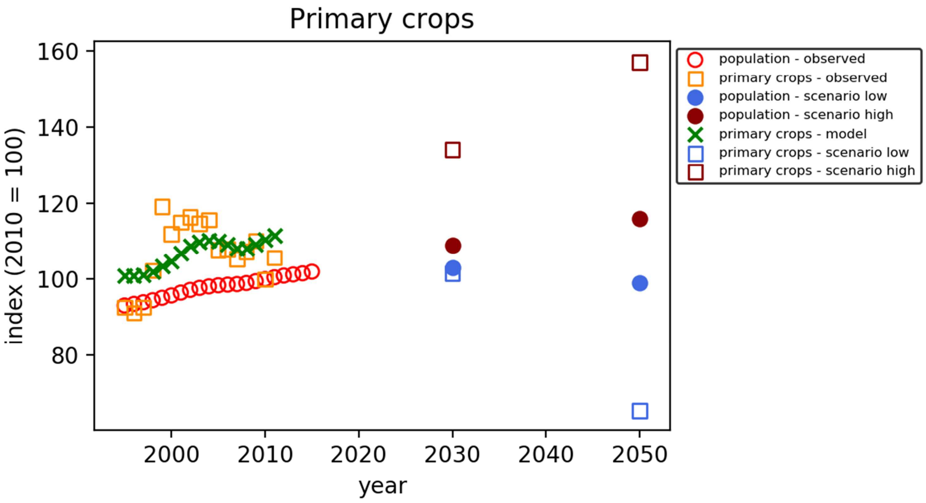

Figure 3.1: Extrapolating past trends in primary crop use related to Dutch final consumption. Extrapolation based on population development in the Netherland.

3.2.4 Relating trends in drivers and resource use

Following the calculation of resource use in the years 1995 – 2011 and collecting the development of drivers in the year 1995 – 2011, the relationship between the two series of data can be examined and a model may be formulated that can be used to extrapolate resource use to 2030 and 2050 following the WLO scenarios.

As noted above the primary crop use shows an inverted U shape and population is monotoneously growing. Therefore population growth cannot be the only explanatory parameter driving the use of primary crops[3]. This is a general pattern. As we will see later many of the other resources related to final consumption and production show an inverted U-curve and the selected drivers show a monotonous growth.

From other studies it is known that the patterns of resource use are driven by a combination of increasing demand for products and a continuous increasing efficiency in production processes. In the past increasing demand for products outweighted efficiency improvements. However it has been established that in the European Union increasing resource use efficiency often outweights the increasing demand for products (Bringezu, 2002). Likewise our observations, Bringezu sees for the an increasing domestic TMR for the European Union until 1990 and a reduction afterwards.

Based on this information we propose to describe observed resource use trends with two drivers. A driver that relates to the demand for products and an autonomous efficiency improvement. The drives

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[3] A model based on a linear relationship between selected drivers and resource use was only in 3 out of 18 cases successfull in describing the observed resource use trends.

that relates to the demand for products is assumed to be linear related to resource use. The autonomous efficiency improvement is assumed to be a yearly improvement percentage. This relationship takes the form of:

$$y_t = \gamma^t y_0 + \alpha x_t + \beta$$

where x_t is the known driver as a function of time, $y_t$is the resource use as function of time, y_0 is the resource use at time $t = 0$. The parameters γ, β and α are to be fitted and are thought to be constant over time.

Other types of relationships can be thought of. However other relationships between driver and resource use besides the function above has not been explored any further. Given the short time series, limited number of data pairs available and probably poor data quality, establishing superiority of other types of relationships is not seen as feasible. Finding the best values for γ, β and α using the limted number of observations was already challenging as reflected in the large uncertainty ranges for these values.

The model above was fitted to the observed data with a non-linear least squares Levenberg–Marquardt algorithm as provided by the python lmfit (version 0.9.11) package. A plot of the residuals showing the difference between our model and observed primary crop use index is shown in Figure 3.2.

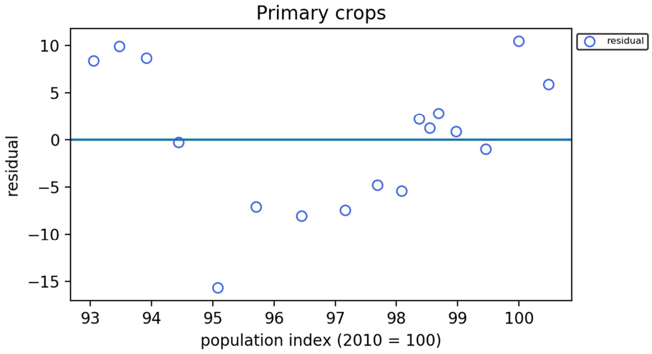


Figure 3.2: Residuals between regression model and observed primary crop use.

If the fitted model can describe the observed data sufficently well this model might be used used to estimate future resource used based on the given trend in driver and continuous efficiency improvements. This is done In Figure 3.1 for primary crop use in the years 1995 – 2011 using the observed population. The fitted model is shown with the green × marks.

We assume that the fitted parameters fitted on the past trends still hold in 2030 and 2050. It’s an assumption that agrees with the objective of establishing a BAU scenario. Policies at play in the years

1995 – 2011 are still operative but new policies are absent in this scenario. Autonomous technological developmentsand/or or changes in the way production and consumption takes place are assumed to continue as they have in the past.

Knowing the WLO population scenarios for 2030 and 2050, it is simply applying the previously established model to obtain primary crop use scenarios in 2030 and 2050 in line with the WLO scenarios. The results are also shown in Figure 3.1 as the blue and red open squares. Additionally uncertainty of the projections based on the correlation and taking into account autocorrelation could be used to make uncertainty estimates of the projections as well. However given the exploratory character of this study this has not been done but is very well possible and advised to do.

The results show that primary crop use in the scenario high increases driven by an increased population. In the scenario low with a decreasing population after 2030, primary crop use remains stable until 2030 and thereafter starts decreasing.

3.2.5 Caveats

Goodness of fit tests and uncertainty ranges for the estimated parameters give information about the correctness of our model and how well the drivers explain observed resource use. The drivers as formulated in Section 3.1 and summarized in Section 3.2.3 are all related to the final consumption of products and services. However, the amount of final consumption may not be the main driver explaining resource use. For instance, more important drivers may have been changes in the structure of final consumption of products, or changes in the structure of the economy or changes in the technology to create those products and services or weather that affects agricultural production. If that is the case, our model may very poorly describe observed data. Using our model for extrapolation towards 2030 and 2050 thus also becomes very questionable. Therefore, a first caveat is that a poor explanation of past trends by the model means that an extrapolation into the future using that (poor) model is questionable.

A second caveat is that only a correlation between the driver and past resource use trend can be established, not a relationship. The drivers, such as the car kilometers, are only a proxy for the real driver(s) of resource use. The assumption is that the chosen drivers are somehow mechanistically linked to particular resource use aspects. However that might not be the case even if there is a good correlation between driver and resource use. To really establish a relationship additional information about the mechanism it is necessary.

A third caveat is the poor quality of the resource use data. We might think about the resource use data in EXIOBASE as actual observations, unbiased facts. However most of the resource use extensions in EXIOBASE are results of calculations with models or estimations. It could be that a particular resource use was estimated on the basis of GDP or population. Applying our model, we might “rediscover” some of the underlying estimation methods. Poor quality of the resource use data can also be seen in the strange outliers observed in the resource use trends. Such outliers lead to a low goodness of fit.

A fourth caveat is the dependency of the estimated parameters on the selected time series. In the current approach the time series of 1995 – 2011 is used. Given that most of the resource use trends show an initial increase and then an decrease using a time series from 2000 – 2011 would result in a complete different result.

3.3 Additional bottom-up approach for five metals

The top down approach using EXIOBASE provides estimates of future demand for resources based on past trends in demand. While this approach is quite suitable for flow-based resources, such as food and fossil fuels, it is less adequate for stock-based resources such as can be found in the realm of metals and minerals. These resources typically end up in applications with a considerable life span, and therefore obey to different dynamics than flow-based resources. Often there is a considerable delay between a market change or policy change and the response in society. Stock saturation may occur, which also is not captured by the top-down approach. A third reason for the top-down approach to fall short is the emergence of new technologies that are expected to become quite significant in the future, even under BAU conditions. Renewable energy technologies are a good example of that: presently the share of renewables is still minor, but in the future it will take a considerable amount of resources to build up the energy infrastructure.

In this section therefore, we use a bottom-up approach to estimate future demand for five metals: steel, copper, aluminium, zinc and lead. For these metals, we looked at three major applications: buildings, mobility, and energy. For infrastructure (roads, bridges, fences and suchlike) the information base was insufficient – although probably the information would be available, it would have taken too much time to actually collect these data. For these applications, we used a stock-based approach: estimating the in-use stock and stock changes over time, rather than modelling demand as an independent parameter. The stock refers to the application itself, e.g. the number of vehicles or the amount of dwellings in use. This is then combined with a life span to estimate losses from stock. The inflow into stock, or in other words the demand, is then calculated as the losses from stock (replacement) plus the net addition to stock.

For projections into the future, driving forces must be established as well for the bottom-up approach. If possible, we will use the physical information out of the WLO/NEV scenarios. If not, we will use additional driving forces as specified in Chapter 4.

It should be noted that this bottom-up approach is typically suitable for the consumption system. It can be used to include capital goods as well. This however can be regarded as intermediate consumption rather than as production.

4 Results

4.1 Results of the top-down approach

4.1.1 Resource use related to Dutch final consumption

In Figure Figure 4.1, Figure 4.2, and Figure 4.3 the results of the simple model to extrapolate past resource use trends towards 2030 and 2050 are shown. Figures that include the drivers and model to extrapolate resource use are given in Appendix A.

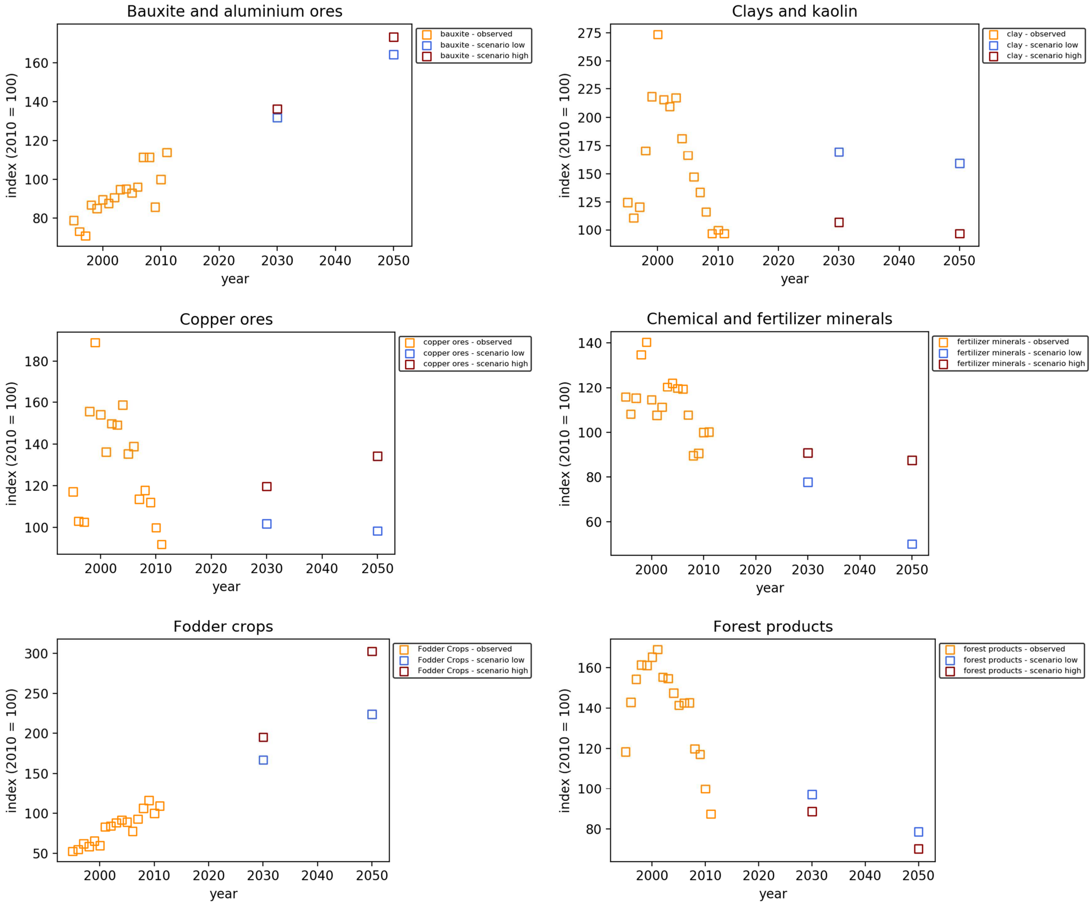
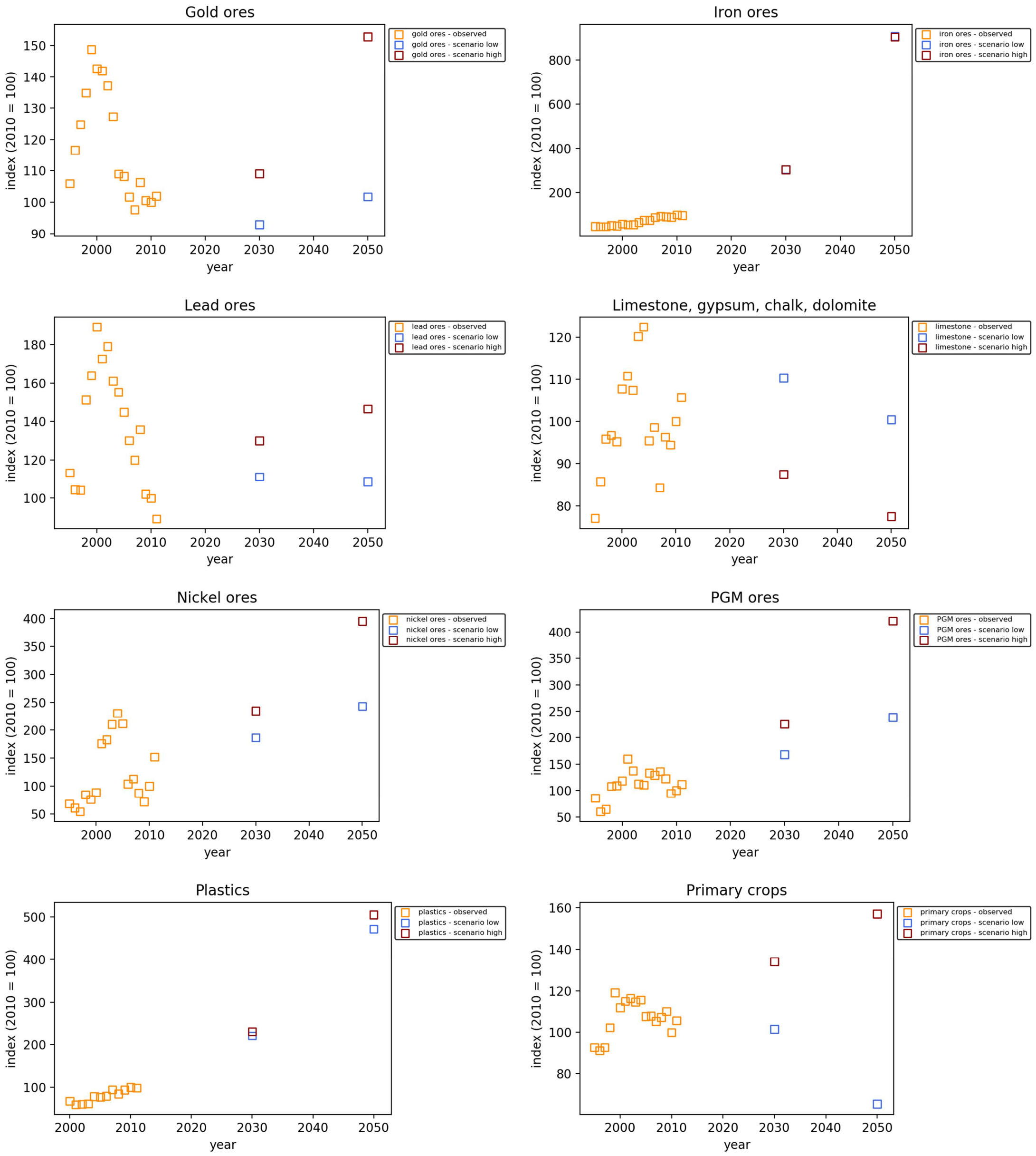


Figure 4.1: Historical trends of resource use related to Dutch final consumption and extrapolations to 2030 and 2050 under scenario low and high assuming a business as usual scenario.



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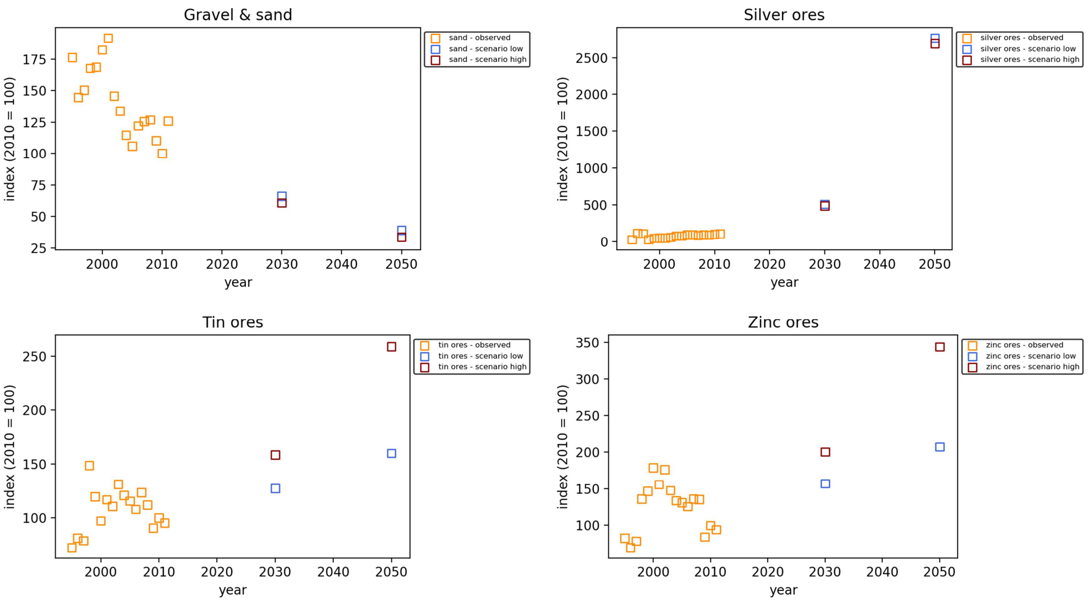

Figure 4.3: Historical trends of resource use related to Dutch final consumption and extrapolations to 2030 and 2050 under scenario low and high assuming a business as usual scenario.

In Table 4.1 below an overview is given of the fitted parameters plus the reduced chi-square value. The reduced chi-square measure can be used as a goodness-of-fit measure. Past trends of resource use that seem to be described correctly by our simple model are indicated by the green background. Correct description was based on the arbitrary criteria of a $\mathrm{X}^2 < 100$ and a positive relationship between driver and resource use ($\alpha > 0$). In Table 4.2 the actual projected values for the resources are shown. Only those resources are projected for which the simple model described past trends in a satisfactory manner are shown.

Table 4.1: Results of fitting the simple model to resource use related to Dutch final demand for the years 1995 – 2011. α, β and γ are the fitted parameter values for the model the reduced chi-square (X^2) measure can be used as goodness-of-fit measure. Green rows indicate a sufficient description of resource use by the simple model. Red rows indicate an insufficient description of the past resource use trend by the model.

Resource	Driver	α	β	γ	reduced. X^2
Primary Crops	population NL	5.48	-502	0.98	62
Fodder Crops	population NL	4.75	-443	1.02	57
Forest Products	new housing NL	-0.20	73	0.97	412
Iron ores	new cars NL	-0.09	2	1.06	29
Copper ores	gdp NL	1.53	-74	0.94	557
Nickel ores	gdp	2.44	-159	0.99	3512
Bauxite and aluminium ores	new cars NL	0.83	-28	1.01	53
Gold ores	gdp NL	0.82	-32	0.96	219
PGM ores	gdp NL	2.92	-211	0.95	431
Silver ores	gdp NL	-1.15	121	1.09	583
Lead ores	new cars NL	1.62	-74	0.94	799
Tin ores	gdp NL	1.58	-90	0.96	383
Zinc ores	new housing NL	2.18	-130	0.95	1086
Limestone, gypsum, chalk, dolomite	new housing NL	-0.54	99	0.99	72
Clays and kaolin	new housing NL	-1.47	271	0.94	2187
Gravel and sand	car kilometer, NL	-0.13	19	0.97	402
Chemical and fertilizer minerals	population NL	2.23	-199	0.97	139
Plastics	gdp, NL	0.53	-55	1.04	35

In general, a poor fit was found between the simple model and the observed resource use trends and drivers. A reduced. X^2 value close to 1 is seen as perfect match between observations and fitted model. Cleary this is not the case. The estimated uncertainty for the α and β parameter, see Appendix A, is often large indicating that the selected driver might not be very well correlated to the observed resource use trends. The γ parameter, a measure for autonomous resource use efficient improvement per year can often established with high certainty.

That the fit is not particularly good is not is not surprising because the year to year resource use tends to show a lot of variation. The inverted U pattern exhibited by the observed data is also difficult to reproduce. The primary crops example shown in Figure 3.1 shows that the model can reproduce an inverted U shape but often not to the full extent shown in the observations. Last but not least, if the observations show a monotonous increase, the parameter fit tends to get uncertain because a postive α value and a $\gamma > 1$ will reproduce the monotonous increase.

For primary crops, fodder crops, bauxite and aluminum ores, chemicals and fertilizer mineral , and plastics the simple model could describe the past trend correctly. For those cases the fitted model was used to extrapolate resource use until 2030 and 2050 given the 2030 and 2050 values for the selected drivers taken from the WLO. Those values are shown in Table 4.2. The resource use efficiency for three of those cases indicate that actually more of the resource is used per Euro final demand.

Table 4.2: Projections of resource use related to Dutch final demand until 2030 and 2030 based on the simple model fitted to past trends. Only those projections are shown for which the model could satisfactory describe resource trends in the years 1995 - 2011.

Resource	Driver	Unit	Scenario	Observed	Projections	
				2010	2030	2050
Primary Crops	population NL	kt[$]	low	42452	43116	28234
			high	42452	56890	89351
Fodder Crops	population NL	kt[$]	low	4955	8280	18511
			high	4955	9672	29287
Bauxite and aluminium ores	new cars NL	kt[#]	low	1296	1708	2808
			high	1296	1766	3062
Chemical and fertilizer minerals	population NL	kt[#]	low	1859	1444	726
			high	1859	1689	1479
Plastics	gdp, NL	kt	low	6696	14779	69794
			high	6696	15487	78308

[$] On dry weight basis

[#] On the basis of ore weight

4.1.2 Resource use related to production in the Netherlands

The past trends in resources used related to production happening in the Netherlands and their extrapolation on the basis of the simple model for the scenario low and high are shown in Figure 4.4, Figure 4.5 and Figure 4.6. Detailed pictures and full regression results are given in Appendix B.

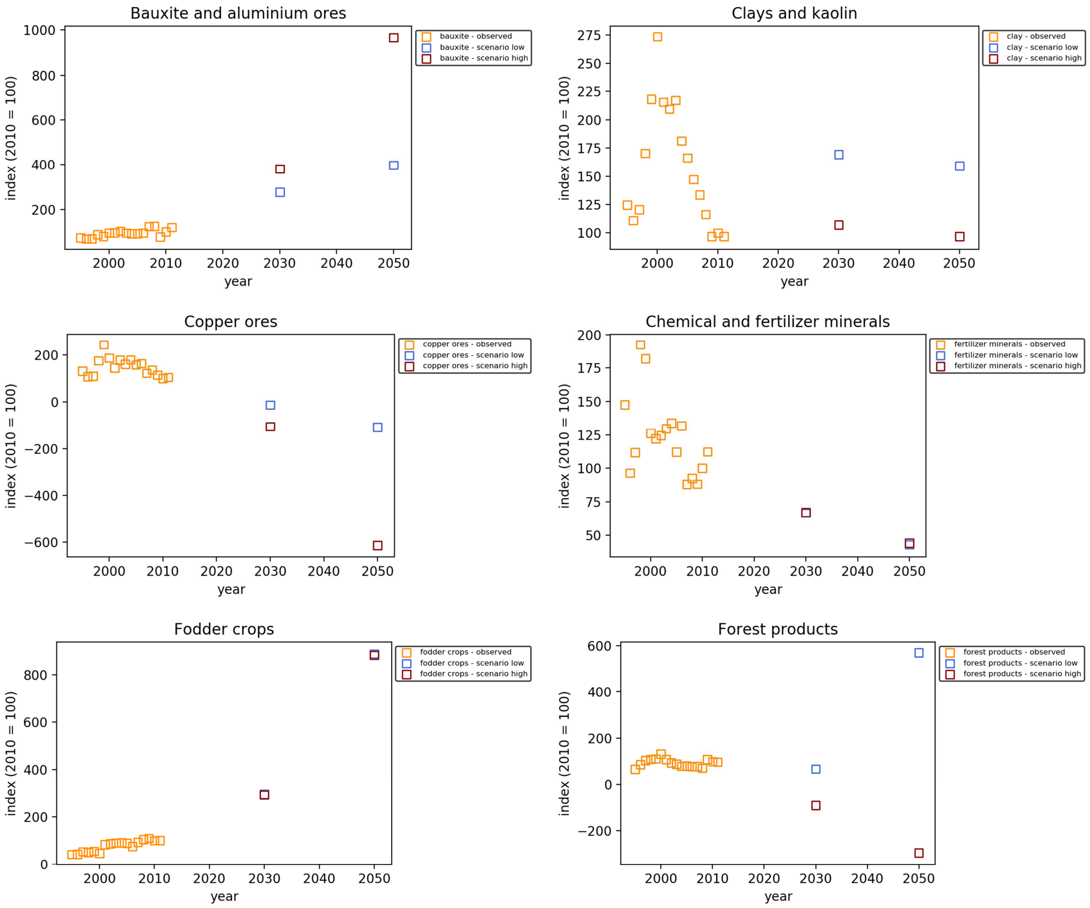

Figure 4.4: Historical trends of resource use related to production in the Netherlands and extrapolations to 2030 and 2050 under scenario low and high assuming a business as usual scenario

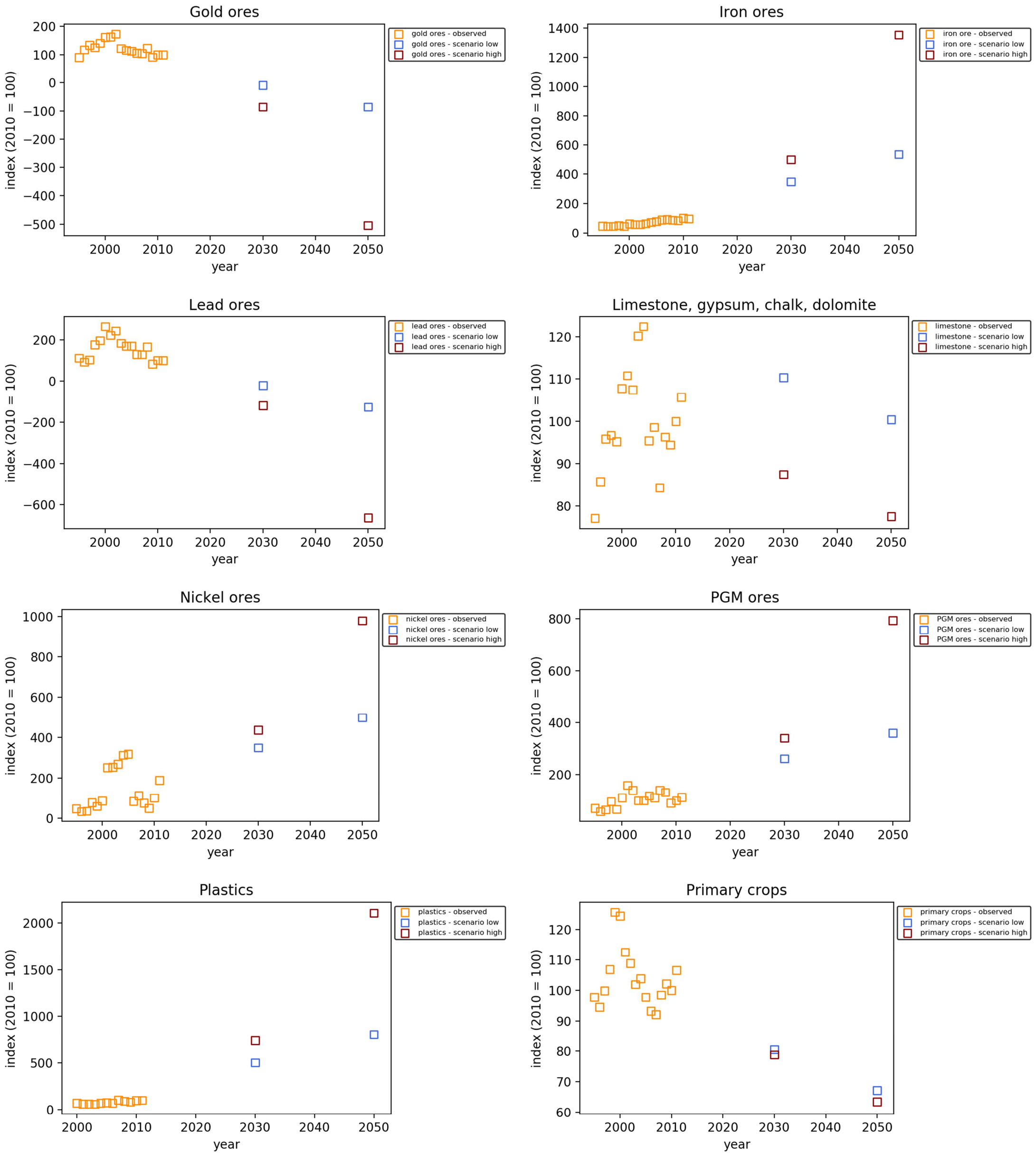

Figure 4.5: Historical trends of resource use related to production in the Netherlands and extrapolations to 2030 and 2050 under scenario low and high assuming a business as usual scenario.

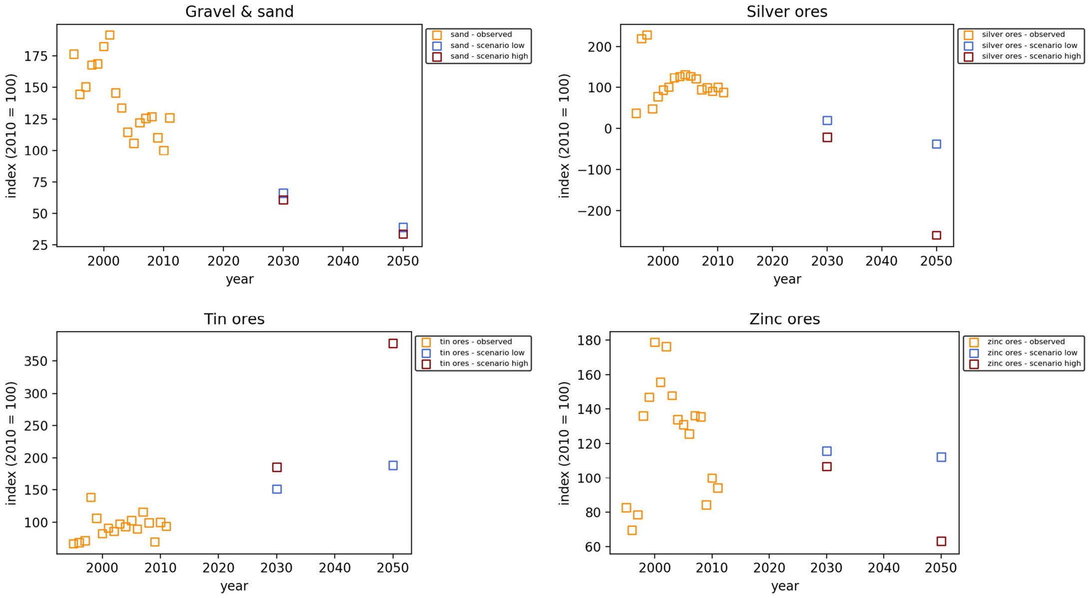

Figure 4.6: Historical trends of resource use related to production in the Netherlands and extrapolations to 2030 and 2050 under scenario low and high assuming a business as usual scenario.

In Table 4.3 below an overview is given of the fitted parameters plus the reduced chi-square value. The reduced chi-square measure can be used as a goodness-of-fit measure. Past trends of resource use that seem to be described correctly by our simple model are indicated by the green background. Correct description was based on the arbitrary criteria of a $\mathrm{X}^2 < 100$ and a positive relationship between driver and resource use ($\alpha > 0$). In Table 4.4 the actual projected values for the resources are shown. Only those resources are projected for which the simple model described past trends in a satisfactory manner are shown.

Table 4.3: Results of fitting the simple model to resource use related to production in the Netherlands for the years 1995 – 2011. α, β and γ are the fitted parameter values for the model the reduced chi-square (X^2) measure can be used as goodness-of-fit measure. Green rows indicate a sufficient description of resource use by driver. Red rows indicate an insufficient description of the past resource use trend by the driver.

Resource	Driver	α	β	γ	reduced. X^2
Primary Crops	crop area, NL	0.88	-76	0.99	88
Fodder Crops	crop area, NL	1.30	-120	1.06	110
Forest Products	gdp, glo	-2.33	183	1.05	301
Iron ores	gdp, glo	2.20	-144	0.94	17
Copper ores	gdp, glo	-1.36	122	1.01	1484
Nickel ores	gdp, glo	1.29	-24	1.02	11473
Bauxite and aluminium ores	gdp, glo	1.53	-96	0.98	155
Gold ores	gdp, glo	-1.13	120	1.01	599
PGM ores	gdp, glo	1.16	-62	1.00	715
Silver ores	gdp, glo	-0.60	128	0.99	2683
Lead ores	gdp, glo	-1.45	158	1.01	3257
Tin ores	gdp, glo	0.51	-13	0.99	370
Zinc ores	gdp, glo	-0.13	50	1.00	1296
Limestone, gypsum, chalk, dolomite	new housing, NL	-0.54	99	0.99	72
Clays and kaolin	new housing, NL	-1.47	271	0.94	2187
Gravel and sand	new housing, NL	-0.13	19	0.97	402
Chemical and fertilizer minerals	crop area, NL	-0.27	27	0.98	736
Plastics	gdp, glo	3.49	-266	0.86	36

The resource use trends related to production happening in the Nethelands is described worse than the resource use trends related to Dutch final consumption. In general higher reduced X^2 values are found. Only for primary crops, iron ores and plastics the past resource trends are satisfactorily described. Using the fitted model the projected resource use related to production in the Netherlands are shown in Table 4.4.

The projections would mean that iron ore use would increase a factor 12 in the scenario high and plastic use a factor 20. These seem unrealistic high estimates but are correct given the past trends. Both iron ore use and plastics show a strong monotonous increase in the past. Their use increased 2 – 3 times as fast as global GDP. Even an linear extrapolation of this trend based on global GDP growth would entail a factor 10 increase. In Appendix B it can be seen that the parameter values were fitted with high confidence. In the end the BAU scenario does not contain considerations about limited production expansion capabilities but is just an extrapolation of what has happened in the past. In this case this indeed means in the scenario high an enormous expansion of iron ore use and plastic use related to production.

Table 4.4: Projections of resource use related to production in the Netherlands until 2030 and 2030 based on the simple model fitted to past trends. Only those projections are shown for which the model could satisfactory describe resource trends in the years 1995 - 2011.

Resource	Driver	Unit	Scenario	Observed	Projections	
				2010	2030	2050
Primary Crops	crop area, NL	kt[$]	low	72299	58216	39069
			high	72299	56970	36096
Iron ores	gdp, glo	kt[#]	low	15389	53534	286187
			high	15389	76563	1036615
Plastics	gdp, glo	kt	low	13134	66234	533666
			high	13134	97353	2047274

[$] On dry weight basis

[#] On the basis of ore weight

4.2 Results of the bottom-up approach

In this section we provide results for a bottom-up approach to forecast resource use. As mentioned, we address five metals (steel, aluminium, copper, zinc and lead) and three categories of applications (residential buildings, mobility and electricity generation).

4.2.1 Residential buildings

The WLO documents contain some, but not much, information on buildings. The information in confined to residential buildings. We included commercial buildings simply by multiplying the data on residential buildings with a factor 2.

The WLO specifies the number of dwellings to be built, according to current plans, until 2025. That time horizon is too short for the present endeavour, and moreover, is probably an underestimation since it does not allow for new plans to be made. Instead of these data, we used the number of households provided by the WLO scenarios as a starting point, and we used those as a scaling factor for the amount of dwellings that have been constructed annually in the period 2000-2011. Numbers therefore represent net inflows or stock changes, not gross inflows. This means we did not take demolition into account, and therefore we were unable to fully account for stock dynamics. The outcomes of this exercise therefore are an underestimation of the demand.

The number of newly built houses is one half of the puzzle. The other half is the material content of those houses. Data are scarce in this area; there are some scattered studies representing different types of houses in different places in the world. It is also apparent that not all houses are equal in that respect.

Lacking a solid database, we nevertheless used a rough estimate of material content of dwellings, such as provided by the PUMA project (Koutamanis et al., 2017). We used the averages they provide for steel, aluminium, copper and zinc. For lead, an estimate is missing. To estimate lead flows, we used an estimate from Elshkaki et al. (2004), related to the total inflow of lead into Dutch houses. To estimate future demand, we scaled this number, likewise, with the development in the number of households.

4.2.2 Mobility

Here, the WLO scenarios provide a lot of very specific information, that could be used directly. Data on cars include the car fleet developments, but also the share of electric and semi-electric vehicles, and the amount of person kilometers driven. For road transport, no such detailed data are available but there is an estimate of the kilometers driven. This was used as a scaling factor to make estimates of the metals in road transport. For air travel, there is data on “vliegbewegingen” related to Schiphol, and on airplanes in Dutch possession. For air transport it is difficult to allocate the material use to a country. We did this by using the airplane possession data (119 planes owned by KLM), scaling that up by the scenario data on passengers transported in the future. For air travel, we made calculations only for aluminium, as this is the main material used in aircrafts.

Material content data we scraped together from various (sometimes informal) sources, that are specified in Appendix D.

We calculated inflows based on stock dynamics, assuming an average life span for cars of 15 years and for aircraft of 40 years.

Transport by ship has not been included. Material contents of ships are not readily available and it would take up too much time to collect them in this project.

4.2.3 Energy

The energy system will go through considerable changes. As agreed on, we did not use WLO scenarios but NEV scenarios for the electricity mix as this better represents BAU assumptions. Already in the BAU, we see a considerable penetration of renewable energy technologies. NEV projections only go to 2035, so we were able to use them only for the 2030 estimates. The 2050 estimates are our own, roughly continuing the 2010-2030 trends. Data on metals used for the different feedstocks have been taken from the Ecoinvent database, a standard database used for LCA assessments, and are expressed in kg material / kWh electricity generated, which we multiplied by the amount of kWh generated according to the different electricity generating technologies. Note that these are cradle-to-gate data related to electricity production, and therefore represent more than the materials actually ending up in the electricity infrastructure. We did not attempt to correct for that, and assume that for the metals included in the assessment, the difference will not be too large. But it leads to a certain overestimation.

4.2.4 The result of the bottom-up estimates for the five metals

The results for the five metals is presented below. Detailed assumptions can be found in Appendix D.

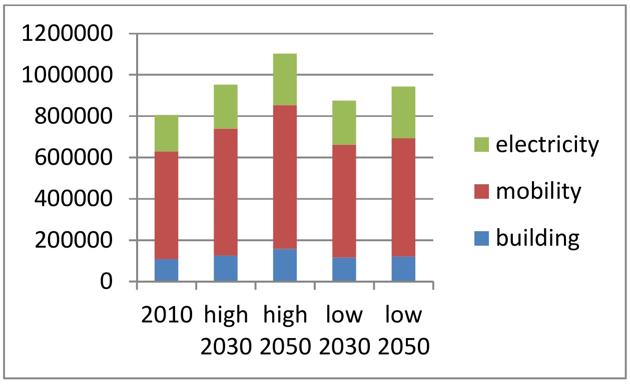

Figure 4.7 Bottom up estimated steel demand related to building, mobility and electricity (ton steel / year) for the present and for 2030 and 2050 under the WLO high and low scenarios

Although the stock in buildings is highest, the flows are higher for mobility. This is due to the very long lifespan of buildings. Steel demand will rise substantially according to these estimations.

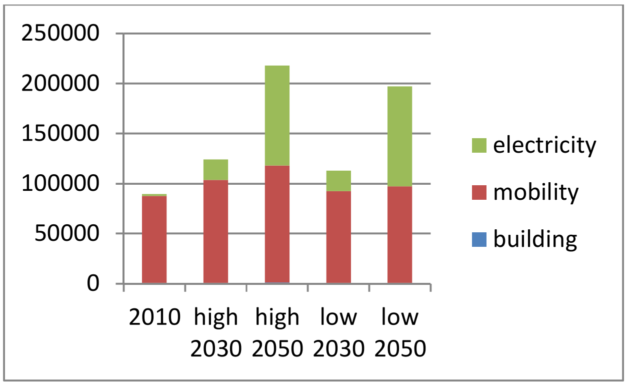

Figure 4.8 Bottom up estimated aluminium demand related to building, mobility and electricity (ton Al / year) for the present and for 2030 and 2050 under the WLO high and low scenarios

For aluminium, a large growth is expected, mainly due to the energy transition, as the aluminium intensity of particularly solar power is high. Even under the low WLO scenario aluminium demand is expected to more than double between 2010 and 2050. This represents a clear trade-off between the energy transition and the circular economy transition.

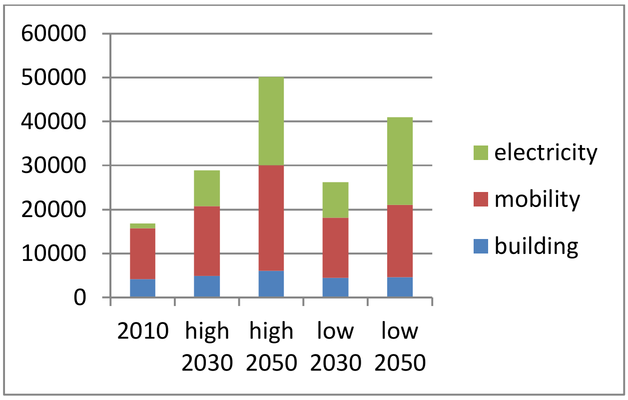

Figure 4.9 Bottom up estimated copper demand related to building, mobility and electricity (ton Cu / year) for the present and for 2030 and 2050 under the WLO high and low scenarios

As for steel, we see that also for copper the largest demand flows are related to mobility, although stocks are largest in the built environment. Due to the electrification of the car fleet, the copper demand for mobility will grow significantly especially in the high WLO scenario. The use of copper for electricity will grow likewise as a result of the transition towards a larger share of renewables.

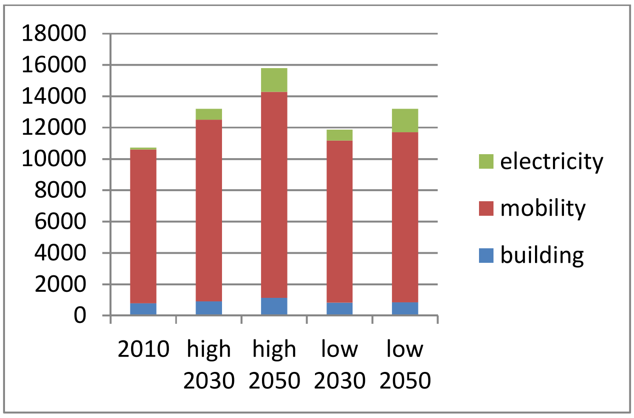

Figure 4.10 Bottom up estimated zinc demand related to building, mobility and electricity (ton Zn / year) for the present and for 2030 and 2050 under the WLO high and low scenarios

For zinc, too, mobility provides the largest share. Zinc in automotive is mainly related to coating of steel. In buildings applications are related to roofing and gutters. The life span of these applications is usually lower than that of buildings. This is not taken into account, therefore, the zinc demand for buildings is substantially underestimated.

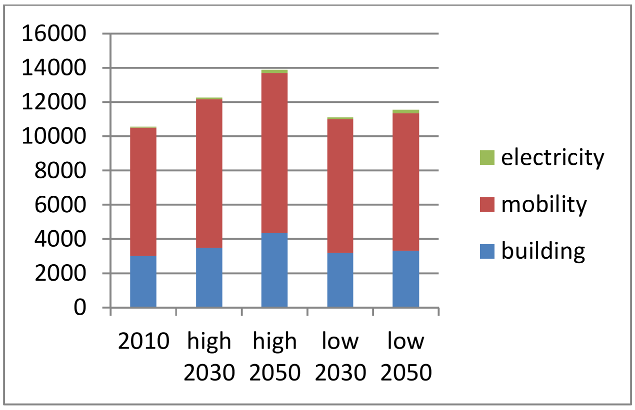

Figure 4.11 Bottom up estimated lead demand related to building, mobility and electricity (ton Pb / year) for the present and for 2030 and 2050 under the WLO high and low scenarios

Most important use, again, is mobility. Conventional cars usually have lead acid batteries, which is responsible for the majority of the demand in that category. The share of these batteries will go down as a result of a larger share of electric and semi-electric vehicles, but the conventional car fleet is also still expected to grow.

Overall, we can conclude that according to these bottom-up calculations, mobility is the most important category for metal demand although the largest share of the stock for the majority of these metals is the built environment. Unfortunately we were unable to include infrastructure which may be important especially for steel and copper. Electricity generation is responsible for the largest expected future growth, especially for copper and aluminium. For zinc, but especially for lead, the energy system is relatively unimportant.

4.3 Comparing results of top-down and bottom up approaches for five metals

4.3.1 Estimates of the present demand for the five metals

A comparison of the bottom-up and the top-down approach with regard to the three main applications involved in the bottom-up calculations is presented below.

Table 4.3 Demand for metals in construction in tonnes / year, top-down vs bottom-up approach

	Top down, 2011	Bottom up, 2010	Difference factor
aluminium	41654	782	53
steel	708346	108327	7
copper	8994	4213	2
lead	5799	3000	2
zinc	1244	782	2

The top-down estimates for metal demand related to building are consistently higher for the top-down approach. The factor 2 difference for copper, lead and zinc are not surprising, as the top-down estimate also includes infrastructure, which is left out of the bottom up approach due to lack of data. The factor 7 difference for steel is unexpectedly high and cannot be explained very easily. The factor 53 for aluminium is really worrying and leads to suspect data errors. One error may be the estimate for the aluminium intensity of buildings used in the bottom-up approach. This estimate (6.5 kg Al per dwelling, from the PUMA project) is really very low compared to other literature sources. But even if this would be an order of magnitude higher, still the difference between top-down and bottom-up estimates would be very large.

Table 4.4 Demand for metals in mobility in tonnes / year, top-down vs bottom-up approach

	Top-down, 2011	Bottom-up, 2010	difference factor
aluminium	19520	86930	0.22
steel	458883	519792	0.88
copper	3064	11551	0.27
zinc	2444	9818	0.25
lead	506	7508	0.07

For mobility, the bottom-up estimates are invariably higher than the top-down ones. For steel and zinc, the estimates are not too far off, but for the other metals, especially lead, the difference is large. An explanation that may be reasonable is that the top-down estimates are not representing the high metal intensity of the sector. The fact that EXIOBASE represents pathways of materials based on monetary information, not in physical information, may be the reason for the difference. In this case, the bottom-up estimates are probably better as they are based on physical information. The estimate for lead is illustrative for that: bottom-up it is based on the weight of a lead acid battery, which is present in the vast majority of cars, and can therefore be expected to be reasonably accurate. The top-down estimate on the other hand is based on a distribution over the different sectors of the “non-ferrous metals” category, of which lead only constitutes a small part and does not represent a lot of the value.

Table 4.5 Demand for metals in electricity generation in tonnes / year, top-down vs bottom-up approach

	Top-down, 2011	Bottom-up, 2010	Difference factor
aluminium	489	2000	0.24
steel	14102	177848	0.08
copper	122	1097	0.11
zinc	220	126	1.75
lead	48	55	0.88

Again we see considerable differences between the top-down and bottom-up estimates, and generally (excepting zinc) higher estimates for bottom-up. Especially for steel and copper, bottom-up estimates are an order of magnitude higher than top-down ones. This may again be due to the lack of detail and technological specificity in the top-down approach.

While using the bottom-up approach mobility represents the largest demand for metals, in the top-down approach this is construction.

4.3.2 Comparison of future trends

The growth rate of the metals is generally higher in the bottom-up estimates, compared to top-down.

For iron and steel, the growth until 2050 compared to 2010 in the top-down analysis is absent (low scenario) or about 25% (high scenario). For the bottom-up approach, this is 17% for the low scenario and double that for the high scenario. For the other metals, differences are even larger. Aluminium demand grows modestly in the top-down approach (15% and 25% respectively), while in the bottom-up approach it more than doubles even for the low scenario. Copper and lead show a zero growth in the top-down approach. For lead, the growth is modest also in the bottom-up approach (10% and 30%, respectively) but copper demand more than doubles for the low scenario and even triples for the high scenario. Zinc is the only metal where the top-down approach actually shows a higher growth than the bottom-up approach.

These differences are considerable. They lead to a need for a careful consideration about the model to select for such forecasts. For these metal resources, we presume the bottom-up approach to provide better projections, especially in combination with already quite detailed explorations of the WLO and NEV scenarios. For other types of resources, we may not want to lose the comprehensive nature of the top-down approach.

5 Discussion, conclusion, recommendations

In this section we draw conclusions from the results displayed in Chapter 4, and add a reflection as well as some options for improvement to better support the Dutch circular economy policy.

5.1 Scenario outcomes

For those resources that reasonably could be analysed with the top-down method. i.e. primary crops, fodder crops, iron ores, bauxite and aluminium ores, chemical and fertilizer ores, and plastics, the resouce use until 2050 either from a final consumption point of view or production point of view will grow considerably in a BAU scenario.

For the minor metals that could not properly be analysed with the top-down approach, the bottom-up apporach similarly indicates that demand is still increasing and is expected to grow considerably until 2050.

There are clear differences between the high and low WLO scenarios, mostly due to the expectations with regard to the population and the number of households. Categories where we can expect the highest growth without any additional policies are plastics, and most of the metals. The increase in plastics use is, most likely, connected to increased consumption in general, as plastics are used in almost all consumption categories. For metals (mainly Al and Cu) we can expect a particularly high growth related to the increase of renewable energy systems that need to be built up, as well as the increased share of electric vehicles. Such growth will be with us for the next decades, but can be expected to slow down when the energy transition is complete.

The demand for food and fodder crops is expected to grow in the high WLO scenario, but decline in the low WLO scenario, as a consequence of the demographics in both scenarios. For construction materials, including wood, the results of our exercise do not show growth at all. In these cases, the data may be insufficient to allow for forecasting (see Section 5.2). Nevertheless it is entirely possible that resource use for Dutch construction and infrastructure will not grow a lot, especially under the low WLO scenario.

The above conclusions refer to the consumption based system. With regard to the production based system, we did come up with projections but very much doubt whether these make sense. For some resources, this may be the case: for construction minerals we expect production not to be very different from consumption, and for agricultural production we rely very much on the assumptions already made in the WLO scenarios. For metals however we observe that there is only a few producers that may or may not take their business elsewhere, with hardly any consequence for global markets or for consumption in the Netherlands. That makes it extremely difficult, if not impossible, to come up with reasonable forecasts.

These outcomes are input for a circular economy policy. The estimation of future demand is an essential first step, however, more information is needed to support a circular economy. In order to assess the “policy challenge” we must have information not just on demand, but also on supply: to what extent is the present demand fulfilled by secondary production, and to what extent could it be? This is a next step that requires additional data and analyses. While it may never be possible for the Netherlands, with its open economy, to close its own cycles, it might be relevant to monitor the balance. In order to do that, we need to extend our knowledge of the urban mine and the waste streams, or potential secondary materials, that come out of that.

A first relevant piece of information at the level of the individual resources is, whether demand is expected to rise, to remain stable or even to go down. In a stabilized or declining situation, it is much less difficult to move towards a closed loop system than in a situation of growth. For resources with a growing use it will take longer, and if growth is exponential circularity will not be possible at all. In the table below, we summarise the expectations per resource type.

Expected developments in demand for resources, consumption based system, in qualitative terms

	Low scenario	High scenario
Primary Crops	Decline, considerable	Growth, considerable
Fodder Crops	Growth, slight	Growth, rapid
Forest Products	Decline, rapid	Decline, rapid
Aluminium*	Growth, rapid	Growth, rapid
Iron / steel*	Growth, slight	Growth, considerable
Copper*	Growth, considerable	Growth, rapid
Lead*	Growth, slight	Growth, slight
Zinc*	Growth, slight	Growth, considerable
Nickel	Growth, considerable	Growth, rapid
Tin	Growth, rapid	Growth, rapid
Gold	Decline, slight	Decline, rapid
PGM	Growth, considerable	Growth, rapid
Silver	Growth, rapid	Growth, rapid
Limestone, gypsum, chalk, dolomite	Decline, considerable	Decline, considerable
Clays and kaolin	Decline, considerable	Decline, considerable
Gravel and sand	Decline, considerable	Decline, considerable
Chemical and fertilizer minerals	Decline, considerable	Decline, considerable
Plastics	Growth, rapid	Growth, rapid

*taken from the bottom-up results in Section 4.2

Rapid or considerable growth is expected for several of the metals and for plastics. For the metals this is due to expected growth in especially transport and energy applications. For plastics it is probably an increase in all consumer related applications.

A decline is expected for forest products, for chemical and fertilizer minerals and for construction minerals. For fertilisers this is the result of expected continued efficiency improvements in agricultural practice. For forest products and construction minerals it is less clear. In view of the reasonably mature state of the Dutch infrastructure and built environment, it is understandable that a stabilization would take place. But a considerable decline is unexpected. In the sections below, we discuss the robustness of these results.

5.2 Data issues

Uncertainties in the outcomes can always be expected. Some originate from the data we used. In our top-down approach, we have chosen to use as few different data sources as possible, to at least keep a consistent and transparent data system. The data sources we used were the following:

- The EXIOBASE environmentally extended input-output tables, in time series 1995 – 2011
- Additional data sources esp. for past time series of the driving forces, as specified in Chapter 3
- WLO and NEV scenarios for the future developments of the driving forces.

For the bottom-up approach, we used WLO and NEV scenarios as well, and a variety of other data sources especially related to the metal content of the applications we included. Here we worked with what we could find.

The WLO and NEV scenarios were very helpful in many respects. It saved us from having to make assumptions on driving forces in several instances. The WLO scenarios were also a good basis for the bottom-up calculations. Especially the data on mobility are excellent and could be used as they are. Data on future construction could have been included more in the WLO reporting. Also missing are bottom-up stock data, for example on number of buildings or square meters of area per capita. Likewise, data on infrastructural works were missing and it would seem possible to include those in the WLO forecasts. For the energy system we used NEV data. These data had a sufficient resolution for our purposes. The largest difficulty here was the limited time horizon: only up to 2035.

In some instances we found unexplained differences in WLO data compared to other sources, for example, the GDP data did not match those of the CBS. The crop area values in the WLOs had an unexplained difference of a about a factor 100 which suggests a unit problem.

EXIOBASE is a worldwide trade-linked EE-IO model distinghuising 49 countries/regions and 200 product groups within each country/region. We were able to use this database, together with information on driving forces, for the purpose of projecting. Some issues that limit the value of our projections:

- Time series are quite short. An update is expected until 2015, providing time series data over 20 years. This is still not much for establishing correlations with a driving force. Expanding into the past would be useful.
- Resource extractions for a number of resources are included in EXIOBASE as extensions. EXIOBASE then distributes these over the different sectors and different countries based on monetary relations. The level of detail is good for fossil fuels and biomass. For metals, the extractions and especially the distribution within the system are not detailed enough to allow for sufficient quality of the projections. “Intermediate” materials such as plastics and concrete are difficult to assess at all. These materials do not represent extractions. We used the “Rubber and plastics” product group output as a proxy for the use of plastics but that may not cover all plastics used.

- Information on the end-of-life stage of the the production-consumption chains is missing to a large extent. This will provide major challenges when attempting to assess circular economy policies.

The calculated resource use related to Dutch final demand and production in the Netherlands almost always shows and inverted U pattern. This is even seen in non-related categories such as primary crops and “clays and clay minerals”. The question arises if this observed trend is real or that it is an artefact introduced by the way EXIOBASE has been build.

The Netherlands is one of the few countries in the world where the size of the trade and especially transit trade flows are large compared to domestic production and consumption. If transit trade is not properly corrected for, footprints calculated for the Netherlands may become distorted. Especially for resources that are exclusively mined outside the Netherlands and must be imported either directly or embedded in products.

A further complication when building a multi-regional input-output model like EXIOBASE is the low quality of trade data. What is reported as export by one country is not matched by the import values of its trading partner. These import and export data must be reconciled when making a multi-regional input-output model. This means that changes must be made to the original trade data. It also means that the import data for the Netherlands with its relatively open economy might be particularly affected.

We checked in how far imports in EXIOABASE v3.3 are consistent with the national import statistics available at CBS. The comparison is shown in Figure 5.1. The EXIOBASE and official statistics compare very well. The EXIOBASE import data see a somewhat more prominent increase in the years 1995 – 2000 and the CBS data show a somewhat more prominent decrease around the financial crisis of 2008 but the overall trend is very similar. The increase in imports in the period 1995 – 2000 likely also explains the increased resource use trends visible in most of the data. Thus the EXIOBASE inverted U resource use trends cannot simply be attributed to uncertain data. For a better understanding of the drivers of resource use trends it is advised to further look at the supply chains breaking down imports into individual product groups and the contribtion of those imported products to resource use.

Moreover if it is necessary to get an as accurate picture of the Dutch economy as possible, EXIOBASE might be tweaked such that the official Dutch statistics are recreated and the reconcilation of trade data of the Netherlands with its trading partners is done by changing the values for the trading partners and not the values reported by the Dutch national statistical agency. A so-called SNAC approach (Hoekstra et al., 2013)

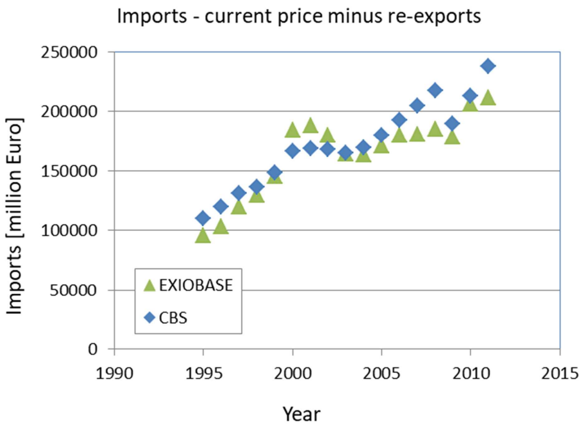

Figure 5.1: Development of imports minus re-exports in the Netherlands from 1995 – 2011. Data as contained in EXIOBASE v 3.3 and data from CBS.

Another way of working with uncertain footprint data is to disregard the historical trend information as being too uncertain. Instead one could use the historical data to calculate an average coefficient between resource use and driver and use that coefficient to extrapolate into the future. This procedure critically depends on the correct identification of the dominant driver. The correctness of the driver cannot be established empirically in this method.

This simplified method can be tested for the some of the resources where a good relationship was established between resource use and driver. It's advised to investigate further this simplified method as it might circumvent some of the data problems that now prevents the use of the linear regression and extrapolation method.

For the bottom-up calculations, especially the material content data are very uncertain. Data collection in this area is, at a global scale, just starting up. First attempts to cover this gap focus mostly on critical materials in electronics. Major metals and major applications such as the built environment are even more scarcely investigated. On this topic, much still needs to be done.

5.3 The modelling approach

The top-down approach

Obviously, the top-down approach designed is a first attempt. Using the simple model, it proved to be possible to generate statistical meaningful extrapolations for 5 resources out of the 18. For the other resources no good fit could be established between model and resouces use. Yet the negative results also provides valuable insights into the problems related creating resource use scenarios.

The search for driving forces is very important, especially for a BAU scenario. Our “best” forecasts are the ones where we were able to avoid using driving forces at all because we could use information from the WLO scenarios directly (like for P use). But these are exceptions; in most cases driving forces will be needed. This needs much more research: what variables are potential candidates, besides the obvious population and GDP? How can we include technology development, and how behavioural change? Or more in general, deviations from the developments of the past? We used proxies rather than drivers in some cases, where we weren’t able to establish good correlations with our supposed driving forces. Whether such proxies are also applicable for forecasting is a bit doubtful. Also, we need to get the statistics right.

For non-BAU scenarios it is much easier: those can be “what-if” scenarios used to test the relevance of certain policy measures. Would it be possible to close cycles? When can we expect such measures to lead to the wished-for results? After such an exploration the next step is to design actual policy measures to implement what is wanted. Such implementation scenarios are yet again different: the effectiveness, uptake rates and market consequences of such measures need to be part of the modelling environment. Here, too, many models lack sophistication, even the widely used ones.

In several cases, maybe in many cases, a bottom-up modelling would lead to more detailed information that can be used better in a circular economy modelling context than a top-down approach. We discuss the pros and cons of both approaches below, as this seems to be a very important issue.

Top-down vs bottom-up modelling

In making forecasts, we used the top-down approach for a number of reasons:

- A top-down approach using EXIOBASE, an input output table covering the whole Dutch economy, guarantees a comprehensive approach wherein economy-wide impacts of changes in any sector are included as a matter of course
- A top-down approach like this one links best with existing approaches and inventories like economic modelling and reporting, material flow accounts, and the CBS-based Materialenmonitor
- A top-down approach like this allows for statistical analysis of driving forces and can be linked to standard ways of uncertainty analysis.

The top-down approach is expected to work well for resources that show a behaviour that matches the flow-oriented, economics oriented models we used. Food products could be examples: their demand is directly related to driving forces such as population (more people, more food) and income (higher GDP/capita, more “luxury” foods). The same top-down approach is expected to be less adequate for resources that are linked to long life span applications, the stock-driven applications. Typical examples of these are related to buildings and different types of infrastructure, household appliances, and in the mobility system. Such applications usually involve metals and minerals, durable materials well known for their lengthy life span. For such applications we know that:

- Past trends need not be representative for future trends
- Driving forces apply to stocks, not flows
- Stock saturation may occur, decoupling material demand altogether from welfare growth
- Long delays may occur between inflow (demand) and outflow (waste generated).

We assessed for five metals and three applications whether a bottom-up stock-based approach would lead to different results from a top-down approach. Our findings were the following:

- Estimates for the present demand are already quite different. The level of detail in the economic system as far as specific product categories and materials are involved is so high that even EXIOBASE does not cover that. The distribution of resource flows over the different end-use categories on a monetary basis is for these metals less than adequate.
- Future trends also are quite different. Reasons for this appear to be twofold: (1) the absence of stock dynamics in the top-down approach, and (2) the difficulty in including technology specific changes in trends such as expected to occur in the energy system.

From this exercise, we conclude that a bottom-up approach is indicated for stock-driven applications. Such an approach is more data intensive than a top-down approach, and there may be difficulties in making such an approach consistent across the economic system. On the other hand it most likely leads to better results and allows for more flexibility to include future developments. And it offers better openings for modelling circular economy policy options, since not only demand but also outflow out of stock is generated by such a model.

Since both approaches have their strong points and limitations, we recommend to the following:

- Include bottom-up information on durable applications in the resource information system that is being / will be developed to support resource policies. In this respect, the urban mining studies popping up here and there provide valuable information
- Integrate top-down and bottom-up approaches in one comprehensive decision support system, so as to retain the value of both
- Try to establish a modelling link between bottom-up and top-down data and approaches to enable sophisticated scenario analyses with regard to resource use and circularity.

5.4 Towards a scenario activity to support the Dutch circular economy policy

This report is a first attempt at making projections for resource demand in the Netherlands, which is an essential piece of information for a resource oriented policy such as a circular economy policy. An approach has been developed which in principle works and can be used. In some respects, improvement is needed to arrive at robust results, as discussed in the previous sections. In summary, these are:

- Development of a good approach to define and include driving forces for resource use
- Supplement the top-down approach with a bottom-up approach at least for metal and mineral resources

- Integrate top-down and bottom-up approaches into one comprehensive modelling environment
- Expand the Materialenmonitor time series into the past as well as the future, so these data, that are more tailored to represent the Dutch situation, can be used instead of EXIOBASE
- Report on additional developments in the, otherwise very useful, WLO scenarios, such as related to construction and infrastructure, in physical terms
- Collect data on the material content of the major applications of the resources.

Having said all this, we have to acknowledge that developing BAU resource demand scenarios is only a first step Further steps in the whole process are:

- Expanding the modelling framework to enable the assessment of circular economy policy options. The most important aspect that is missing right now is the back-end of the production-consumption chain: waste generation. Waste is the food for a circular economy. To take this up into the modelling framework we need to:
    - Upgrade the database on waste generation and waste management for the Dutch situation, by type of waste, and for time series into the past. The top-down approach presently is not able to detect secondary production, as the resource extensions in input output models such as EXIOBASE and the Materialenmonitor only refer to primary extraction.
    - Build up the model in a bottom-up way, including stocks and stock dynamics, to estimate (future) waste flows from past inflows. This is essential to enable carrying outflow projections into the future. Building up a database of the Dutch urban mine is needed for forecasting not only demand, but also the potential supply of secondary resources.
- Developing storylines for circular economy scenarios and translating those into modelling variables. In the end, we want to establish
    - Which part of Dutch demand can be eliminated by lengthening the life span of the applications through reuse, repair, refurbishing and remanufacturing
    - Which part of the Dutch resource use can be met by secondary production by boosting recycling
- Assessing these scenarios on their impacts on the variables a circular economy wants to address:
    - Benefits in demand reduction for primary resources
    - Benefits in reducing waste that cannot be put to use again
    - Benefits OR drawbacks in the area of environmental impacts related to resource extraction and use
- Identifying changes that need to be made in society to actually realise these benefits in terms of industrial activity, consumer behaviour etc., and identifying policy instruments to implement such changes in society. These then, again, must be translated into modelling.

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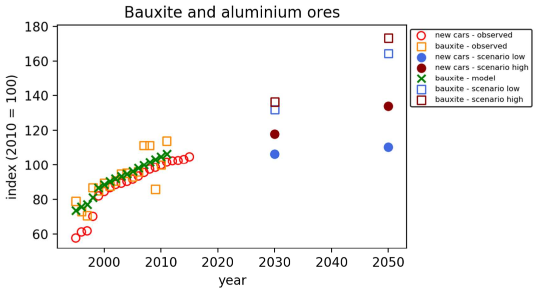
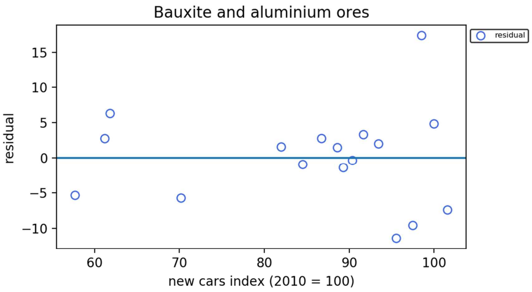
7 Appendices

Appendix A: Resource use related to Dutch final demand

Bauxite and aluminium ores

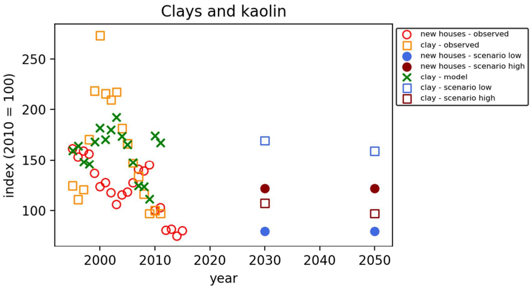
Parameter	Value
reduced chi-square	52.9
Akaike info crit	70.2
Bayesian info crit	72.7
alpha	0.38 +/- 0.33
beta	-28 +/- 22
gamma	1.01 +/- 0.01

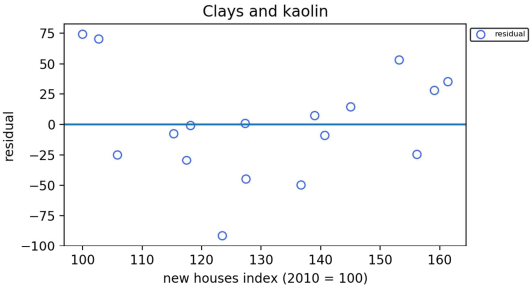




Clays and clay minerals

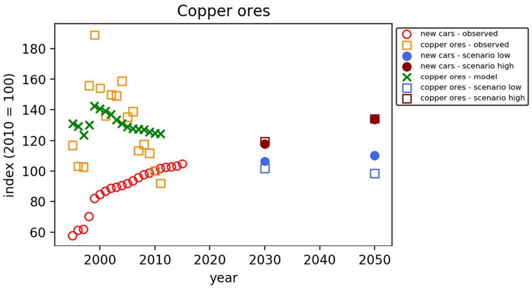
Parameter	Value
reduced chi-square	2187.1
Akaike info crit	133.4
Bayesian info crit	135.9
alpha	1.47 +/- 0.83
beta	271 +/- 137
gamma	0.94 +/- 0.07

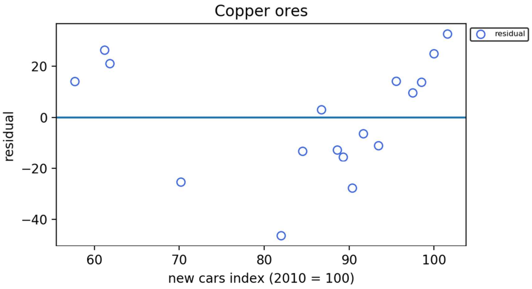




Copper ores

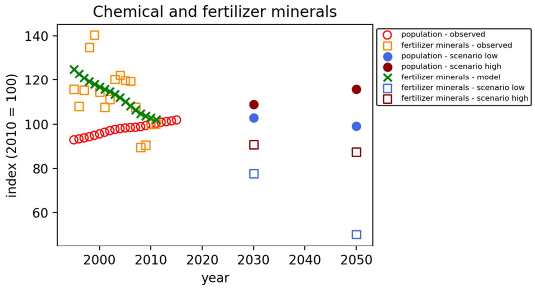
Parameter	Value
reduced chi-square	556.5
Akaike info crit	110.2
Bayesian info crit	112.7
alpha	1.53 +/- 2.21
beta	-74 +/- 121
gamma	0.94 +/- 0.13

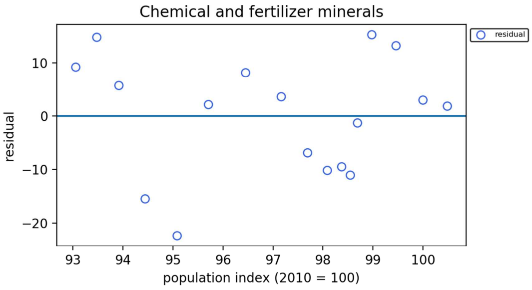




Chemical and fertilizer minerals

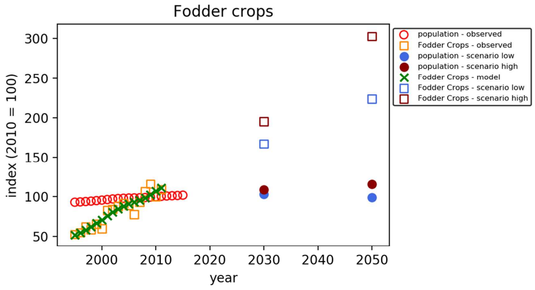
Parameter	Value
reduced chi-square	138.7
Akaike info crit	86.5
Bayesian info crit	89
alpha	2.23 +/- 12.53
beta	-199 +/- 1163
gamma	0.97 +/- 0.07

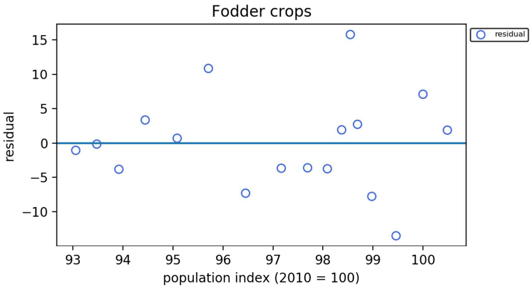




Fodder crops

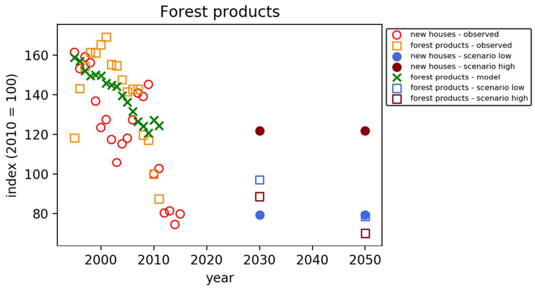
Parameter	Value
reduced chi-square	56.8
Akaike info crit	71.4
Bayesian info crit	73.9
alpha	4.75 +/- 3.33
beta	-443 +/- 313
gamma	1.02 +/- 0.02

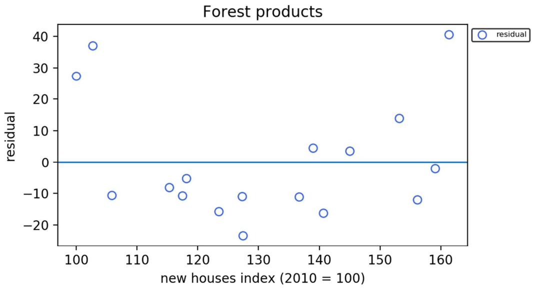




Forest products

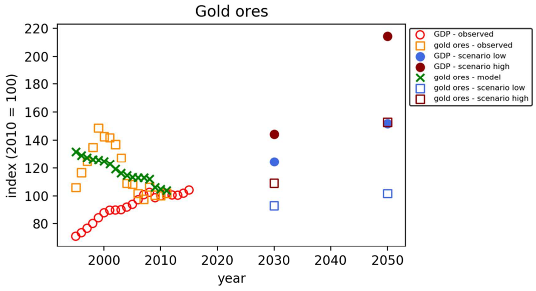
Parameter	Value
reduced chi-square	412.2
Akaike info crit	105.1
Bayesian info crit	107.6
alpha	0.2 +/- 0.34
beta	73 +/- 55
gamma	0.97 +/- 0.02

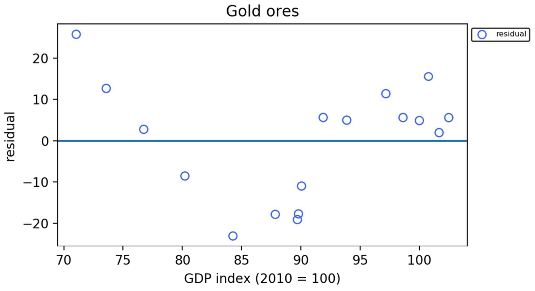




Gold ores

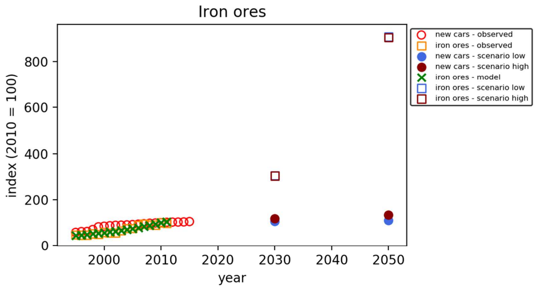
Parameter	Value
reduced chi-square	219.4
Akaike info crit	94.3
Bayesian info crit	96.8
alpha	0.82 +/- 2.3
beta	-32 +/- 162
gamma	0.96 +/- 0.08

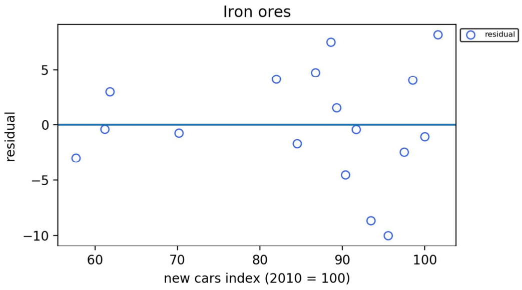




Iron ores

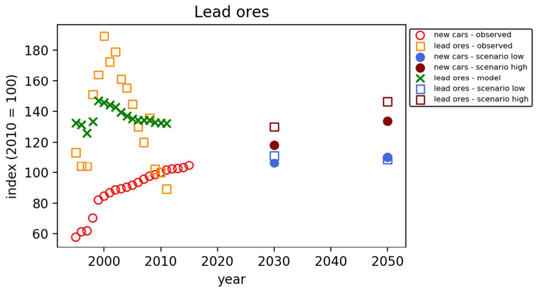
Parameter	Value
reduced chi-square	29
Akaike info crit	59.9
Bayesian info crit	62.4
alpha	0.09 +/- 0.19
beta	2 +/- 14
gamma	1.06 +/- 0.01

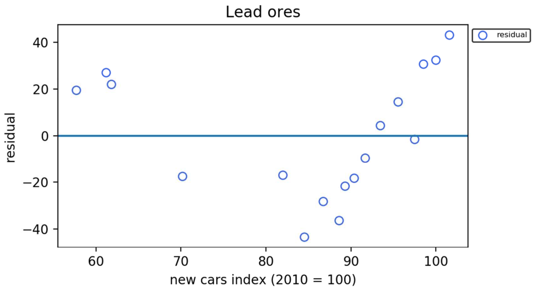




Lead ores

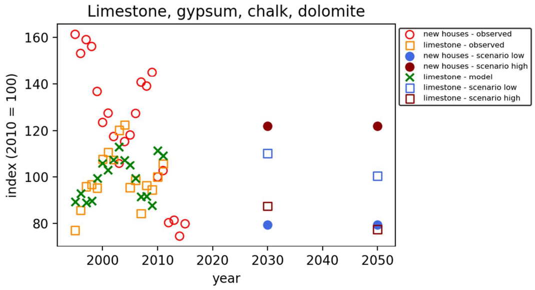
Parameter	Value
reduced chi-square	799.1
Akaike info crit	116.3
Bayesian info crit	118.8
alpha	1.62 +/- 2.63
beta	-74 +/- 145
gamma	0.94 +/- 0.17

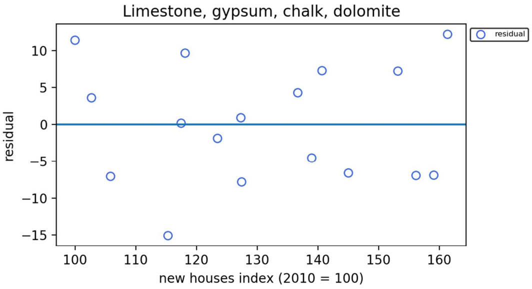




Limestone, gypsum, chalk and dolomite

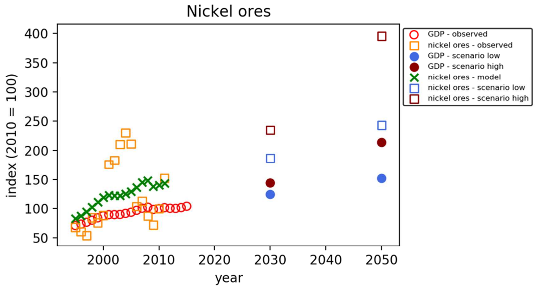
Parameter	Value
reduced chi-square	72.2
Akaike info crit	75.5
Bayesian info crit	78
alpha	0.54 +/- 0.14
beta	99 +/- 22
gamma	0.99 +/- 0.01

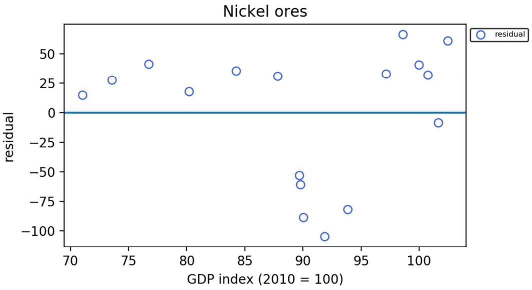




Nickel ores

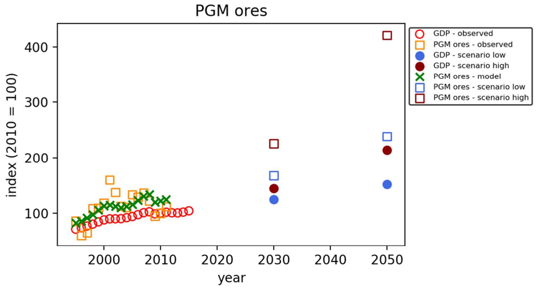
Parameter	Value
reduced chi-square	3512
Akaike info crit	141.5
Bayesian info crit	144
alpha	2.44 +/- 6.86
beta	-159 +/- 504
gamma	0.99 +/- 0.25

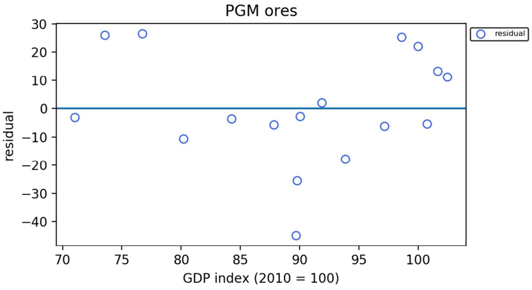




PGM ores

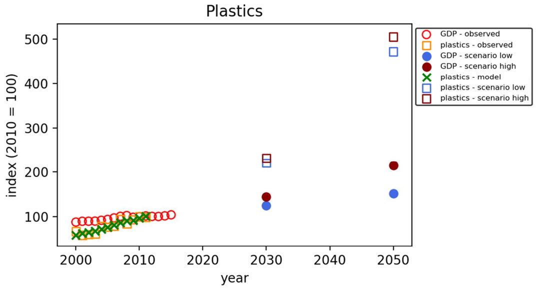
Parameter	Value
reduced chi-square	431
Akaike info crit	105.8
Bayesian info crit	108.3
alpha	2.92 +/- 3.04
beta	-211 +/- 212
gamma	0.95 +/- 0.15

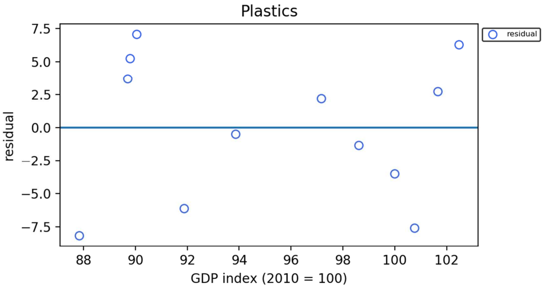




Plastics

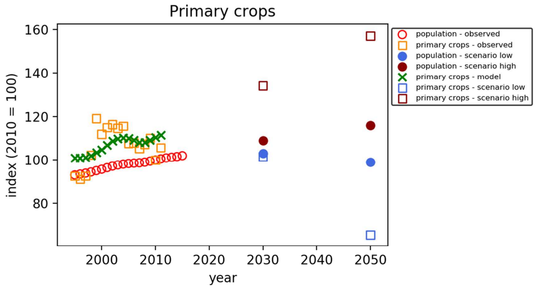
Parameter	Value
reduced chi-square	35.4
Akaike info crit	45.4
Bayesian info crit	46.8
alpha	0.53 +/- 0.85
beta	-55 +/- 75
gamma	1.04 +/- 0.01

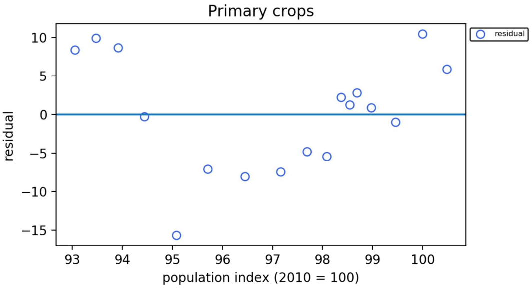




Primary crops

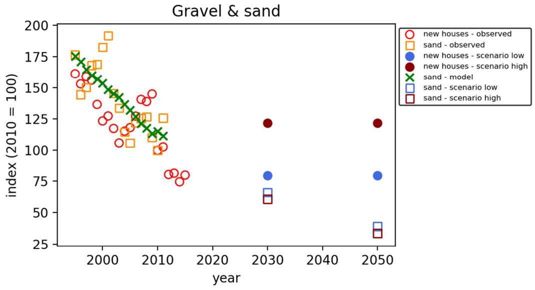
Parameter	Value
reduced chi-square	62.3
Akaike info crit	72.9
Bayesian info crit	75.4
alpha	5.48 +/- 8.39
beta	-502 +/- 779
gamma	0.98 +/- 0.06

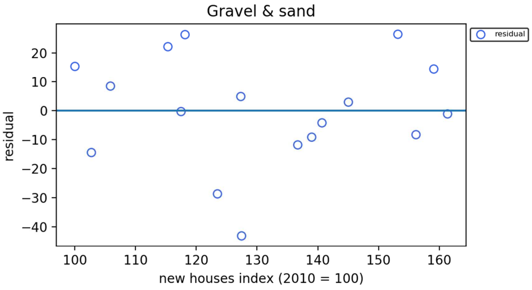




Gravel and sand

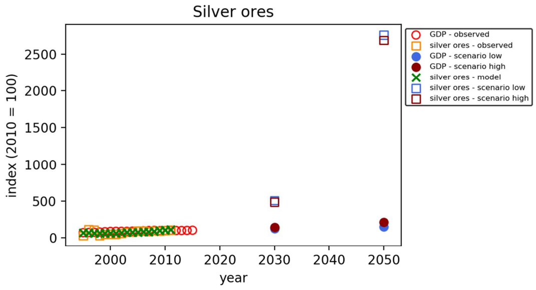
Parameter	Value
reduced chi-square	401.8
Akaike info crit	104.6
Bayesian info crit	107.1
alpha	0.13 +/- 0.34
beta	19 +/- 54
gamma	0.97 +/- 0.01

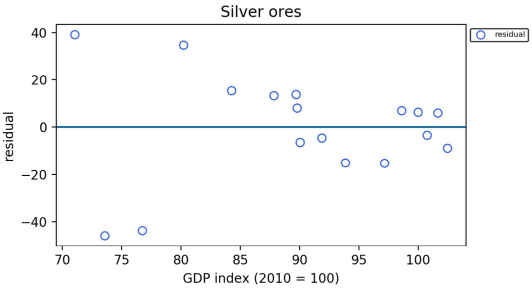




Silver ores

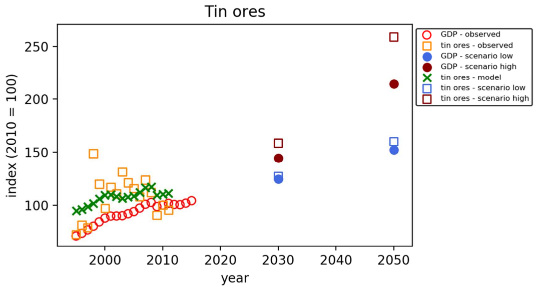
Parameter	Value
reduced chi-square	582.7
Akaike info crit	110.9
Bayesian info crit	113.4
alpha	1.15 +/- 1.24
beta	121 +/- 100
gamma	1.09 +/- 0.02

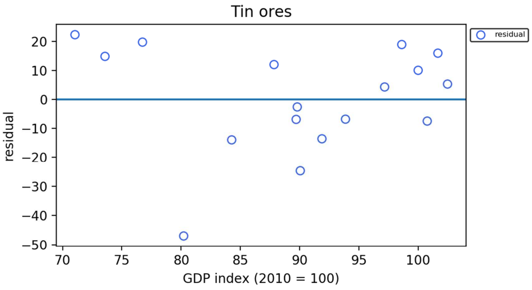




Tin ores

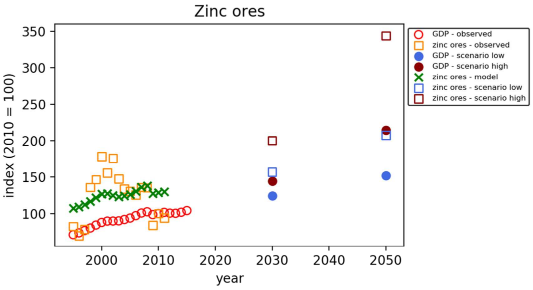
Parameter	Value
reduced chi-square	382.8
Akaike info crit	103.8
Bayesian info crit	106.3
alpha	1.58 +/- 3
beta	-90 +/- 213
gamma	0.96 +/- 0.14

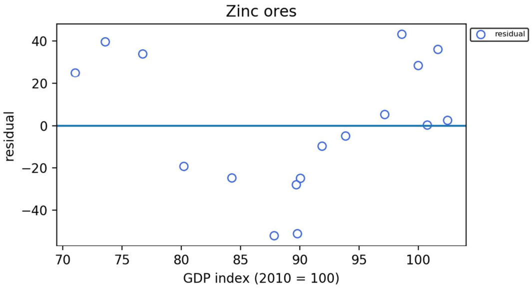




Zinc ores

Parameter	Value
reduced chi-square	1085.5
Akaike info crit	121.5
Bayesian info crit	124
alpha	2.18 +/- 4.95
beta	-130 +/- 346
gamma	0.95 +/- 0.24

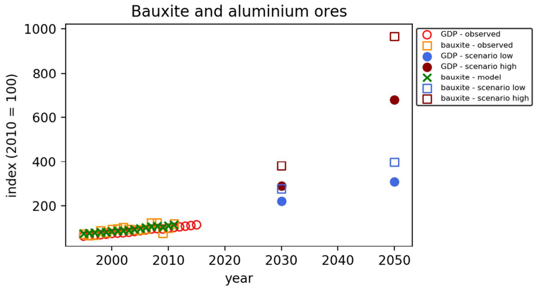

Zinc ores
index (2010 = 100)
350
300
250
200
150
100
2000
2010
2020
2030
2040
2050
year
GDP - observed
zinc ores - observed
GDP - scenario low
GDP - scenario high
zinc ores - model
zinc ores - scenario low
zinc ores - scenario high

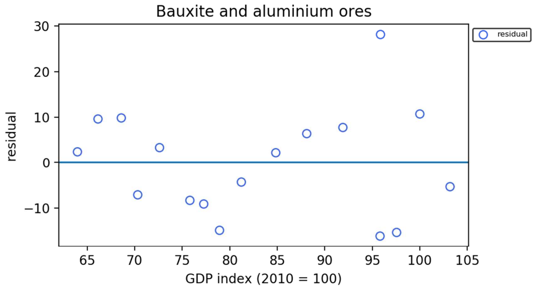

Zinc ores
residual
40
20
0
−20
−40
70
75
80
85
90
95
100
GDP index (2010 = 100)
residual

Appendix B: Resource use related to production in the Netherlands

Bauxite and aluminium ores

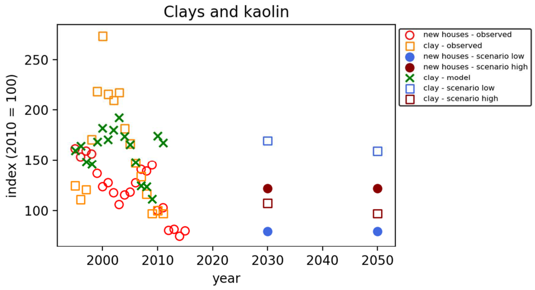
Parameter	Value
reduced chi-square	155.1
Akaike info crit	88.5
Bayesian info crit	90.9
alpha	1.53 +/- 1.53
beta	-96 +/- 93
gamma	0.98 +/- 0.07

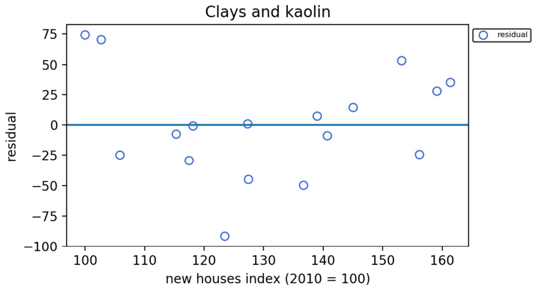




Clays and clay minerals

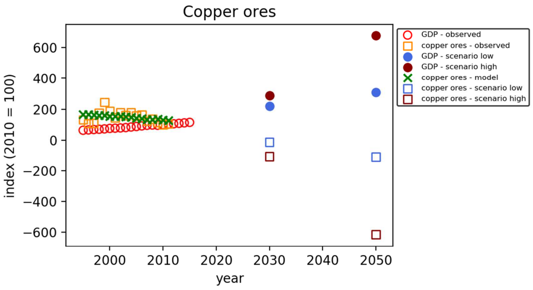
Parameter	Value
reduced chi-square	2187.1
Akaike info crit	133.4
Bayesian info crit	135.9
alpha	1.47 +/- 0.83
beta	271 +/- 137
gamma	0.94 +/- 0.07

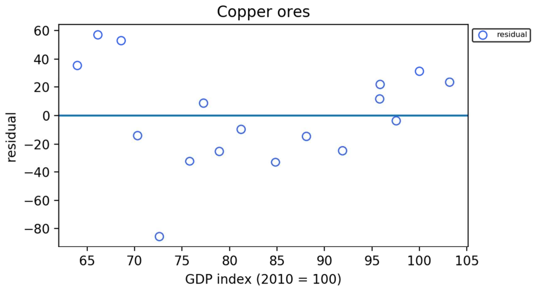




Copper ores

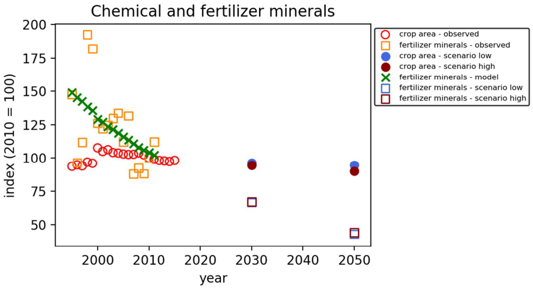
Parameter	Value
reduced chi-square	1484
Akaike info crit	126.8
Bayesian info crit	129.3
alpha	1.36 +/- 7.48
beta	122 +/- 477
gamma	1.01 +/- 0.13

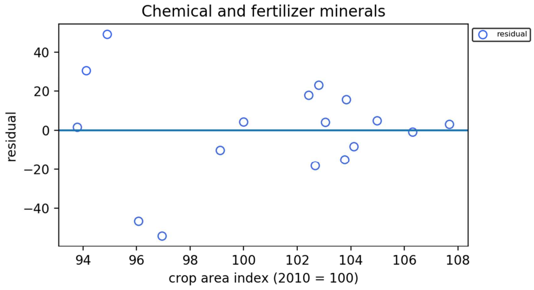




Chemicals and fertilizer minerals

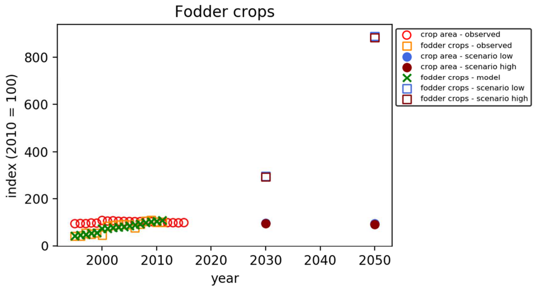
Parameter	Value
reduced chi-square	735.9
Akaike info crit	114.9
Bayesian info crit	117.4
alpha	0.27 +/- 1.85
beta	27 +/- 179
gamma	0.98 +/- 0.02

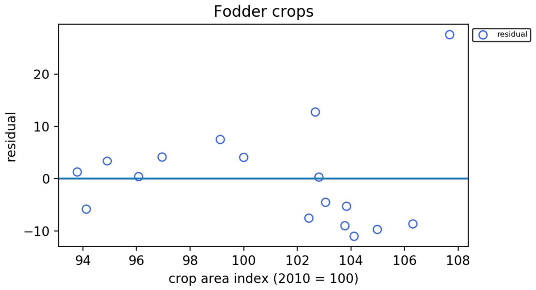




Fodder crops

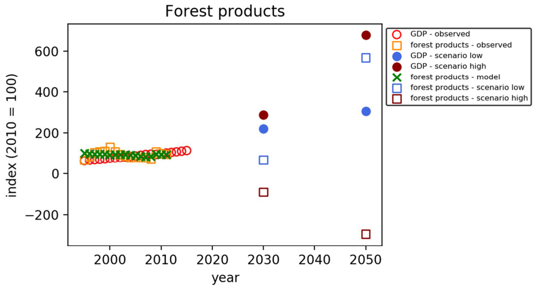
Parameter	Value
reduced chi-square	109.7
Akaike info crit	82.6
Bayesian info crit	85.1
alpha	1.3 +/- 0.63
beta	-120 +/- 63
gamma	1.06 +/- 0.01

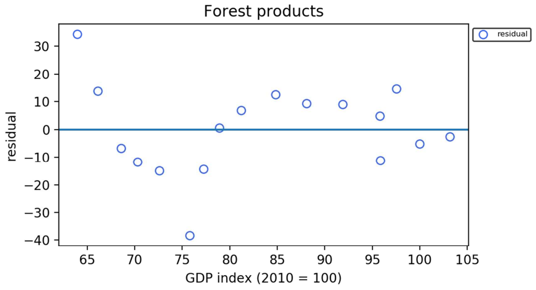




Forest products

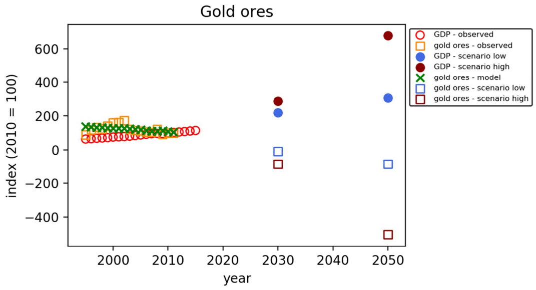
Parameter	Value
reduced chi-square	301.3
Akaike info crit	99.7
Bayesian info crit	102.2
alpha	2.33 +/- 1.75
beta	183 +/- 119
gamma	1.05 +/- 0.03

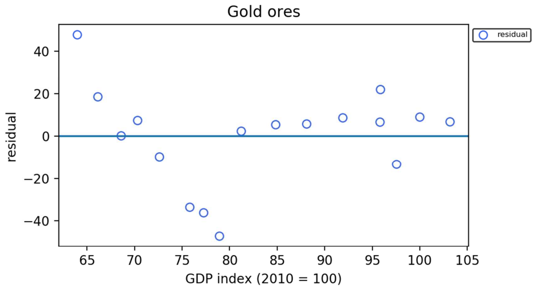




Gold ores

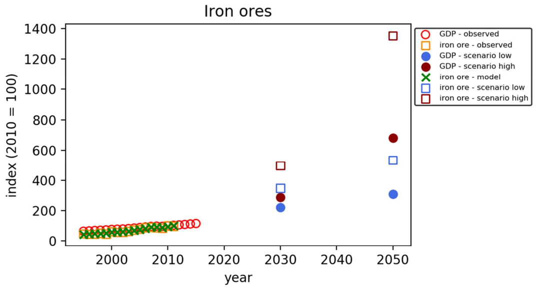
Parameter	Value
reduced chi-square	598.9
Akaike info crit	111.4
Bayesian info crit	113.9
alpha	1.13 +/- 4.72
beta	120 +/- 301
gamma	1.01 +/- 0.12

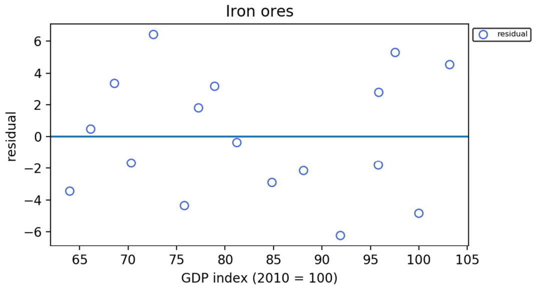




Iron ores

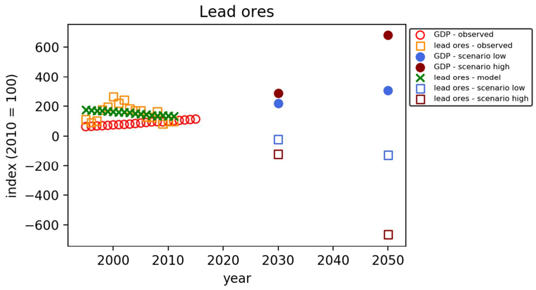
Parameter	Value
reduced chi-square	16.7
Akaike info crit	50.6
Bayesian info crit	53.1
alpha	2.2 +/- 0.22
beta	-144 +/- 13
gamma	0.94 +/- 0.03

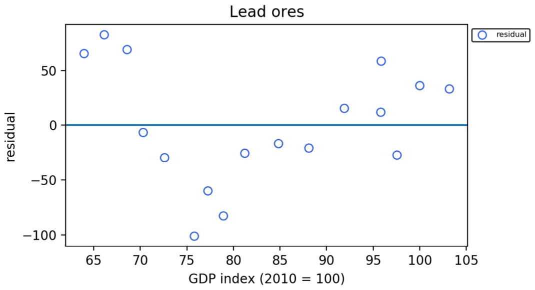




Lead ores

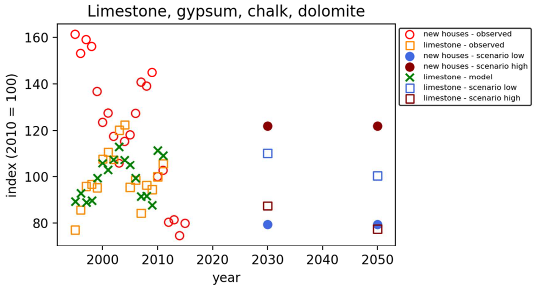
Parameter	Value
reduced chi-square	3257.2
Akaike info crit	140.2
Bayesian info crit	142.7
alpha	1.45 +/- 11.08
beta	158 +/- 706
gamma	1.01 +/- 0.23

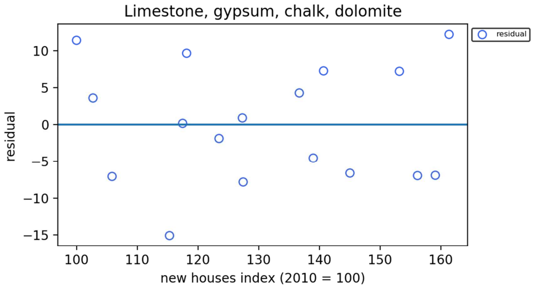




Limestone, gypsum, chalk and dolomite

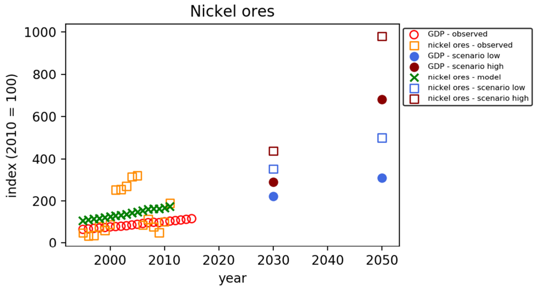
Parameter	Value
reduced chi-square	72.2
Akaike info crit	75.5
Bayesian info crit	78
alpha	0.54 +/- 0.14
beta	99 +/- 22
gamma	0.99 +/- 0.01

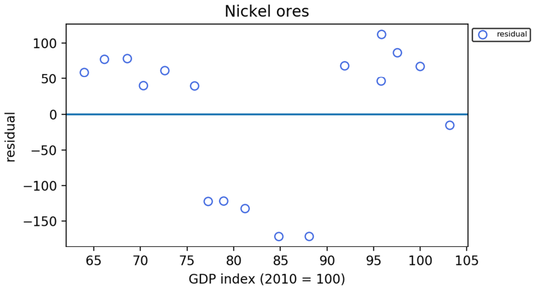




Nickel ores

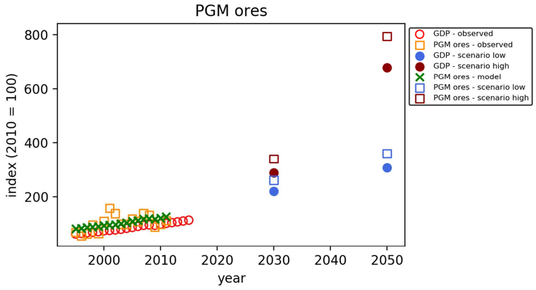
Parameter	Value
reduced chi-square	11473.3
Akaike info crit	161.6
Bayesian info crit	164.1
alpha	1.29 +/- 18.44
beta	-24 +/- 1196
gamma	1.02 +/- 0.75

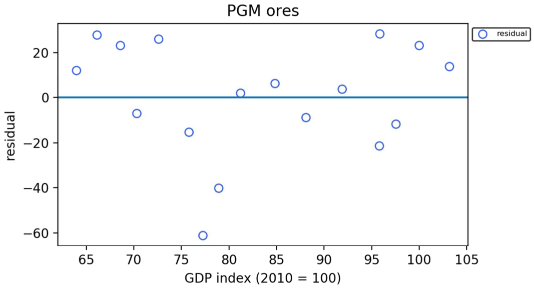




PGM ores

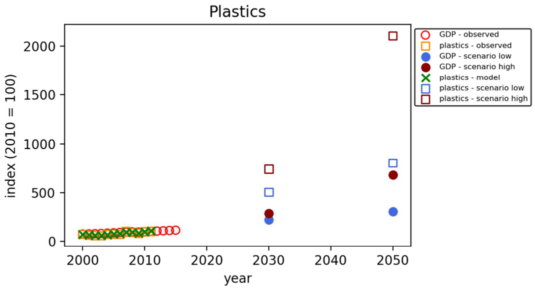
Parameter	Value
reduced chi-square	714.6
Akaike info crit	114.4
Bayesian info crit	116.9
alpha	1.16 +/- 5.03
beta	-62 +/- 317
gamma	1 +/- 0.18

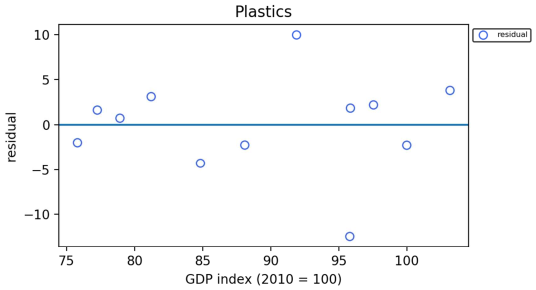




Plastics

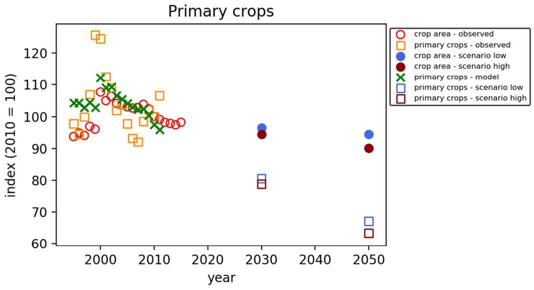
Parameter	Value
reduced chi-square	35.9
Akaike info crit	45.5
Bayesian info crit	47
alpha	3.49 +/- 0.27
beta	-266 +/- 20
gamma	0.86 +/- 0.04

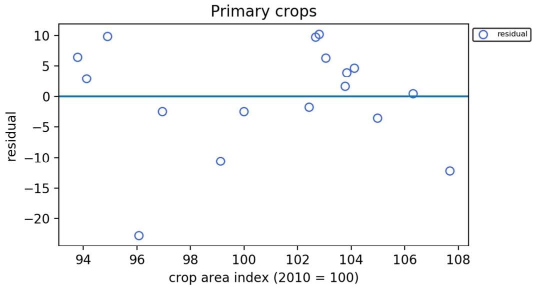




Primary crops

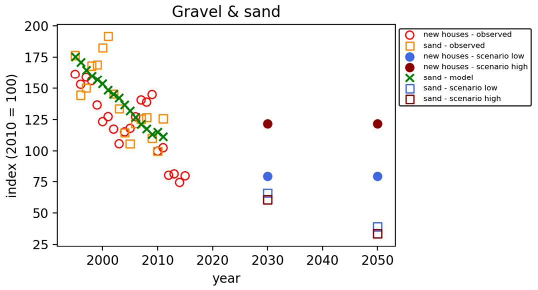
Parameter	Value
reduced chi-square	88.2
Akaike info crit	78.8
Bayesian info crit	81.3
alpha	0.88 +/- 0.62
beta	-76 +/- 60
gamma	0.99 +/- 0.01

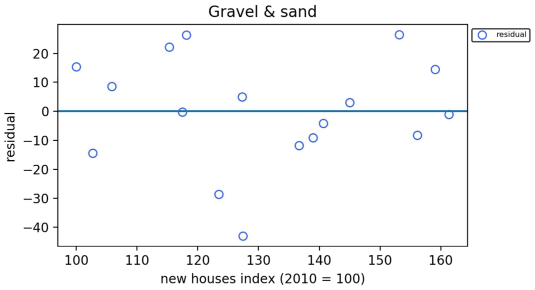




Sand and gravel

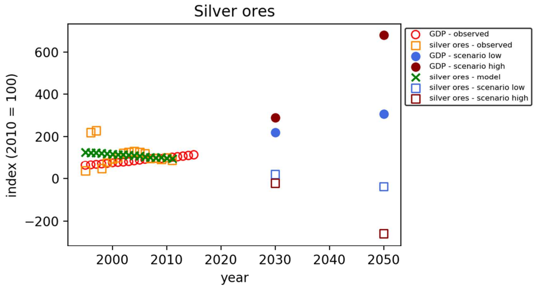
Parameter	Value
reduced chi-square	401.8
Akaike info crit	104.6
Bayesian info crit	107.1
alpha	0.13 +/- 0.34
beta	19 +/- 54
gamma	0.97 +/- 0.01

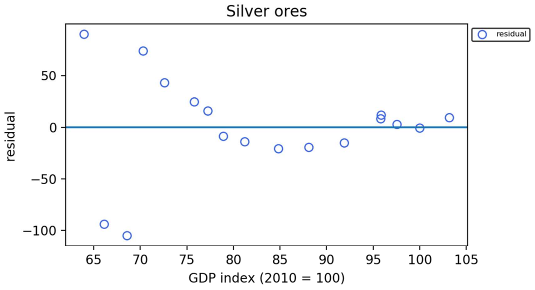




Silver ores

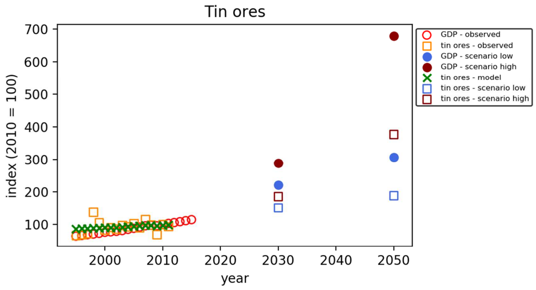
Parameter	Value
reduced chi-square	2682.6
Akaike info crit	136.9
Bayesian info crit	139.4
alpha	0.6 +/- 8.05
beta	128 +/- 499
gamma	0.99 +/- 0.65

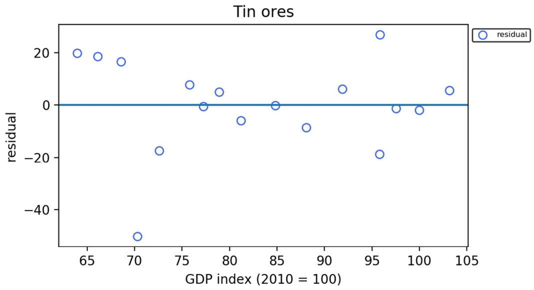




Tin ores

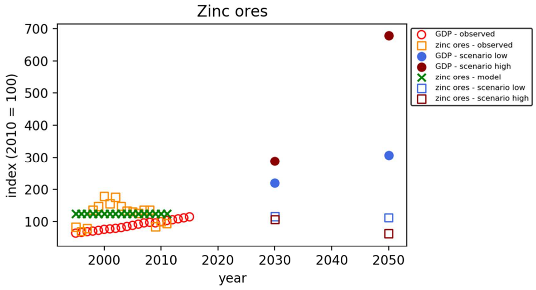
Parameter	Value
reduced chi-square	369.6
Akaike info crit	103.2
Bayesian info crit	105.7
alpha	0.51 +/- 3.31
beta	-13 +/- 207
gamma	0.99 +/- 0.14

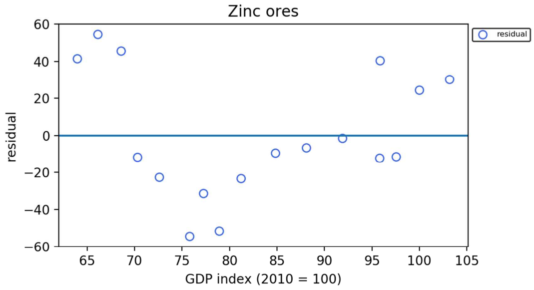




Zinc ores

Parameter	Value
reduced chi-square	1295.9
Akaike info crit	124.5
Bayesian info crit	127
alpha	0.13 +/- 7
beta	50 +/- 445
gamma	1 +/- 0.2

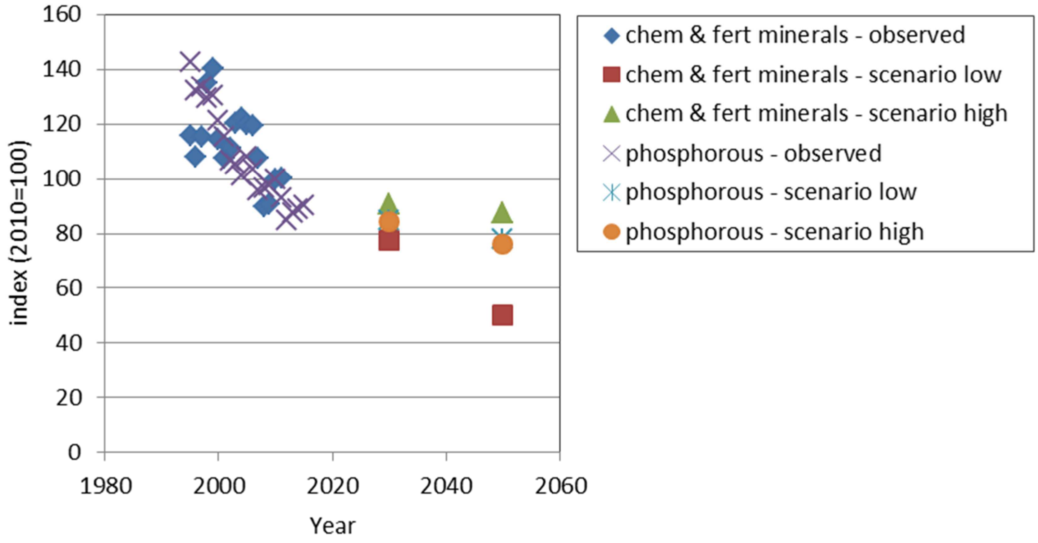




Appendix C: Phosphorous compared to Fertilizer minerals

The application of phosphorous by the Dutch agricultural sector in the Netherlands in 2050 can be found in the WLO – Cahier Landbouw. The phosphorous comes from manure and artificial fertilizer application. It is expected that the phosphorous application decreases about 25% compared to 2010 levels (see Figure bewlow, for WLO scenario and historical data).There is very little difference between the low and high scenario. In the WLO scenario the phosphorous is specifically addressed as an emission of concern, not as a resource use problem.

In EXIOBASE phosphorous is not identified as such but is part of the larger group of "chemical and fertilizer minerals". Guano, fluorite are also part of this group of chemical and fertilizer minerals.In this case phosphorous, as part of a larger group of minerals, is assessed as resource use problem. Our assessment shows that the use of this resource, driven by population growth and increased efficiency, decreases about 15% in scenario high and decreases about 50% in scenario low.



Appendix D: Bottom-up assessment for five metals

Metals in housing

Information in the various Cahiers of the WLO scenarios is not really adequate for bottom-up calculations. Ideally we would need a number of dwellings to be added to stock, or a number of square meters dwelling surface, per capita or in total. Neither was available.

The information we did have was the following:

- Number of dwellings built over 2000-2011
- Growth rates of "construction activity" in the high and low WLO scenarios
- Maximum number of dwellings to be realized (from the Regional Development cahier)

Estimates based on the construction activity in the past are very low and certainly would not lead to accommodate the number of households. The maximum number of dwellings does not seem related to any realistic expectations, as it would lead to ridiculously high estimates.

We therefore referred to the number of households as forecast by the WLO scenarios, and used these numbers as scaling factors for the construction activity estimates in 2010 in terms of number of dwellings. This number we multiplied by 2, to include (extremely crudely) commercial buildings as well. And that number we multiplied by a metal content per dwelling, such as provided in the PUMA project.

Data and results are provided below.

	Number of dwellings built 2000-2011
total	662000
annually	60182

Metal content in kg metal / dwelling	
aluminium	6.5
steel	900
copper	35
lead	?
zinc	6.5

For the lead content in buildings, the PUMA project made no estimate. Therefore we used the estimate of lead demand in construction in the NL as provided by Elshkaki et al. (2007) and applied the same scaling factor. This number is somewhat older, and the estimate therefore quite crude.

Scaling factors based on number of households			
	2012	2030	2050 (compared to 2030)
WLO high	1.00	1.16	1.25
WLO low	1.00	1.06	1.04

Metal demand (tonnes / year)		WLO high	WLO high	WLO low	WLO low
	2010	2030	2050	2030	2050
aluminium	782	909	1133	831	863
steel	108327	125815	156858	115017	119486
copper	4213	4893	6100	4473	4647
lead	3000	3484	4344	3185	3309
zinc	782	909	1133	831	863

Metals in mobility

For privately owned cars, the WLO scenarios provide quite detailed information on the car fleet and its composition, that we could use directly. We multiplied this by a metal content of the different types of cars as found in various sources, mostly of the metal branch organisations. We calculated demand data from these stock data by using an average life span of 15 years.

For road transport, no such data were available. The WLO scenarios did specify data on carkilometers driven as well as truckkilometers driven. We used this ratio as a scaling factor. We could not find usable data for ship transport. For aviation, we were able to find data. We specified only aluminium, as airplanes are made primarily out of that material. Allocation of air transport to the Netherlands is an issue. We tried out various options and used the one related to the number of airplanes in possession of the Dutch based company KLM.

		WLO high		**WLO low**	
	2010	**2030**	**2050**	**2030**	**2050**
Car fleet (x 1000)	7735	9128	10351	8229	8539
Composition of car fleet					
conventional	100%	91%	70%	92%	84%
semi electric	0%	7%	23%	6%	13%
full electric	0%	2%	7%	1%	3%

metal content (kg/car)				
	conv	hybr	elec	source
aluminium	150	150	150	http://www.aluminiumtoday.com/news/view/aluminium-in-cars-up-30
steel	900	900	900	https://www.worldsteel.org/steel-by-topic/steel-markets/automotive.html
copper	20	50	80	https://www.copper.org/publications/pub_list/pdf/A6191-ElectricVehicles-Factsheet.pdf
zinc	17	17	17	http://www.stockhouse.com/news/newswire/2015/05/19/how-much-copper-and-zinc-average-vehicle
lead	13	13	0	http://car-battery.org/much-car-battery-weigh/

		WLO high		WLO low	
metal in car fleet (tonnes)	2010	2030	2050	2030	2050
aluminium	1160250	1369200	1552650	1222007	1280850
steel	6961500	8215200	9315900	7332039	7685100
copper	154700	212682	321916	182684	219452
zinc	131495	155176	175967	138494	145163
lead	100555	116291	125144	104837	107677

		WLO high		WLO low	
metal demand (tonnes / year)	2010	2030	2050	2030	2050
aluminium	77350	91280	103510	81467	85390
steel	464100	547680	621060	488803	512340
copper	10313	14179	21461	12179	14630
zinc	8766	10345	11731	9233	9678
lead	6704	7753	8343	6989	7178
metal trucks demand (tonnes / year)					
aluminium	9282	10954	12421	9776	10247
steel	55692	65722	74527	58656	61481
copper	1238	1701	2575	1461	1756
zinc	1052	1241	1408	1108	1161

lead	804	930	1001	839	861

Air transport			WLO high		WLO low	
		2010	2030	2050	2030	2050
	Number of passengers (million/year)	52.6	112.2	166.8	84.7	112.1
	Flight movements (scaled with passengers)	402375	858298	1275972	647931	857533
NL	Passenger profile Schiphol: 34% NL	17.884	38.148	56.712	28.798	38.114
NL	Airplanes in possession of KLM	119	254	377	192	254
	Airplanes in use at global level (incl freight)	27000				
NL	share 1% (like global GDP)	270	576	856	435	575
Aluminium in airplanes (tonnes / piece)*: 100 (airplane weighs 120 ton, 80% of weight is Al)						
Stock (ton)						
Al	Based on KLM possession	11900	25384	37736	19162	25361
Al	Based on share of 1%	27000	57593	85620	43477	57542
Air transport demand (tonnes / year): life span assumed 40 years, for the rest see car fleet						
Al	Based on KLM possession	298	635	943	479	634
Al	Based on share of 1%	675	1440	2140	1087	1439

*https://www.schiphol.nl/nl/jij-en-schiphol/pagina/vijf-vragen-over-vliegtuigen/

Metals in electricity generation

The electricity mix we took from the NEV. Metal content data related to the different energy generation technologies we derived from the Ecoinvent database. These two pieces of information we combined to obtain the metal demand for the electricity production system. To also estimate the metal use related to electricity consumption, we assumed the Dutch mix to apply to the Dutch use as well.

Table 13a from the NV report: electricity supply mix as a result of already established policy													
	Realisaties					Projecties							
	2000	2005	2010	2015	2016[2]	2017	2018	2019	2020	2023	2025	2030	2035
Production (kWh)													
Total	9.04E+10	1.01E+11	1.18E+11	1.09E+11	1.14E+11	1.03E+11	9.61E+10	9.75E+10	1.01E+11	1.22E+11	1.30E+11	1.28E+11	1.38E+11
Natural gas	5.25E+10	5.82E+10	7.36E+10	4.59E+10	5.23E+10	3.76E+10	3.28E+10	2.96E+10	2.75E+10	2.82E+10	2.56E+10	1.37E+10	1.57E+10
Centralised	2.58E+10	3.47E+10	4.30E+10	2.45E+10	3.16E+10	1.48E+10	1.20E+10	1.14E+10	1.03E+10	1.39E+10	1.48E+10	7.87E+09	1.03E+10

Decentralised	2.67E+10	2.35E+10	3.05E+10	2.13E+10	2.07E+10	2.28E+10	2.09E+10	1.82E+10	1.72E+10	1.43E+10	1.07E+10	5.81E+09	5.42E+09
Coal	2.34E+10	2.31E+10	2.19E+10	3.95E+10	3.71E+10	3.66E+10	2.96E+10	2.84E+10	2.74E+10	2.96E+10	2.99E+10	2.25E+10	1.74E+10
Other fossil	4.86E+09	5.23E+09	4.34E+09	4.03E+09	3.89E+09	4.19E+09	3.59E+09	3.80E+09	3.85E+09	4.13E+09	4.38E+09	4.71E+09	4.65E+09
Nuclear	3.92E+09	4.00E+09	3.97E+09	4.08E+09	3.96E+09	4.22E+09	4.22E+09	4.22E+09	4.22E+09	4.22E+09	4.22E+09	4.15E+09	0.00E+00
Renewable	3.18E+09	7.71E+09	1.15E+10	1.29E+10	1.37E+10	1.79E+10	2.34E+10	2.87E+10	3.52E+10	5.35E+10	6.29E+10	8.06E+10	9.80E+10
Wind	8.29E+08	2.07E+09	3.99E+09	7.55E+09	8.16E+09	1.15E+10	1.24E+10	1.37E+10	1.92E+10	3.45E+10	4.22E+10	5.86E+10	7.53E+10
Solar	2.00E+08	2.76E+08	3.16E+08	3.19E+08	3.58E+08	1.90E+09	2.75E+09	4.01E+09	4.95E+09	7.74E+09	9.54E+09	1.42E+10	1.86E+10
Hydro	1.43E+08	8.81E+07	1.04E+08	9.31E+07	1.00E+08	1.17E+08	1.17E+08	1.17E+08	1.17E+08	1.17E+08	1.17E+08	1.17E+08	1.17E+08
Biomass	2.01E+09	5.28E+09	7.06E+09	4.93E+09	5.07E+09	4.34E+09	8.18E+09	1.09E+10	1.10E+10	1.11E+10	1.10E+10	7.71E+09	3.97E+09
Other	2.49E+09	2.81E+09	3.14E+09	2.86E+09	2.81E+09	2.17E+09	2.46E+09	2.76E+09	2.51E+09	2.54E+09	2.54E+09	2.68E+09	2.68E+09
International trade (kWh)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Net import[3]	1.89E+10	1.83E+10	2.78E+09	8.75E+09	4.72E+09	1.44E+10	2.04E+10	1.86E+10	1.54E+10	-5.54E+09	-1.27E+10	-1.30E+10	-2.40E+10
Import	2.29E+10	2.37E+10	1.56E+10	3.08E+10	2.42E+10	2.88E+10	3.63E+10	3.85E+10	3.70E+10	3.38E+10	3.06E+10	2.96E+10	2.58E+10
Export	4.03E+09	5.40E+09	1.28E+10	2.20E+10	1.94E+10	1.44E+10	1.59E+10	1.99E+10	2.16E+10	3.93E+10	4.33E+10	4.26E+10	4.98E+10

Multiplyers to use for energy (from Ecoinvent)								
kg/kWh	wind	solar	hydro	biowaste	oil	hard coal	gas	nuclear
Aluminium	2.15E-05	0.00136	2.24E-06	3.19E-05	1.23E-05	2.77E-05	0.00000694	0.000023
Chromium	0.00016	4.61E-05	1.78E-05	0.000032	8.41E-06	8.05E-06	0.00000169	8.66E-08
Copper	3.92E-05	0.000402	4.17E-07	1.95E-05	1.23E-05	9.79E-06	5.437E-06	2.34E-06
Gold	1.58E-11	1.31E-08	4.37E-12	1.14E-09	8.93E-11	7.07E-11	1.3097E-11	4.43E-13
Iron	0.00195	0.00174	0.000455	0.00355	0.00233	0.00111	0.00149	0.00014
Lead	5.05E-07	2.08E-06	2.89E-08	2.83E-06	7.94E-07	1.29E-07	3.35E-07	3.1E-07
Manganese	0.000019	3.27E-05	5.4E-06	2.57E-06	2.75E-06	3.68E-06	6.29E-07	3.22E-08
Nickel	0.000377	0.000109	4.39E-05	9.71E-05	3.84E-05	2.74E-05	1.6304E-05	1.44E-06
Pt group	2.96E-12	4.51E-11	1.57E-12	1.07E-10	1.06E-09	2.65E-11	5.5281E-12	1.47E-13
Silver	4.57E-11	2.84E-06	1.28E-11	3.08E-09	2.68E-10	2.12E-10	3.78E-11	1.25E-12
Zinc	4.02E-07	4.27E-05	1.52E-07	6.66E-06	2.97E-06	1.13E-06	3.39E-07	2.49E-07

Metals for energy production (tonnes / year)	2010	2015	2020	2030
Aluminium	2003	2310	8594	21677
Chromium	1219	1812	3947	10527
Copper	1099	1216	3431	8514

Gold	0	0	0	0
Iron	178050	155038	165987	223421
Lead	55	43	68	93
Manganese	244	353	684	1703
Nickel	4201	5354	10185	25423
Pt group	0	0	0	0
Silver	1	1	14	40
Zinc	126	123	345	726

Metals for energy use (tonnes / year)	2010	2015	2020	2030
Aluminium	2000	2212	8174	20669
Chromium	1217	1735	3755	10038
Copper	1097	1165	3264	8118
Gold	0	0	0	0
Iron	177848	148442	157891	213031
Lead	55	42	65	89
Manganese	244	338	650	1624
Nickel	4196	5126	9689	24241
Pt group	0	0	0	0
Silver	1	1	13	39
Zinc	126	117	328	692