The price of resource consumption using the Ecopoint concept under consideration of regional differences

G Grause*
Graduate School of Environmental Studies, Tohoku University, Sendai, Japan

*E-mail: grause.guido.a2@tohoku.ac.jp

Abstract. The Ecopoint concept was developed to control the worldwide resource consumption. Resource shares are distributed to the world’s population and freely traded among individuals. The number of shares limit the amount of resources that can be used. In this work, the question is investigated how plastic production is affected by such a system under special consideration of local difference in the energy generation and way of goods transportation. The polymerization of high-density polyethylene (HDPE) was modelled using a combination of the databases Ecoinvent 3.4 and Exiobase 2.2 for different feedstocks: fossil fuel in Brazil, the USA, and Germany; sugar cane in Brazil and India; maize in the USA; and grass in Switzerland. As a result, regional conditions have a strong impact on the resource consumption and the Ecopoint price. Using mainly fossil fuels for energy production increases the Ecopoint price by 30%. The combination of renewable energy and biomass as feedstock can significantly reduce the resource consumption. The resource consumption of the combination of fossil fuel for energy production and biomass as feedstock for HDPE is comparable to the use of renewable energy and fossil fuel as a feedstock. An Ecopoint price of 0.07 to 0.12 US$ would make HDPE from biomass competitive to such from fossil fuel.

1. Introduction
The 21st century is on the way to become the century mankind becomes aware of the Anthropocene [1]. We cannot longer close our eyes in front of the impact our behavior imprints on Earth’s global systems. Resource squandering threatens the climate by excessive carbon dioxide emissions and oceans by pollution with the leftovers of our disposal societies. Agriculture has to provide food for more and more people [2] and in future also for an increasing energy demand covered by biomass [3].

All these problems as the symptoms of a global crisis can be reduced to human’s mismanagement of resources and pinpointed to two issues facing into diametric opposite directions. First, there is an excess of carbon dioxide emissions from fossil fuels. There is nothing such as fossil fuel depletion. If climate change shall be prevented, most of the today’s known fossil fuel reserves have to remain unextracted [4]. Second, other resources, minerals and land area, are limited. Mineral deposits are formed slowly and some processes might not even occur anymore in modern geology. Depletion of some minerals, such as antimony or molybdenum, is foreseeable [5].

Efforts made to reduce climate impact of modern lifestyle result commonly in the switch to other resources putting more pressure on these. The increasing use of biomass for energy supply can be taken as an example. Production of biofuel from eatable crops causes rising food prices. Even if crops are not eatable, energy crops compete with food production for arable land. This is known as energy-food-nexus [6].
This situation can be avoided by the implementation of a resource management system that does not only consider a single type of resource, but takes into account all relevant resources and puts them into relation. The recently developed Ecopoint concept [7] fulfills this task by including fossil fuels, biotic and abiotic resources into a point system in which the amount of points is limited. Therefore, only a certain amount of resources can be used annually. If one resource is used to some extent, other resources have to remain unused. Allowances for resource consumption are distributed among the world’s population. These resource shares can be freely traded between individuals and provides a monetary exchange between rich and poor societies.

It was shown in an earlier work [8] that biomass and recycling are able to reduce resource consumption during the production of high density polyethylene (HDPE). However, some types of biomass (maize, rye, potatoes) were also identified as inappropriate for this purpose as yield and energy consumption during growth and processing requires more resources than the production of ethylene from crude oil. As the earlier work only investigated processes on a global scale, in this work regional aspects of production are considered.

2. Methods
In this work, the production of HDPE from different feedstocks and at different locations was investigated. The inventory comprised processes starting with the HDPE polymerization and following the path of the resources required for material and energy provision down to the resource extraction. Ethylene was obtained either by steam cracking of naphtha with crude oil as the initial resource or from ethanol obtained from the fermentation of biomass. Three different types of biomass were investigated: sugar cane as a provider for sugar, maize as the source of starch, and grass as a lignocellulosic material. More details are available in Grause [8].

2.1. Data and data processing
The method for the evaluation of the Ecopoint demand differs in important details from those applied in earlier publications [7, 8]. As the aim was to elaborate regional differences, Ecoinvent 3.4 and Exiobase 2.2 were combined to model the routes of goods. If available, country-based undefined Ecoinvent unit processes were used, otherwise global processes were taken into account. For this purpose, flows in Ecoinvent processes were incorporated into Exiobase categories and their flows were divided in accordance with fractions given for countries and regions. In this way, individual processes for each country or region were achieved for a certain product. In order to reduce the number of countries, countries with low contribution to a certain flow were eliminated until only countries with a contribution of more than 5% remained.

Processes included into the inventory were selected by their impact. Therefore, it was necessary to estimate the Ecopoint price of each input flow in advance. That was achieved by calculating the prices from cumulative inventories of the Ecoinvent apos database. Processes were added to the inventory until 95% of the impacts were included.

Transportation was also calculated by making use of both databases. The transportation distance $t$ (metric tons * km) was calculated by

$$ t = \frac{EURO2005_{Product} \times x_{Transportation}}{EURO2005_{Transportation}} $$

where the price of the production $EURO2005_{Product}$ (Euro) obtained from Ecoinvent is multiplied with the fraction of the cost required for transportation $x_{Transportation}$ obtained from Exiobase and the cost for transportation is received. This is divided by the cost of transportation $EURO2005_{Transportation}$ (EURO * metric tons$^{-1}$ * km$^{-1}$) to obtain the transportation distance. Only transportation methods with an impact of more than 0.1% of the estimated product Ecopoint price were included.

3. Results and discussion
In this work, regional differences in the production of HDPE are considered, produced from fossil fuel at three different locations, from sugar cane at two locations, and additionally from maize and grass,
each at one location. The results are compared with those of the global processes [8]. Differences in the results are expected to be related to differences in the production of the feedstock, the electricity production, and transportation routes.

3.1. HDPE production from fossil fuel
It is assumed that ethylene for the production of HDPE is obtained from the steam cracking of naphtha. As it can be seen from Figure 1, Resource consumption in Brazil (BR) is about 30% lower than in Germany (DE) or the USA (US). This is related to lower consumption of fossil fuels. In all three cases, the same processes for polymerization and steam cracking are assumed, consuming the largest fraction of the crude oil present in the analysis. In fact, the crude oil consumption differs only slightly between the smallest and the largest consumer and the Brazilian consumption was only 4% lower than that of the USA scenario (Table 1). More important for the differences in the fossil fuel consumption is the dependence on coal for the production of electricity and heat. Both the USA and Germany scenarios use mainly coal for the energy provision, 39% in the USA scenario and 49% in the Germany scenario for electricity. For heat production, the ratios are even higher. Energy provision in Brazil is based on the renewable resources hydropower and biomass, instead. As a result, only 98 g of coal (0.36 Ecopoints, EP) are required for the production of 1 kg of HDPE in Brazil, while 930 g (3.43 EP) and even 1060 g (3.91 EP) are needed in the USA and Germany, respectively. The USA uses additionally natural gas as an energy source. The gas consumption is about three times higher than in Brazil or Germany.

When the HDPE production is oil-based, biotic and abiotic resource consumption is negligible. Only Brazil uses 0.26 EP for wood as an energy source. About 0.4 EP have to be spent for transportation in the Brazilian and the German case (Figure 2). Oversea shipment contributes to 75% to the Brazilian scenario, while in the German case freight transport by lorry (60%) dominates. Resources consumption are three times higher in the USA scenario. The most important means of transportation are pipelines (49%) and lorry (40%). This might be attributed to the size of the country, which requires to bridge longer transportation distances.

Figure 1. Ecopoint distribution for the production of HDPE in dependence of feedstock and location.

Figure 2. Ecopoint distribution of transportation for the production of HDPE.
3.2. **HDPE production from biomass**

Three different types of biomass are investigated in this work: sugar cane, maize, and grass. Sugar cane was used in two locations, Brazil and India.

It can be seen from Figure 1 that using sugar cane as a feedstock for HDPE production requires three times more resources in India than in Brazil as India depends strongly on fossil fuels. The most important energy carrier is coal (Table 1). About 1.4 kg of coal (5.05 EP) are required for the production of 1 kg of HDPE. About 77% is used for electricity, the rest for heat production. Additional 170 g of oil (0.89 EP) are needed for transportation as diesel and bitumen for road construction. Natural gas is of minor importance. Only 76 L 0.35 (EP) are used mainly for electricity production. Some 14% are required for ammonia synthesis, which is required for fertilizer production.

As Brazil is less dependent on fossil fuels for energy supply, only 0.80 EP are used in this domain. About the half is required for crude oil, mainly used for transportation purposes. A minor fraction is converted into monomers for plastics used in agriculture. About 0.24 EP are used for coal consumption. Half of the coal is used for the production of steel, most of it required for the production of agricultural machinery; the other half is used for electricity production. Natural gas in the Brazilian scenario is mainly used for electricity generation.

Polyethylene production from sugar cane requires in both countries Brazil and India about the same area of arable land in the range of 1.8 to 1.9 m$^2$ (about 0.65 EP) per 1 kg of HDPE. Production in Brazil requires additional 5 \times 10^{-4} m$^3$ (0.54 EP) of wood for energy production.

Biomass based HDPE production requires more abiotic resources than fossil fuel based production as additional machinery and fertilizers are needed. The Indian scenario requires 0.008 EP for minerals, mostly for phosphorus and sylvite used in the production of fertilizers. A small amount is required for the production of steel. Sugar cane production in Brazil makes use of larger amounts of fertilizers requiring about 0.01 EP. Another 0.015 EP are used for metals, such as iron, nickel, and copper. Iron and nickel are solely used for steel production, while copper has various applications such as building constructions, electricity distribution networks, and machinery.

The transportation requirement in the Brazilian case (0.48 EP) is slightly higher than that for the fossil fuel based scenario (Figure 2). The fraction of the oversea shipment only a half of the total amount and that of road transportation is one third. The rest is mostly related to agricultural transportation. Transportation in India requires more than twice the amount (1.07 EP) of Brazilian transportation. This is mostly related to the large part of road transportation (77%), while other means of transportation are negligible.

### Table 1. Some selected categories and their Ecopoint prices: Energy, fossil fuels, and abiotic resources. The total value represents 95% of the actual impact.

|                     | Coal EP | Gas EP | Oil EP | Al EP | BaSO$_4$ EP | Cr EP | Cu EP | Fe $10^{-3}$ EP | P EP | Pt EP | KCl EP | Zn EP | Biotic EP | Total EP |
|---------------------|---------|--------|--------|-------|-------------|-------|-------|-----------------|------|-------|--------|-------|-----------|----------|
| Fossilfuel (global) | 2.86    | 0.76   | 6.44   | 3.41  | 1.65        | 0.03  |       |                 |      |       | 10.1   |       |           |          |
| Fossilfuel (BR)     | 0.36    | 0.24   | 6.17   |       |             | 0.28  |       |                 |      |       | 7.1    |       |           |          |
| Fossilfuel (US)     | 3.43    | 0.75   | 6.43   |       |             | 0.09  |       |                 |      |       | 10.7   |       |           |          |
| Fossilfuel (DE)     | 3.91    | 0.25   | 6.28   |       |             | 0.01  |       |                 |      |       | 10.4   |       |           |          |
| Sugar cane (global) | 2.40    | 0.33   | 0.38   |       |             | 2.48  |       |                 | 5.89 |       | 3.7    |       |           |          |
| Sugar cane (BR)     | 0.24    | 0.16   | 0.41   |       |             | 1.48  | 1.48  | 3.70            | 7.09 | 0.50  | 2.0    |       |           |          |
| Sugar cane (IN)     | 5.05    | 0.39   | 0.89   |       |             | 1.33  | 3.69  | 2.90            |      |       | 7.1    |       |           |          |
| Maize (global)      | 4.17    | 2.77   | 2.56   | 2.94  | 1.08 2.53   | 9.47  | 26.8 | 15.5            | 14.0 |       | 10.8   |       |           |          |
| Maize (US)          | 5.03    | 3.56   | 1.11   |       |             | 4.81  | 8.83 | 4.76 11.9      | 1.09 | 13.5  | 2.83   | 1.74  | 11.3     |          |
| Grass (global)      | 4.20    | 0.42   | 0.58   |       |             | 2.16  |       |                 | 0.21 |       | 5.4    |       |           |          |
| Grass (CH)          | 0.37    | 0.13   | 1.03   | 0.29  | 1.50 2.27   | 1.17  |       |                 | 0.39 |       | 1.9    |       |           |          |

Al: aluminium, BaSO$_4$: barite, Cr: chromium, Cu: copper, Fe: iron, Ni: nickel, P: phosphorus, Pt: platinum, KCl: sylvite, Zn: Zinc
The USA scenario for polyethylene production from maize as a feedstock does not provide any advantage over fossil fuel regarding resource consumption. As can be seen from Figure 1, fossil fuel consumption is only reduced by 10% compared with fossil fuel derived HDPE. Even if crude oil consumption is reduced to 0.21 kg (1.11 EP), consumption of coal (1.35 kg, 5.02 EP) and natural gas (0.86 m³, 3.34 EP) increase considerably. Remarkable is the discrepancy in energy demand of the conversion of maize starch into ethanol requiring most of the natural gas compared with the conversion of sugar from sugar cane. Additional coal is needed as heat source for drying of maize. Crude oil is used as feedstock for plastic production and as fuel for agricultural machinery and road transportation. The resource demand for transportation (0.69 EP) was reduced by half compared with the USA fossil fuel scenario. Since the demand for oil decreases in the case of maize, less transportation by pipelines (18%) is required and the fraction of road transportation increases to 70%.

The marginal reduction of the fossil fuel consumption is outweighed by the additional use of arable land requiring 1.27 EP. Therefore, the land use for growing maize is doubled compared with that of sugar cane. Additional biomass in form of wood chips is required for the higher electricity consumption of the process. The total requirement for wood was calculated to be about 0.40 EP.

The mineral demand for HDPE production from maize (0.048 EP) is considerably higher than for the production from sugar cane. This is related to a higher fertilizer consumption (0.025 EP) and a stronger dependence on agricultural machinery. Iron and nickel require 0.0088 and 0.0048 EP, respectively. Copper (0.0047 EP) and zinc (0.0028 EP) are mainly used for building construction. Platinum (0.0011 EP) is used as a catalyst for the production of nitric acid.

At last, the HDPE production from grass in Switzerland was investigated. The resource demand for fossil fuel consumption requires 1.53 EP of which two third are used for crude oil, mainly required for heating the ethanol fermentation process. Since Swiss electricity production depends almost completely on nuclear and hydro power, little fossil fuel is consumed in this area. However, Switzerland depends also strongly on electricity imports from other countries. In this way, most of the coal used in this process (0.37 EP) is converted into electricity. Transportation requires 0.58 EP of which 56% and 41% are used for oversea and road transportation, respectively.

About 2.35 m² of grassland is required for the production of 1 kg of HDPE. This is more than for the production of sugar cane, but less than for the production of maize. Compared to the earlier feedstocks is the prize of 0.14 EP for the required area comparably low as the productivity of grassland is considerably low [9]. Wood (0.29 EP) is mainly used for heat and electricity production.

In opposite to sugar cane and maize production, fertilizers are not used to support the growth of grass. Therefore, most of the mineral resources (0.0059 EP) are related to steel production with iron (0.0023 EP) and nickel (0.0012 EP) being the most important ones. Copper (0.0015 EP) is used for agricultural machinery and electricity transmission networks.

3.3. Origin of resources and trade routes

One important aspect of this investigation is the resource demand for transportation, which depends strongly on the distance of resource extraction sites and the final processing location. As it can be seen from the concentration of Ecopoints in Figure 3, most extraction sites are located in the global region of the imagined HDPE production facility. However, it has also to be considered that the global distribution of many resource is very uneven. Resource extraction does often not satisfy the local demand.

One good example is the trade of crude oil and petrochemical products. National economies try to satisfy their demand from near sources: the USA scenarios from the USA, Canada, and Mexico; the Brazilian scenario from South America; the European scenarios from the North Sea; and the Indian scenario from India and Middle East. However, in most cases the local supply is not sufficient and has to be increased by oversea sources.

A special case is the Swiss grass scenario in which most of the consumed goods are not produced directly in Switzerland, but imported from Germany or Italy. This leads to the virtual consumption of especially coal used in steel production, while the resources are extracted in third countries.
3.4. Comparison of regional and global scenarios

Earlier [8] the processes of interest were investigated on a global scale ignoring the differences in the local energy mix and distances to resource extraction sites. The introduction of local processes caused an inflationary increase of processes, which had to be developed for a certain flow separately for different countries. In the end, both global and local Ecopoint prices are in a good agreement as global values can be interpreted as an average (Table 1).

As it can be expected, scenarios placed in Germany, India, and the USA having a high fossil fuel consumption show Ecopoint values higher than the global average; Brazil and Switzerland having a low consumption are below. The values for the different fossil fuel types are located around the global average values and do not provide any surprises. Surprising is, however, the lower values for biotic resources used in all scenarios. Especially the biotic resource consumption in the Brazilian sugar cane

![Origin of resources for different production paths of HDPE given in Ecopoints.](image)
scenario is twice as high as the global one, even if the global process is based on Brazilian data. This might be caused by the lower global conversion of biomass to energy. Especially in the Brazilian case, land use increases by the energy generation during sugar and ethanol production. Also, the energy production from wood was assumed to be very high.

Differences in the mineral consumption are mostly related to changes in the cut-off conditions. Getting back to the mineral extraction requires long production chains. As the mineral content in most processes is anyway comparably low, minerals seem to be always underrepresented. When a process is characterized by a view big resource providers, such as fossil fuels, the cut-off condition of 95% of all impacts is already fulfilled before and minerals are considered. The more processes are involved in the inventory, the better the representation of minerals. This is better achieved in the Swiss grass scenario with its 1000 processes involved than with fossil fuel scenarios including about 100 processes.

4. Conclusions

The Ecopoint concept was used to evaluate the resource consumption of fossil fuel based and biomass based production routes for HDPE in different world regions. Different means of electricity generation and transportation cause already considerable differences in the EP price. The replacement of fossil fuel by sugar cane or grass results in an even stronger reduction in the resource consumption. However, if the energy required for growing the biomass is still provided mainly by fossil fuel, the advantage of biomass is neglected as HDPE produced in India from sugar cane and in Brazil from fossil fuel result in the same EP price. Some biomass resources, such as maize, are not suitable for HDPE production as resource consumption even increases by the high energy demand of the agricultural and fermentation process.

Assuming a price difference of US$ 600 per ton between fossil fuel and biomass based HDPE [8], it requires an EP price of US$ 0.12 for Brazilian sugar cane based HDPE to become competitive with fossil fuel based HDPE. For Swiss grass based HDPE, already an EP price of US$ 0.07 is sufficient to compete with German fossil fuel based HDPE. Inappropriate biomass, such as maize is not supported by the system and does not become competitive. For comparison, an EP price of US$ 0.06 would provide the world’s population with an income comparable with the World Bank’s international poverty line.

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