Final Report for

Qiagen N.V.

on

Life Cycle Assessment of QIAGEN‘s QIAamp DNA Mini Kit (250)

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1 Background

QIAGEN N.V. (hereafter QIAGEN) commissioned sustainable AG (hereafter sustainable) to carry out a life cycle assessment for one of its products to improve the performance of the environmental performance of the product within the next five years constantly. The first assessment was conducted in May 2020, in February 2022 a reassessment takes place with extended details and evaluation of impacts. QIAGEN is the owner of this study and provided all the data needed for the results.

1.1 Goal and Scope

Goal of this project is to gain insights into the impacts associated with QIAGEN's products, maintaining a good overall cost-benefit ratio. It was therefore chosen to carry out the LCA on one of QIAGEN's selling products, the QIAamp DNA Mini Kit.

1.2 Representativity and Coverage of QIAGEN's Product Portfolio

QIAGEN splits its product portfolio into two categories: instruments, and consumables & bioinformatics (cp. Figure 1). The studied product is part of the largest category "consumables & bioinformatics", under which about 86% of QIAGEN's sales (by turnover) are filed as of 2021. With about 3.5 kg, the kit is marginally heavier than an "average" QIAGEN kit. World-wide, QIAGEN has sold over 14 million kits in 2020. The QIAamp DNA Mini Kit, as one of QIAGENs best-selling product, is considered representative for this category. In 2020, QIAGEN sold over 11.000 QIAamp DNA Mini Kit (250) which, together with the QIAamp Viral RNA Mini Kit (250), account for almost 7% of QIAGEN's revenue.

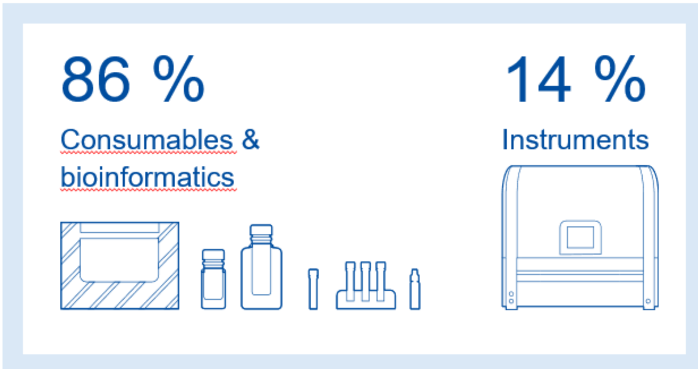


Figure 1: QIAGEN's Product Portfolio by Turnover 2020

1.3 Conformity with International Standards, Critical Review

This LCA is carried out in accordance to ISO 14040/14044. Accordance to ISO 14040/14044 is certified by an independent third party (GUTcert) for the year 2020.

1.4 Product description

The QIAamp DNA Mini Kit contains a series of collection tubes, bottled buffer solutions and spin-columns used to isolate DNA from human tissue samples (see Figure 2 and Figure 3). DNA binds specifically to the QIAamp silica-gel membrane while contaminants pass through. Any inhibitors are removed in two washing steps, leaving pure DNA to be eluted in either water or a buffer provided with the kit. The kit yields DNA from samples ready to use in further procedures.

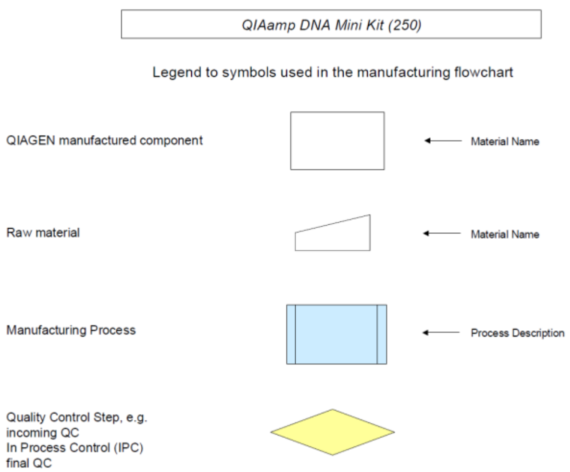


Figure 2: Item description for process description of DNA Mini Kit

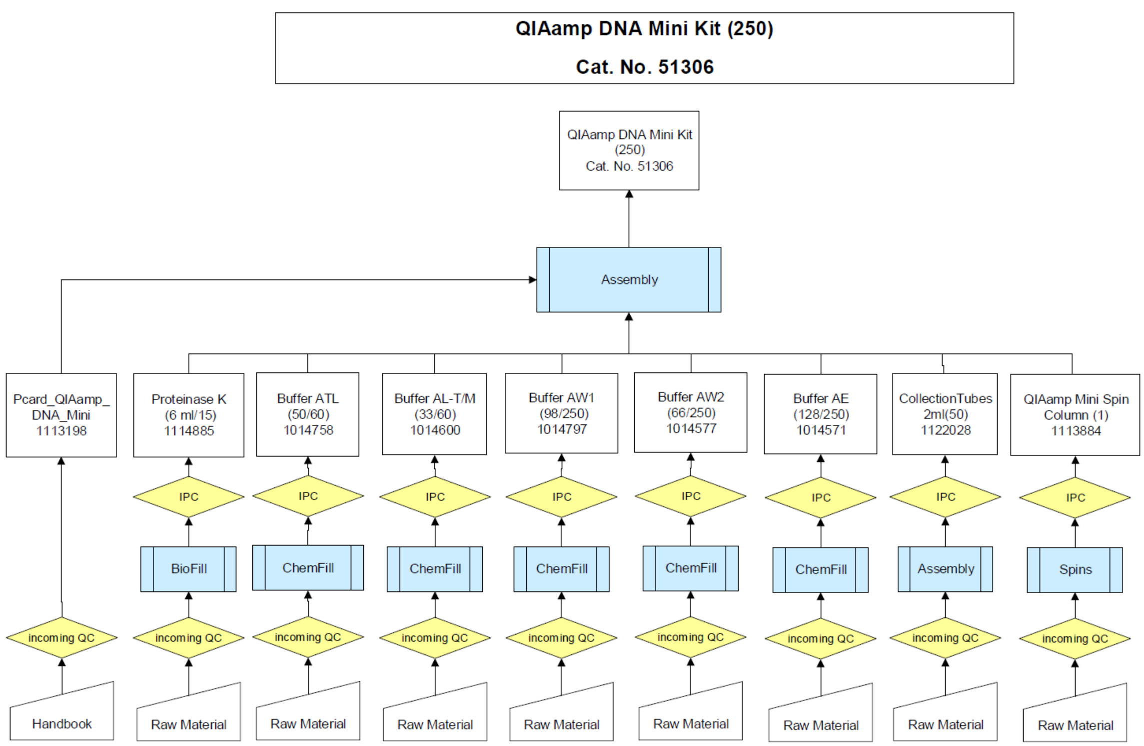


Figure 3: Process description of DNA Mini Kit

The scope of the study will be the full life cycle of the product, including extraction and processing of raw materials, transport to the customer, energy and material input required when using the product, as well as transport to the disposal facility and incineration of remaining materials. These system boundary setting is commonly referred to as “cradle to grave”.

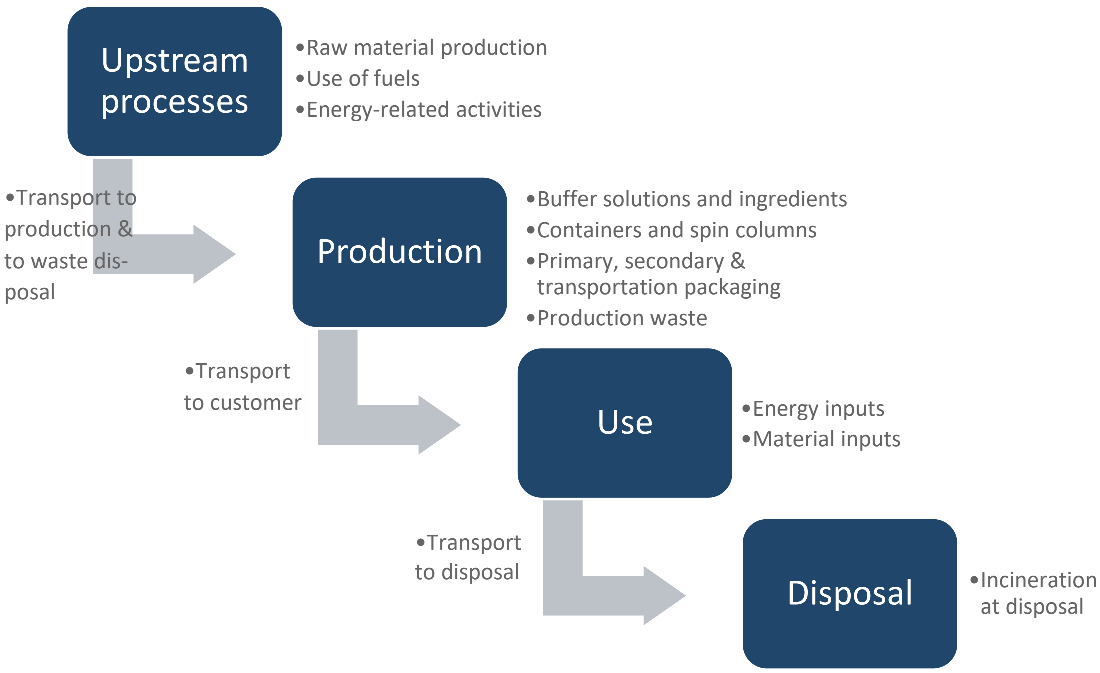


Figure 4: System Boundary of this LCA: Cradle to Grave

The product consists of 250 sampling elements and spin columns, accompanied by several buffer solutions and reagents in plastic bottles and packaged in a cardboard box.

1.4.1 Fillings

The manufacturing process of the fillings (bottles) can be performed manually or automatically. For larger lot sizes, the automated process is chosen. For smaller lot sizes, for small filling volumes or in the case of particularities the manual process is chosen. The filling of the buffer bulks is performed inside a cleanroom under laminar airflow.

1.4.2 Spin columns

The spin columns consist of a collection tube and a spin column containing a membrane, a frit, and a retainer ring. They are assembled by an automated spin assembly machine and afterwards blistered by an automated blister machine.

The plastic components and the material of the membranes and frits are purchased by a supplier. The frits are punched at QIAGEN by a separate punching machine and washed before further processing. The membranes are punched by the spin assembly machine during spin column assembly. The spin columns are blistered by an automated blister.

In the forming-station the forming-film is preheated and formed into pockets. At the feed area, the pockets are filled with spin columns by a robot. The sealing-foil is heat-sealed to the forming-film containing the product.

1.4.3 Packaging

All components are finally packed into a cardboard box accompanied by the necessary documents, sealed and are subsequently ready for shipping.

The product is sent off to customers around the globe mostly in small charges via the logistics provider. It is not uncommon for the kits to be sent by airplane. Secondary packaging is used if reasonable, with often two or more kits being packaged together.

1.5 Functional Unit

The functional unit of this LCA is defined as

Manufacturing, transporting to the customer and using one (1) QIAamp DNA Mini Kit with 250 spin columns and subsequent disposal by incineration.

1.6 System boundaries

All elementary flows at the incoming ecosphere boundary to the product system are considered. The product system includes the production of the spin columns, their packaging as well as packaging of the kit and its outer packaging for transport. The preparation of the buffer solutions and their packaging are also considered, however, the mass contribution of most chemicals used is negligibly small. Production waste is also considered in the model.

After provision of the kit at the factory gate, transport to the customer is considered with an average transport scenario, derived from QIAGEN's geographical sales statistics. During the use phase of the kit, additional resources from the lab are required for using the kit as intended, of which alcohol for washing and diluting is considered in this LCA. To isolate the DNA, the spin columns are spun for a total of about 6 minutes in a micro-centrifuge. Electricity required for this step is also considered in the LCA.

The subsequent disposal of the kit's elements by incineration also lies within/inside the system boundary. Elementary flows are entirely connected to predefined processes from the ecoinvent-database.

1.7 Cut-Off Rules

Individual flows with less than 1% of the total mass of one kit (3,505 grams) are aggregated and a proxy substance is used for the LCA. The proxy substance accounts for less than 0,1% of the weight of the kit.

Energy flows resulting from energy recovery during incineration in the form of electricity and steam are omitted, therefore any positive effects of possible energy recovery are intentionally not considered for this LCA.

2 Life Cycle Inventory

The Life Cycle Inventory contains information on each mass and energy flow entering or exiting the system boundary as well as flows within the system boundary.

2.1 Data Basis

If not otherwise stated, inventory data have been supplied by QIAGEN, partly with guidance by sustainable. The following Table displays information on materials used for production and filling of the kit, including the buffer solutions and packaging. Detailed information can be found in a separate excel file ("QIAGEN_LCA_datacollection_220221").

All information in the following tables refers to the functional unit of one QIAamp DNA Mini Kit.

Life cycle stage	Scope CCF	Activity	Quantity [2020]	Unit
Raw material production	Scope 3.1	Deionized water	446,542	g
Raw material production	Scope 3.1	Ammonia (proxy for chemicals <1% in aqueous buffer solution	2,511	g
Raw material production	Scope 3.1	Guanidine Hydrochloride	101,940	g
Raw material production	Scope 3.1	Additives	18,465	g
Raw material production	Scope 3.1	NaCl	1,274	g
Raw material production	Scope 3.1	Enzymes	0,108	g
Raw material production	Scope 3.1	Polypropylene, injection molded	1.121,656	g
Raw material production	Scope 3.1	Polypropylene, injection molded	40,500	g
Raw material production	Scope 3.1	Polyethylene, blow molded	148,500	g
Raw material production	Scope 3.1	Polyethylene, foil (plastic bags)	14,650	g
Raw material production	Scope 3.1	Polypropylene, foil (plastic bag)	10,000	g

Raw material production	Scope 3.1	Cardboard	228,000	g
Raw material production	Scope 3.1	Labels	24,000	g
Raw material production	Scope 3.1	Paper	48,500	g
Raw material production	Scope 3.1	Labels	2,000	g
Raw material production	Scope 3.1	Paper	10,000	g
Raw material production	Scope 3.1	PVC blister foil	214,910	g
Raw material production	Scope 3.1	Cardboard	1.070,00	g
Raw material production	Scope 3.1	Styrofoam	0,0086	g
Raw material production	Scope 3.1	Plastic wrap	0,0018	g
Raw material production	Scope 3.1	Air pillows/bubble wrap	0,0020	g
Raw material production	Scope 3.1	Bags	0,0007	g
Raw material production	Scope 3.1	Tape	0,0005	g
Raw material production	Scope 3.1	Other	0,0003	g
Energy inputs	Scope 2	Electricity used at Hilden	4,36	kWh
Energy inputs	Scope 1	Natural gas used at Hilden	8,87	kWh
Fuel- and energy related activities	Scope 3.3	Electricity used at Hilden	0,0002078	kgCO2e
Fuel- and energy related activities	Scope 3.3	Natural gas used at Hilden	0,0002122	kgCO2e
Waste	Scope 3.5	Waste disposal in facilities (mixed waste)	695,98	g
Transportation to customer	Scope 3.4	Light ridig truck	2,148	tkm

Transportation to customer	Scope 3.4	cargo plane	0,099	tkm
Transportation to customer	Scope 3.4	Large rigid truck	0,642	tkm
Transportation to disposal	Scope 3.4	Large rigid truck	0,000	tkm
Transportation to disposal	Scope 3.4	Large rigid truck	0,43	tkm
Energy inputs	Scope 3.11	Electricity used at laboratory	2,25	kWh
Material inputs	Scope 3.11	Ethanol	290,00	ml
Incineration	Scope 3.12	PP	1.172,16	g
Incineration	Scope 3.12	PE	148,50	g
Incineration	Scope 3.12	LDPE	14,65	g
Incineration	Scope 3.12	Paper	1.356,50	g
Incineration	Scope 3.12	Labels	26,00	g
Incineration	Scope 3.12	PVC	214,91	g
Incineration	Scope 3.12	Polystyrene	0,01	g

For the end-of-life phase, complete incineration of the kit's components was assumed to represent a conservative assumption, keeping in mind the global application of the product. While recycling of plastic and especially paper waste is not uncommon, adequate waste separation in laboratories around the world is not considered given.

Different assumptions regarding disposal could significantly change the overall impacts of the product system, ranging from recycling (likely to have beneficial impact) to landfilling (likely to have adverse impact). Although open dumps and landfills are the most prevalent form of solid waste disposal globally, incineration at the end of life is deemed an accepted and reasonably conservative approach for this product.

2.2 Assumptions for the Life Cycle Inventory

Technological representativeness: The production of input materials was modeled to represent typical global supply chains. Plastic production, which accounts for the largest share of the overall weight of the kit, was modeled using latest datasets from ecoinvent. Supplier-specific information was not applied. Datasets for the production of the chemical compounds used in the buffers and chemicals were mostly not available and have therefore been modeled using ammonia production as a proxy. Ammonia has been chosen for its relatively energy intensive production process, thereby averting underestimation of energy-related impacts.

Geographical representativeness: The studied product is manufactured in Germany and distributed and used globally. The LCIA datasets used to model its life cycle must therefore represent the situation in different regions. To accomplish this without overcomplicating the model, different processes have been chosen to represent all relevant regions.

Electricity generation was modeled using the German electricity mix, while transport processes represent the global situation. Plastics, Paper and Cardboard datasets represent the global market. Disposal by incineration also represents the global technology. Note that no form of energy recovery was assumed.

Production waste was calculated by using the conservative approach with the assumption, that all waste is polypropylene. The position packaging waste accounts for the quarter of the total waste emissions. Therefore, this was used as representative

Generally, the most recent available datasets were used (ecoinvent 3.8).

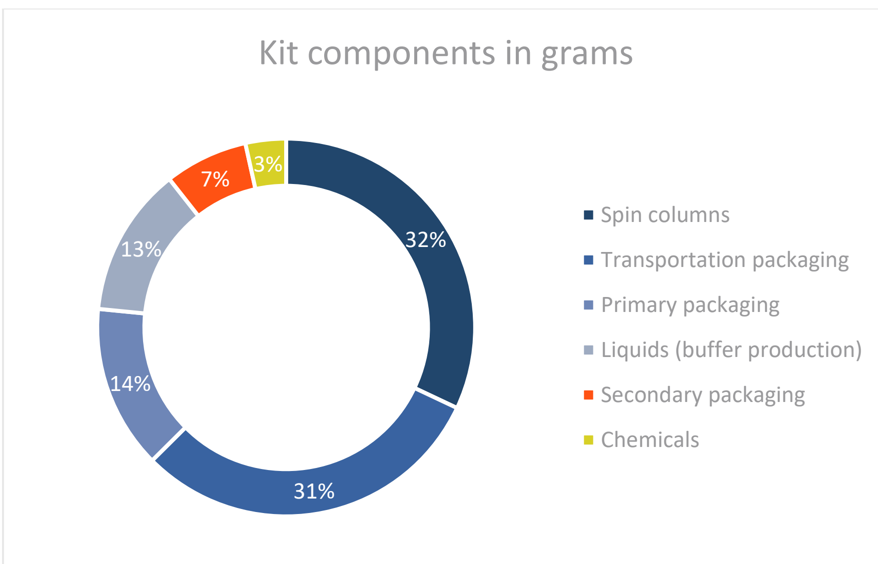
Most parameters were modeled using primary data with low uncertainty, especially the material composition of the kit is defined as accurate. Transport is outsourced to a logistics provider, which results in higher uncertainties for the amount of secondary packaging and transport distances. The conditions of use at the labs also cause uncertainties in the amount of alcohol and electricity demand during use.

2.2.1 Production

Guanidine hydrochloride and sodium chloride were separately matched in the section chemicals. Other chemicals used in the production of the buffer solutions with a proportion smaller than one percent per kit were summarized into one position. Their impacts were modeled using ammonia production as a proxy for all chemical compounds involved. This simplification can be justified by their relatively small contribution to overall weight. For the additives also used a proxy in form of dioxane was used in the model. Sodium chloride and enzymes were matched separately.

Most processes are modeled to represent a global situation. This is especially true for electricity generation in the use phase but holds for emission standards of road-going vehicles, as well as plastic production. The transportation of all raw materials to the production site QIAGEN GmbH in Hilden is covered by using a market emission factor in ecoinvent which incorporates an average global transportation scenario. As the collection of more specific data regarding the suppliers of the kit is challenging for QIAGEN, using an average transportation scenario is a feasible and representative method to manage these data uncertainties.

The total kit has a weight of 3,505 grams which can be divided into the following categories: spin columns, liquids, chemicals, as well as primary, secondary and transportation packaging. Primary packaging is generally the packaging that has direct contact with the ingredients of the kit. Secondary packaging can be defined as additional packaging without direct contact, whereas transportation packaging has the functionalities for transportation.



Accordingly, the spin columns and all packaging materials are responsible for 84% of the kit's weight.

The energy input during the production and processing was approximated by dividing the energy consumption of the production site QIAGEN GmbH (Hilden) by the total number of kits produced at QIAGEN GmbH. This means the data is not specific to the QIAamp DNA Mini Kit. However, deriving the energy input distinctly for this kit was not feasible nor considered a sensible allocation.

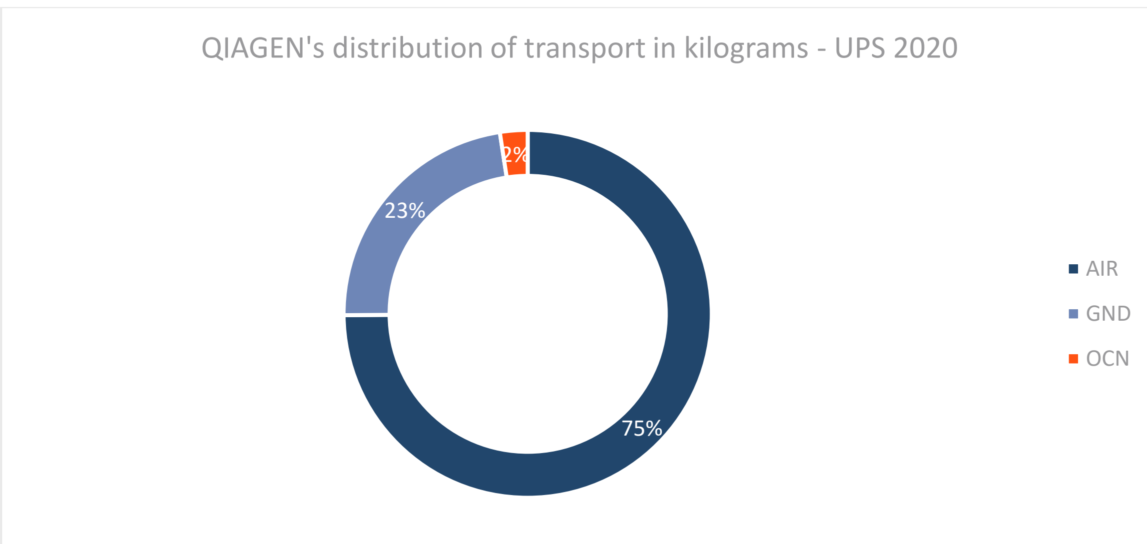
Electricity and natural gas consumption for the production of one kit was calculated by dividing annual Hilden electricity and natural gas consumption by the number of kits produced there annually (approx. 1.8 mio. kits). Note that the German electricity mix was used to meet electricity consumption.

2.2.2 Transport

Transporting the kit to the customer can require vastly different amounts of transportation. Customers close to the production site might receive their kit via a single delivery vehicle from the logistics hub, while other customers further away might require delivery by air.

In fact, QIAGEN's transportation heavily depends on aircraft generally. This is because kits often need to arrive very quickly to customers and because some products may require cooling due to the chemical compounds of some products. The QIAamp DNA Mini Kit does not require cooling, however, it is assumed that it is transported via air.

The assumption is made based on weight data from UPS, QIAGEN's main transportation supplier in 2020 in EMEA and the United States. According to UPS data, 75% of the weight is transported via air (AIR), 23% is transported via trucks (GND) and only 2% is transported by ship (OCN).



The transportation scenario developed for this LCA is also based on data regarding QIAGEN's market share for the total portfolio as well as for the QIAamp DNA Mini Kit in 2020. The following table gives an overview of QIAGEN's market share.[1]

Region	Share total portfolio 2020	Share DNA Mini Kit 2020
Americas	44%	27%
EMEA	37%	40%
Asia-Pacific & Japan	19%	33%
Sum	**100%**	**100%**

A transportation scenario was developed based on UPS data as well as based on assumptions and it is distributed into different steps.

Step 1: At the QIAGEN GmbH production site, waste is produced during the production of the kit. The assumption is made that the waste is transported via a disposal truck to a close waste disposal site, where it is incinerated. A nearby waste disposal facility in Hilden is AWISTA Gesellschaft für Abfallwirtschaft, which makes 18km.

Step 2: It is assumed that the kit is transported from QIAGEN GmbH, Hilden, to the closest large airport in the region, which is the airport of Frankfurt, with 239km.

Step 3: From the airport of Frankfurt, the kit is transported globally into different regions. According to UPS data, most of the weight (in kg) is transported to the United States, Germany, China and Spain. For the region Americas, the United States (New York) is chosen as the representative destination country. For EMEAS, it is not Germany but Spain (Madrid) which is chosen as the representative destination country, as it may be more representative for other European countries, such as the United Kingdom, France, and the Netherlands. Choosing Spain over Germany as a representative country is also the more conservative approach for the LCA. For the region Asia-Pacific & Japan, China (Shanghai) is chosen as the representative country.

[1] https://financialreport.qiagen.com/non-financial-statement - see section "Region of Origin of Suppliers"

Countries	Transported Weight_KG
Netherlands	**6.775.456**
United States	**2.777.082**
Germany	
United States	306.211
Germany	69.788
China	16.364
Spain	9.048
United Kingdom	6.823
France	5.398
Netherlands	5.107
Italy	4.582
Switzerland	3.908
Austria	2.539
Sweden	2.471

Figure 5: UPS transportation data 2020

The above-mentioned assumptions result in the following distances. It should be stated that the transportation scenario is based on very rudimentary assumptions and that data availability could be improved in the following years. Based on the distances between the airports and the market share, the average flight distance of a kit is 5,187km.

Region	Scenario 2 (DNA Mini Kit)	Distance	Distance [km]	Source for distance	Scenario 2 Average distance [km]
Americas	27%	Frankfurt - New York	6.261	https://www.distance.to/	
EMEA	40%	Frankfurt - Madrid	1.434	https://www.distance.to/	
Asian-Pacific/Japan	33%	Frankfurt - Shanghai	8.858	https://www.distance.to/	
Ergebnis	**100%**		**5.518**		**5.187**

Step 4: From the different international airports, the kit is transported via truck to the customers. There is not sufficient data to retrieve how a kit generally travels after arriving at an airport. For this reason, very general assumptions are applied, namely that travel distances in the Americas and Asia-Pacific/Japan are longer (1,000km) whereas in EMEA, they are generally shorter (500km). It needs to be pointed out that these assumptions are very generalized, and that data availability should be improved to develop a more accurate transportation scenario in the future. Based on these assumptions as well as the market share of the QIAamp DNA Mini Kit, a distance of 800km via truck is calculated.

Region	Scenario 2 (DNA Mini Kit)	Distance	Distance [km]	Source for distance	Scenario 2 Average distance [km]
Americas	27%	New York - Other cities	1.000	Assumption sustainable	
EMEA	40%	Madrid - Other cities	500	Assumption sustainable	
Asian-Pacific/Japan	33%	Shanghai - Other cities	1.000	Assumption sustainable	
Ergebnis	**100%**		**833**		**800**

Step 5: After the kit has been used by the customer, it is assumed that it is disposed of and incinerated in a nearby disposal site. It is assumed that disposal sites are readily available in every town which is why the distance does not exceed 50km via disposal truck.

These five steps result in the following transportation scenario. For the modelling of the LCA, emission factors per transported kilometer and weight are used. In the first step, it is assumed that 3.04 grams are transported which are calculated by dividing QIAGEN GmbH's total waste by the number of total kits produced at QIAGEN GmbH in 2020 (~1.8 million). In Step 2-5, the total kit weight including secondary and transportation packaging is summed up which results in 3.5 kilograms.

Step	Description	Distance [km]	Transportation medium	Transported weight [g]
1	QIAGEN GmbH - AWISTA	18	Disposal truck	3,04
2	QIAGEN GmbH - Frankfurt airport	239	Truck	3.503,6
3	Frankfurt airport - Airports world-wide	5.187	Airplane	3.503,6
4	Airrports world-wide - customer	800	Truck	3.503,6
5	Customer - Waste disposal	50	Disposal truck	3.503,6

2.2.3 Use

Using the kit requires some materials to be added from the laboratory, notably alcohol and purified water.

Spin columns were assumed to be spun in a microcentrifuge. The designated time for centrifugation is stated 6 min in the instructions of use. However, certain steps require additional spinning, while some sampling methods require incubation of samples in a heated environment. To account for the different circumstances, energy consumption during spinning was therefore modeled with a wattage of 180 watts from the European electricity mix, assuming that 2.5 columns are spun at the same time, with a total spinning duration of 10 min. The data is derived for the centrifuge "Thermo Scientific" which is an average centrifuge used for DNA mini kits. Further data regarding the use time is derived from the DNA Mini Kit Protocol and is based on QIAGEN's recommendations. The amount of electricity used can vary significantly with the efficiency of the centrifuges and the operating mode. More samples per run significantly reduce the amount of electricity used per sample.

2.2.4 Disposal

Some residuals of the used kit can be subject to material recycling. Provided they are collected separately, paper, cardboard, and most uncontaminated plastic parts are well recyclable as single-variety materials (bottles, bottle caps, sample tubes). However, the circumstances of use in laboratories on a global scale makes the assumption of consistent waste separation difficult to uphold.

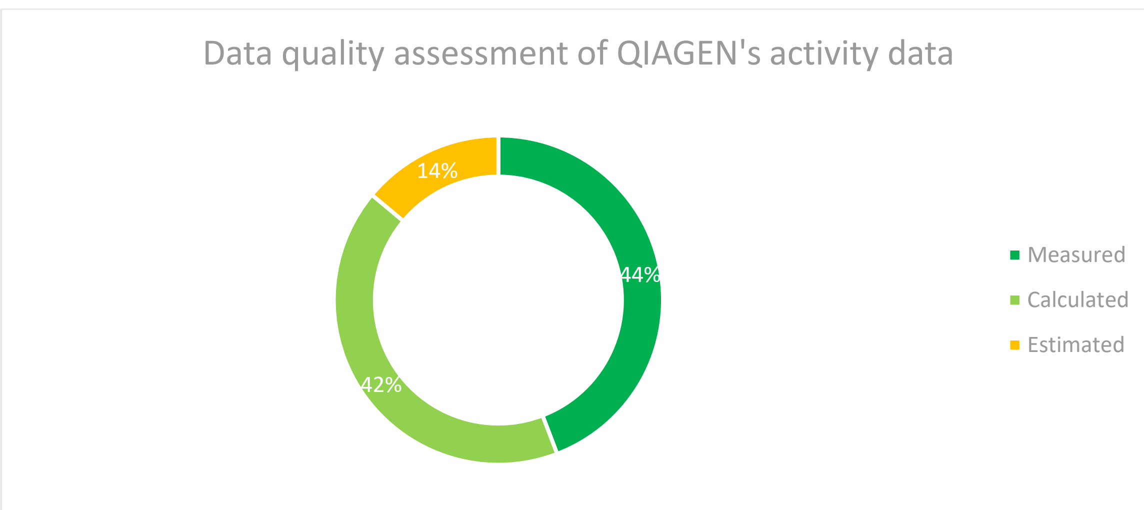
It is therefore assumed that the entire kit is disposed of by incineration, preceded by transport to suitable incineration facilities over a distance of 50 km.

Improper disposal can impose a huge impact on the environment. Plastics pollution of soil and water bodies is not adequately accounted for in LCIAs in general, as is the impact of biotechnology, if the chemical compounds reach the ecosphere untreated. Environmentally safe disposal is therefore crucial to prevent such impacts.

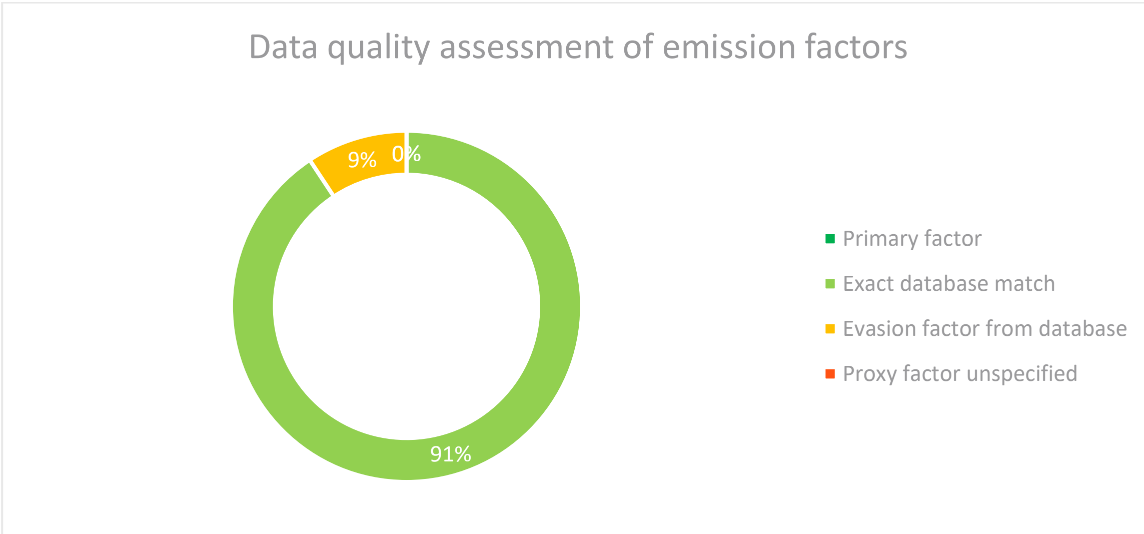
2.3 Data quality

Most information has been primary activity data supplied by QIAGEN. Secondary data had to be used to model the sensible parameters of transport and electricity consumption during use. Supplier-specific information on the production processes of semi-finished goods has not been used.

Regarding the input/activity data, 44% has been measured and is retrieved from SAP systems. 42% of data is calculated and 14% is estimated.



Regarding the emission factors, no primary factors (from suppliers) were applied. For more than 90% of materials and inputs, an exact database match (in ecoinvent v3.8) was applied. For 9% of data, an alternative emission factor (e.g. ammonia for chemicals with less than 1% of the kits total weight) was chosen.



Overall, the data quality both regarding QIAGEN's activity data and the emission factors can be rated as good. In the future, data quality could be improved by replacing estimated and calculated data points with measured data points.

3 Impact Assessment

For the Life Cycle Impact Assessment, all elementary flows from (e.g., crude oil) and into the eco-sphere (e.g., CO_2-emissions) are consolidated and factored into different impact categories, according to the chosen Life Cycle Impact Assessment method. The most prominent set of impact factors refers to Global warming and is published in the 5th Intergovernmental Panel on Climate Change's (IPCC) assessment reports. It includes factors for atmospheric emissions to represent their impact on climate change, referred to as Global Warming Potential (GWP), and expressed as carbon dioxide equivalent (CO_2e). Over the timeframe of 100 years, every gram of CO_2 emission has a GWP of 1 g CO_2e, while methane emissions have a GWP of 28 g CO_2e.

3.1 Life Cycle Impact Assessment Method (LCIA)

The method chosen is CML-IA baseline within SimaPro. CML-IA is a LCA methodology developed by the Center of Environmental Science (CML) of Leiden University in The Netherlands[2]. This method is an update of the CML 2 baseline 2000 and corresponds to the files published by CML in August 2016 (version 4.7). The CML 2 baseline 2000 version can be found in the 'superseded' list. For most impact categories, substances have been added and removed and/or characterization factors were updated, according to new scientific insight. Only the impact category Photochemical oxidation did not undergo any changes.

The CML-IA (baseline) method elaborates the problem-oriented (midpoint) approach. The CML Guide provides a list of impact assessment categories grouped into:

- A: Obligatory impact categories (Category indicators used in most LCAs)
- B: Additional impact categories (operational indicators exist, but are not often included in LCA studies)
- C: Other impact categories (no operational indicators available, therefore impossible to include quantitatively in LCA)

In case several methods are available for obligatory impact categories a baseline indicator is selected, based on the principle of best available practice. These baseline indicators are category indicators at "mid-point level" (problem-oriented approach)". Baseline indicators are recommended for simplified studies. The guide provides guidelines for inclusion of other methods and impact category indicators in case of detailed studies and extended studies.

[2] More information on: http://cml.leiden.edu/software/data-cmlia.html

Only baseline indicators are available in the CML method in SimaPro (based on CML Excel spreadsheet with characterization and normalization factors). In general, these indicators do not deviate from the ones in the spreadsheet. In case the spreadsheet contained synonyms of substance names already available in the substance list of the SimaPro database, the existing names are used. A distinction is made for emissions to agricultural soil and industrial soil. Emissions to agricultural soil are made clear by placing 'agricultural' in the column 'sub compartment' while emissions to industrial soil are blank. Emissions to seawater are indicated with 'ocean', while emissions to fresh water are blank (we assume that all emissions to water in existing process records are emissions to fresh water)[3].

3.2 Impact categories

CML 2001 (baseline), updated August 2016, contains the following impact categories

- Depletion of abiotic resources
- Global warming
- Ozone layer depletion (steady state)
- Human toxicity (HTP inf),
- Freshwater aquatic ecotoxicity (FAETP inf),
- Marine aquatic ecotoxicology (MAETP inf) and Terrestrial ecotoxicity (TETP inf)
- Photochemical oxidation (high NOx)
- Acidification (incl. fate, average Europe total, A&B)
- Eutrophication (fate not included)

[3] Guinee, J.B., Marieke Gorree, Reinout Heijungs, Gjalt Huppes, Rene Kleijn, Lauran van Oers, A. Wegener Sleeswijk, S. Suh, H.A. Udo de Haes, H. de Bruijn, R. van Duin, M.A.J. Huijbregts (2001). Handbook on Life Cycle Assessment, Operational guide to the ISO standards Volume 1, 2a, 2b and 3.

Huijbregts, M.A.J. LCA normalisation data for the Netherlands (1997/1998), Western Europe (1995) and the World (1990 and 1995).

Wegener Sleeswijk, A., L. van Oers, J. Guinee, J. Struijs and M. Huijbregts (2008). Normalisation in product Life Cycle assessment: An LCA of the Global and European Economic Systems in the year 2000.

3.3 Information sources

Information on environmental impacts of raw materials production (plastics, cardboard, basic chemicals, etc.) and energy input (electricity, heat) are taken directly from aggregated datasets included in the ecoinvent 3.8 database.

3.4 Results Overview

The following section gives an overview of the results overall impact categories. Table 1 shows all results at a glance with their total amounts. Every category is listed with their respective unit and description, this is called the characterization of results.

Table 1: Impact categories with total amount of impacts

Impact category	**Unit**	**Total**
Abiotic depletion	[kg Sb eq]	0,00006
Abiotic depletion (fossil fuels)	[MJ]	413,28
Global warming (GWP100a)	[kg CO2 eq]	29,55
Ozone layer depletion (ODP)	[kg CFC-11 eq]	0,00000
Human toxicity	[kg 1,4-DB eq]	13,41
Fresh water aquatic ecotox.	[kg 1,4-DB eq]	23,16
Marine aquatic ecotoxicity	[kg 1,4-DB eq]	32.349,19
Terrestrial ecotoxicity	[kg 1,4-DB eq]	0,02569
Photochemical oxidation	[kg C2H4 eq]	0,00353
Acidification	[kg SO2 eq]	0,08425
Eutrophication	[kg PO4--- eq]	0,03421

The other perspective is called normalization. There, a single score defines the share of impacts per category compared to the others. Table 2 shows the results with their total share. Within this analysis there is a clear picture of four material impact categories: Abiotic depletion [3.8%], Global warming [1.7%], Fresh water aquatic ecotoxicity [12.8%] and Marine aquatic ecotoxicity [79.2%].

Table 2: Impact categories with share of impacts

Impact category	Unit	Share
Abiotic depletion	[kg Sb eq]	0,2%
Abiotic depletion (fossil fuels)	[MJ]	**3,8%**
Global warming (GWP100a)	[kg CO2 eq]	**1,7%**
Ozone layer depletion (ODP)	[kg CFC-11 eq]	0,0%
Human toxicity	[kg 1,4-DB eq]	0,5%
Fresh water aquatic ecotox.	[kg 1,4-DB eq]	**12,8%**
Marine aquatic ecotoxicity	[kg 1,4-DB eq]	**79,2%**
Terrestrial ecotoxicity	[kg 1,4-DB eq]	0,2%
Photochemical oxidation	[kg C2H4 eq]	0,1%
Acidification	[kg SO2 eq]	0,9%
Eutrophication	[kg PO4--- eq]	0,7%

As these four categories result in a share of more than 97 percent of the total impacts only their analysis per product life cycle stage is shown. In general, the product was divided into ten stages:

- Chemicals
- Liquids
- Spin columns
- Primary packaging
- Secondary packaging
- Transportation packaging
- Transport
- Energy
- Operational waste
- Use phase

Table 3: Detailed analysis from SimaPro for impact categories sorted by chosen life cycle stage

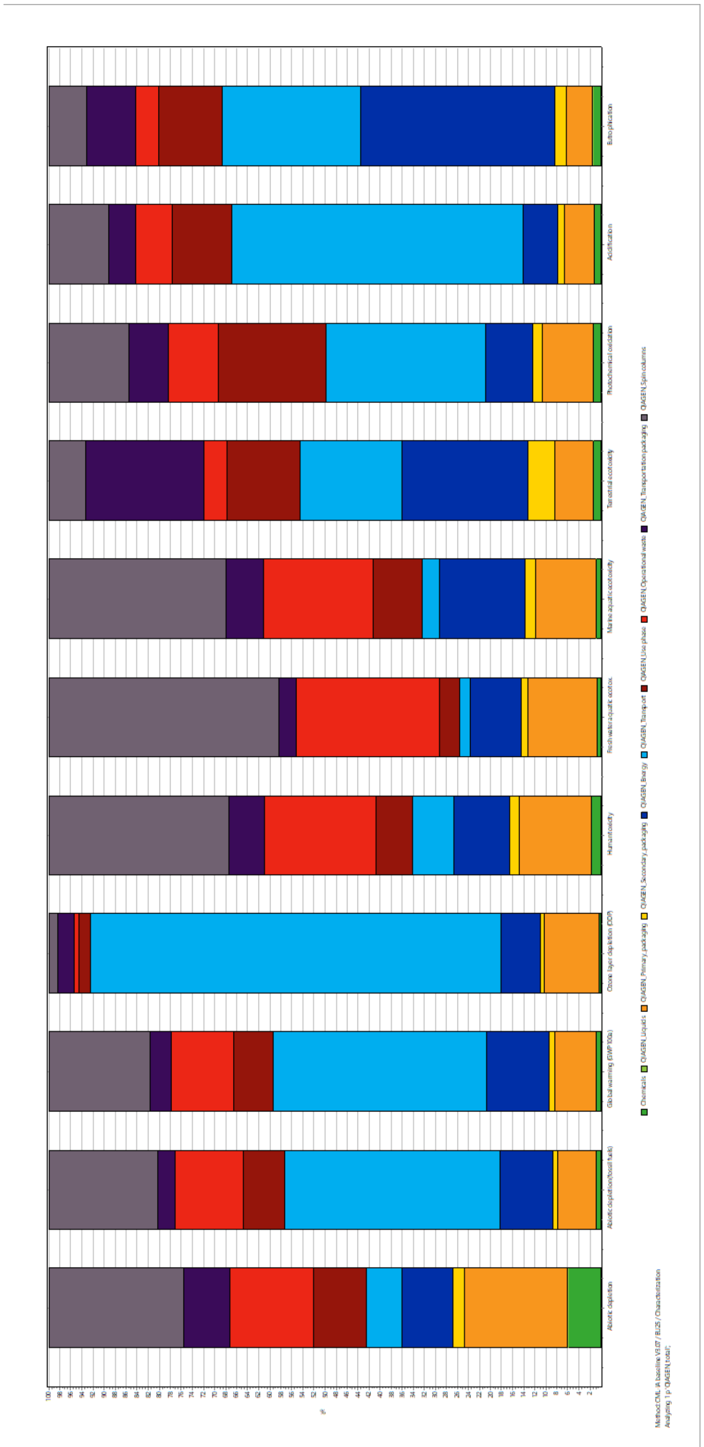


Table 4: Global warming (GWP100a) defined in kg CO2 eq

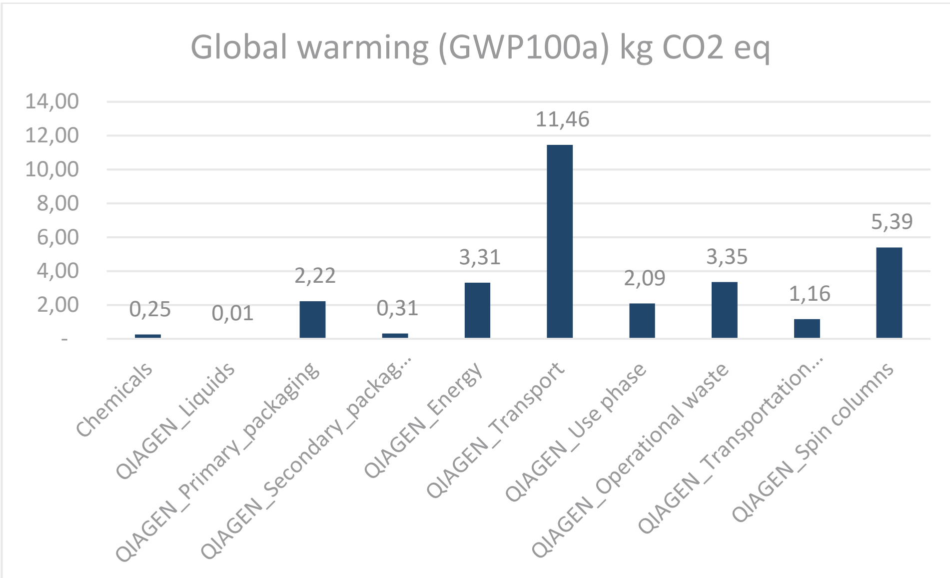


Table 5: Fresh water aquatic ecotoxicity defined in kg 1,4-DB eq

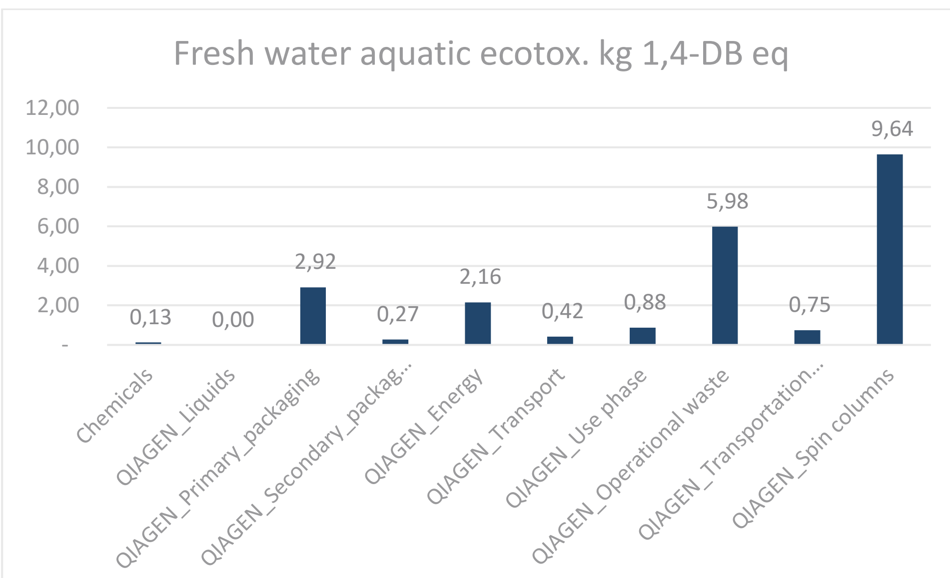


Table 6: Marine aquatic ecotoxicity defined in kg 1,4-DB eq

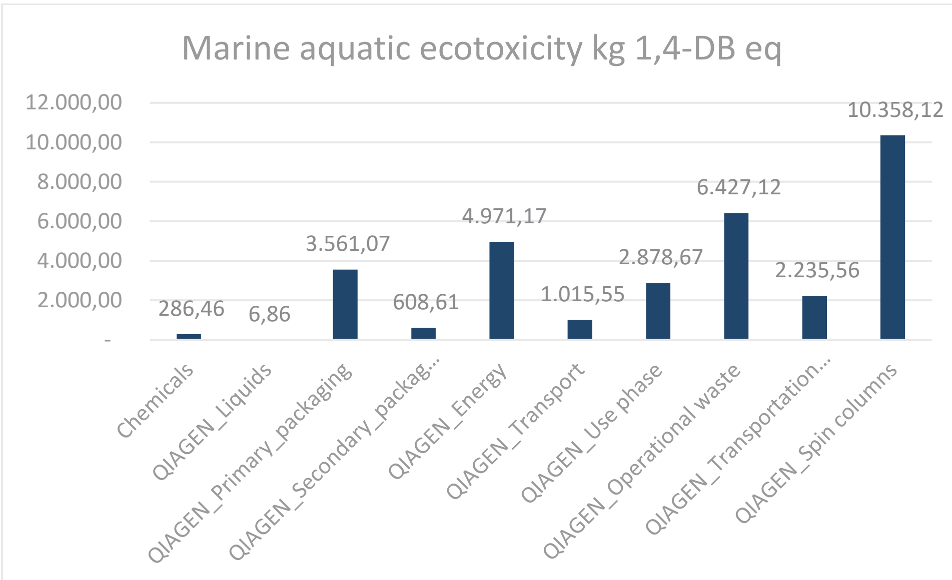
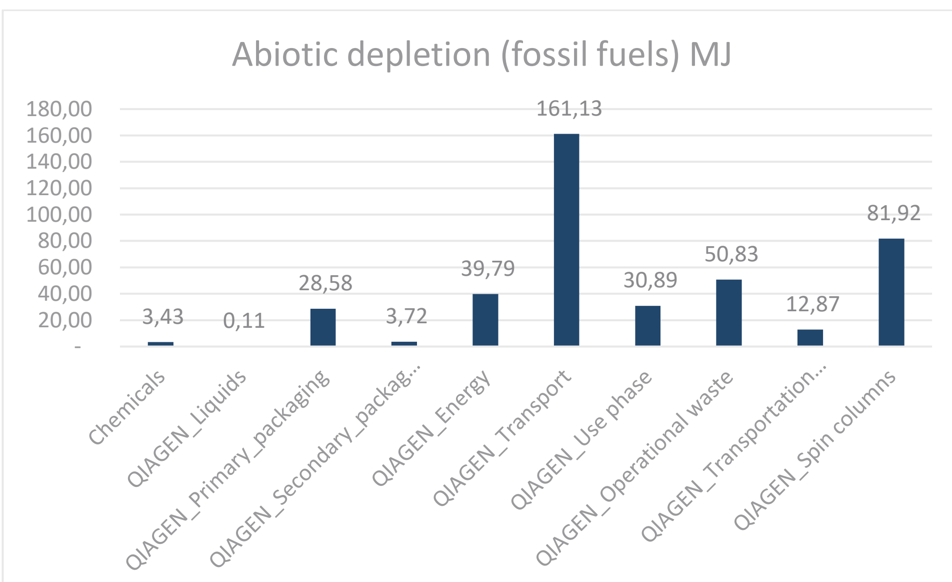


Table 7: Abiotic depletion (fossil fuels) defined in MJ



3.5 Relevant impact categories

Depletion of abiotic resources

Two impact categories: Abiotic depletion (elements, ultimate reserves) and abiotic depletion (fossil fuels)

Abiotic depletion (elements, ultimate reserves) is related to extraction of minerals due to inputs in the system. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals (kg antimony equivalents/kg extraction) based on concentration reserves and rate of deaccumulation. Abiotic depletion of fossil fuels is related to the Lower Heating Value (LHV) expressed in MJ per kg of m3 fossil fuel. The reason for taking the LHV is that fossil fuels are considered to be fully substitutable.

Global warming

The characterization model as developed by the Intergovernmental Panel on Climate Change (IPCC) is selected for development of characterization factors. Factors are expressed as Global Warming Potential for time horizon 100 years (GWP100), in kg carbon dioxide equivalent/kg emission.

Ozone layer depletion (steady state)

The characterization model is developed by the World Meteorological Organization (WMO) and defines ozone depletion potential of different gases (kg CFC-11 equivalent/ kg emission).

Human toxicity (HTP inf), Freshwater aquatic ecotoxicity (FAETP inf), Marine aquatic ecotoxicology (MAETP inf) and Terrestrial ecotoxicity (TETP inf)

Characterization factors, expressed as Human Toxicity Potentials (HTP), are calculated with USES-LCA, describing fate, exposure and effects of toxic substances for an infinite time horizon. For each toxic substance HTP's are expressed as 1,4-dichlorobenzene equivalents/ kg emission.

Photochemical oxidation (high NOx)

The model is developed by Jenkin & Hayman and Derwent and defines photochemical oxidation expressed in kg ethylene equivalents per kg emission.

Acidification (incl. fate, average Europe total, A&B)

Acidification potential expressed in kg SO2 equivalents per kg emission. Model is developed by Huijbregts.

Eutrophication (fate not included)

Eutrophication potential developed by Heijungs et al and expressed in kg PO4 equivalents per kg emission.

4 Interpretation of the Results

To contextualize the resulting values for all impact categories, they are interpreted against the goal and scope of the study. Categories with high share contribute substantially to the totals of the respective category. Note that this share rating is based on weighting from CML-IA baseline and should be understood as an indication of the impact profile for the studied product system.

4.1 Description of the Results

Generally, most processes and materials are driven to be the largest contributors to most impact categories by their energy demand. Impacts from transport, electricity generation and plastics production therefore lead most categories. About two thirds of electricity is consumed for production, the remainder is used in the labs to spin the columns. Note that the electricity demand is modeled to be met by the German and Rest-of-World electricity mix.

The relevance rating described above makes ecotoxicity impacts to marine and freshwater aquatic systems a very relevant issue. Together, they define 92 percent of the single score weighing by CML-IA. Production of polypropylene for the spin columns and the assumption that the operational waste is mostly polypropylene cause the highest impacts in this category, closely followed by electricity generation and primary packaging. Note that impacts from polypropylene production are independent of the varying aspects like customer location. Impacts from electricity generation in turn will vary with the lab's efficiency and the local electricity mix.

Depletion of fossil resources is third rated in relevance per share of single score. Transport and electricity generation both use large amounts of fossil resources for fuel. In addition, plastics have multifold impacts in this category, due to them being made from fossil resources and depleting a large amount of fossil resources for meeting the energy demand during their production.

Global Warming Potential is rated fourth in relevance. This showcases the subjective nature of the weighting process, as the method used in weighting does not account for urgency. Climate change is arguably the most urgent global environmental challenge. Again, impacts in this category are closely linked to energy demand. Transport contributes the largest impact in this category, followed by plastics, operational waste, and electricity production. Plastics also have multifold impacts here since their embodied carbon is released to the atmosphere during incineration. Note that a possible energy recovery is not considered in this LCA, which would reduce the impact in this and other categories.

Further interpretations:

- Photochemical creation of ozone (summer smog): Although transport and electricity generation are large contributors to this category.
- Acidification of soil and water bodies: Transport, plastics production and electricity generation contribute most to this category.
- Toxic effects on humans: Impacts in this category stem mainly from plastics production.
- Except for toxicity to ozone depletion, all other impact categories are dominated by impacts from transport of electricity generation.

4.2 Limitations

Transport is the most impactful activity during the product life cycle. Concerning data quality, the transport model is based on QIAGEN global sales statistics, such that the regional location of customers is known, therefore the share of transport in the overall impacts is considered representative. The transport datasets available in the databases are modeled to primarily represent bulk logistics. Especially the first steps in the delivery chain to the customer resemble bulk logistics. As most of the transport was conducted via UPS and per air freight the emissions and energy contributions are the largest.

Electricity generation causes a big amount of the impact in this LCA. Note that the consumption was modeled using the national electricity mix of Germany. Germany has a relatively emission-intensive electricity mix. Compared to the German average, has Europe a relatively “clean”, i.e., greenhouse gas electricity mix. However, using the kit in geographic regions with a high emission factor, like the US or China, could easily double the emissions in the use phase.

Impacts from Electricity generation are assessed on a location-based approach with German regionality. All electricity produced is therefore assumed to be produced by a mix of power plants representative of Germany. The emission intensity of individual contracts, e.g., for renewable electricity supply, is not considered to ensure comparability of the LCIA results. Employing a location-based approach is good practice in LCA. In contrast, employing the so-called market-based approach, individual contract’s electricity mix are considered, which can lead to significantly lower impacts, particularly in Global Warming Potential.

Biotechnology in general is a challenging sector for LCA studies, especially when some of the chemicals involved reach the ecosphere untreated, for example by run-off water, when chemicals are not disposed of properly. In this LCA, all chemical compounds with strongly detrimental effects on lifeforms are assumed to be disposed of properly, removing toxic properties through incineration.

The disposal of the kit's elements by incineration can yield electricity and heat. These flows are cut off in the model, assuming that no form of energy recovery takes place. By assuming an avoided burden for electricity production from fossil fuels, one could incorporate a credit for these.

No supplier-specific information on the production processes of semi-finished goods has been used, for example to model the plastic containers. It is advisable to use an average consumption mix, until more precise information is known. Possible future use of recycled material in bottles production could significantly reduce emissions and many other impacts.

Other products in QIAGEN's consumables portfolio are transported cooled using dry ice and/or gel packs. These products can be expected to have a larger impact due to increased package weight, faster and therefore less emission-efficient transport and the additional impacts of producing the coolants.

4.3 Conclusion and possible improvement potential

From the perspective of LCIA, the assessed product's impacts are – and therefore QIAGEN's consumable products' impacts – can be expected to be headed by plastic production (parts and packaging) and transport. Using plastic from fossil resources – especially combined with incineration instead of recycling – leads to relatively large impacts across several categories. Note that single score introduced above suggests that the product has a relatively large contribution to marine and freshwater aquatic ecotoxicity, resource depletion and global warming. While the studied product is not considered a particular greenhouse gas intensive product, climate change might well be seen as the most urgent issue among those covered.

The studied product – representative for QIAGEN consumables – serves an important purpose and must meet high demands regarding consistent properties, inertness to samples and chemicals as well as reliable, contamination-free use. Therefore, the factors influencing environmental impact (e.g., amount and choice of materials) cannot be changed arbitrarily. Between choosing different materials for production and ensuring proper waste separation and recycling, it becomes clear that different aspects of the product life cycle can be engaged more easily than others to improve the impact profile.

Some aspects are **under direct control** of QIAGEN:

- energy efficiency during production
- QIAGEN's electricity provider, i.e., the electricity mix
- choice of materials

- choice of suppliers

QIAGEN arguably has a **limited influence** on some aspects:

- electricity demand during use
- proper disposal of waste and residuals
- emission intensity of transport to the customer
- upstream production and transport
- manufacturing conditions at suppliers

Certain aspects are **not under control** of QIAGEN:

- the customer's electricity provider and therefore the electricity production mix
- local regulations concerning disposal of contaminated and non-contaminated material
- local emission regulations for transport and incineration

Local circumstances of **waste management** systems cannot by influenced by QIAGEN. During incineration of the product, any form of **energy recovery** would make a huge difference to several impact categories, notably global warming potential. Disposal by incineration could (should) also be preceded by material **recycling**. Most of the kit's elements are made from single-material plastics and should therefore be well recyclable. Especially the included plastic bottles could represent a valuable material flow, as they are not being contaminated during use and therefore considered non-dangerous waste.

Given the above impact profile, different aspects of the product life cycle can effectively reduce the impacts in several categories. QIAGEN has indirect influence on the actual **handling of the kit during use.** QIAGEN could research secure and reliable procedures of use ("protocols") to ensure successful application of their products with **minimized energy and resource consumption** – therefore minimized impacts. Raising customers' awareness and thereby reducing the amount of energy consumed during use and facilitating and **ensuring proper disposal** – thereby enabling material recycling – can effectively limit impacts in several categories. Integrating information into the instructions of use and printing disposal and recycling information directly onto packaging and kit elements could therefore potentially lower impacts from the product's end of life. **Providing training** (e.g., regarding energy and material efficient application, as well as waste separation and management), **equipment** (e.g., energy efficient sampling and processing machines) **and services** (e.g., collecting and recycling used containers) can effectively influence customer behavior.

Transport is another very influential aspect regarding the product's environmental impacts. The overall distance to the customer is certainly the most significant factor here. The huge differences in mileage between an inland transport and a transcontinental flight will lead to a large impact under most circumstances, due to the sheer distance covered. Of course, **efficient capacity utilization** is also an important factor and could reduce emissions by a significant amount.

Transporting a larger number of kits per trip reduces transport emission intensity. Using **fuel-efficient** vehicles reduces consumption and advanced emission control technologies significantly reduce the environmental impacts in several categories. Finally, the **choice of transport vehicle** determines delivery speed, but also environmental impacts. Especially when shipping transcontinental, container ships use a fraction of the energy compared to cargo planes. QIAGEN can therefore **promote und encourage** customers to choose slower and more efficient forms of transports, with a focus on reducing transports by plane. Generally, and across all transport modes, the closer the transport approaches the customer, the more impact per mile can usually be expected, along with other common challenges of the "last mile". The environmental impacts will most likely decrease from progressing developments by logistics companies in this aspect. Finally, the only way to **reduce the actual transport distances** is to increase the number of global production sites and **ensure regional sourcing** of materials.

Regarding **production** itself, QIAGEN can directly influence several aspects with a direct connection to environmental impacts. While not manufacturing the bottles in-house, QIAGEN has the choice of **materials and suppliers**. While the material choice could also possibly increase weight (i.e., with glass), other options can reduce environmental impacts without influencing other factors, notably sourcing **recycled plastic** for the containers and other elements of the kit. In-house at QIAGEN, traditional methods of **energy management** – with a certain focus on carbon emissions – reduce not only running costs, but also the amount of energy used during production. By continuously **implementing reduction measures** in the areas of e.g., **lighting, efficient equipment and machinery, energy saving procedures and energy recovery** as well as by **self-producing or sourcing energy from high-quality renewable sources**, impacts in connection with electricity and gas consumption can be mitigated effectively.

Finally, after putting reasonable approaches to avoid impacts reduction into practice, **compensation** can play a role for some impact categories. Some impacts have a strong regional component (e.g., POCP, or "summer smog"). Others cannot be reasonably compensated for (e.g., resource depletion). On the other hand, especially impacts on Global Warming are independent of geographic emission intensity and can be negated by removing greenhouse gases from the atmosphere. Therefore, investing in high-quality **certificates from the voluntary carbon compensation market** to avoid emissions elsewhere or preferably remove greenhouses gases from the atmosphere is a complementary step to holistic management of environmental impacts. With the right approach, QIAGEN could credibly offer services and products with neutralized impact on global warming.