# Case study: Chemical industry

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Monitoring the Bioeconomy

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[1] PU = public
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# 1 Summary

This case study will focus on a selected part of the chemical industry and will apply the developed monitoring methodologies to assess the applicability to a diverse sector which consists of both mature and new industries using bio-based materials. Several socio-economic indicators will be tested in the course of the case study regarding feasibility, meaningfulness, data requirements and validity for monitoring the bioeconomy. To apply these indicators to the chosen sectors of the chemical industry, we have to collect and assess the required data. Therefore, several valid sources of information and data will be introduced and exploited in order to cover the various aspects of a heterogenous and hybrid sector that is the chemical industry. This data and the subsequently calculated indicators are then complemented and validated during expert interviews with stakeholders and experts from the chosen sectors. The strengths, weaknesses, barriers and opportunities of the methodology will be shown as a result of this analytical task. The outcome of this case study will support the work previously accomplished and yet to come in WP3 and provide valuable input for the proceeding of the work in WP3.

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# 2 Introduction

In today's data collection and monitoring frameworks of (socio-)economic data, there is no sufficient distinction between the conventional, fossil-based economy and its counterpart, the bioeconomy. Having a clear and meaningful overview of the bioeconomy in Europe is a critical step towards sustainability and environmental goals that already are or are becoming a great part of the focus of policy makers and regulatory instruments. The Horizon2020 project BioMonitor aims to provide mechanics and instruments to support a qualitative and quantitative monitoring of the bioeconomy, that is superior to the approaches so far.

Some of these core mechanics and methodologies will be tested and evaluated in this case study to point out valuable lessons learnt during the first parts of the project and also provide practical examples on how these methodologies can be applied fruitfully.

A great challenge when trying to distinguish between the fossil-based and bio-based economy are these sectors, that can neither be fully attributed towards the fossil-based economy nor the bio-based economy. These hybrid sectors demand a broad set of methods and approaches to be split reputably into the two underlying sectors bio- and fossil-based.

One of these hybrid sectors, which also accounts for a great amount of value generated by manufacturing goods in the EU economy, is the chemical industry. This case study will focus on a selected part of the chemical industry in order to point out the challenges and barriers that exist, the learnings we achieved so far, and the opportunities the status quo in the EU already provides.
We will apply the developed monitoring methodologies to assess the applicability on a diverse sector which consists of both mature and new industries using bio-based materials.

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# 3 Scope and goal of the case study

In order to usefully monitor and understandably display the collected data of the EU bioeconomy, indicators applying and processing the available data are necessary. Therefore, a set of indicators covering all relevant aspects of the bioeconomy has been developed in the early work packages WP 1, WP 2 and WP 3 of BioMonitor. These indicators aim to be meaningful for all relevant topics, that the bioeconomy touches, impacts and relies on. However, the data the indicators require to be calculated and expressed correctly are often of a very specific nature. The main challenges when working with the indicators are gathering the required data, pointing out issues of the available data, and identifying data gaps. Following these three challenges it is also important to provide helpful advice and learnings to simplify and improve the data collection methods in the long term.

## 3.1 Methodological scope

In general, this case study's aim is to test the data collection methods identified for the indicators regarding these likely challenges. In this process, the findings are verified with experts to receive feedback and subsequently apply this feedback to improve the process. Two aspects are critical to define the scope of the case study. On the one hand, there is the selection of indicators, that the methodology is tested on. On the other hand, specific cases, that fit the intentions and scope of the case study had to be identified.

This case study examines the previously developed monitoring methodology in the field of the chemical industry. nova Institute draws on a long and fruitful history researching and cooperating with the chemical industry. The experiences, information, networks, and overall expertise in this field are key components to thoroughly perform this case study.

As mentioned before, monitoring the bioeconomy with a broad set of indicators requires an even broader set of initial data, which is processed and interpreted by the indicators. The earlier work packages examine the data collection processes and reveal limitations of the prevalent data. Also, methodologies to overcome these data limitations have been developed and proposed. This case study aims to exemplarily test on a smaller set of indicators how feasible the quantification of these indicators turns out to be and how well these methodologies work in practice. The indicators to be tested in the case studies were previously identified and for the chemical industry case study the following socio-economic indicators were identified:

1. Patents submitted (number)
2. Private and public sector bioeconomy investments in R&D
3. Turnover and Value-added of sectors
4. Share of SMEs and high-tech companies in the respective sectors
5. Bio-material replacing non-renewable resources
6. Terms-of-Trade/export & import prices of sectors
7. Production/consumption of sector
8. People employed by the sectors

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These indicators cover a broad field of information, that they are able to display and process. Also, the nature of input data required to quantify the indicators is diverse and allows for testing different data sources regarding their viability.

## 3.2 Field of observations

The chemical sector is an interesting sector to look at when monitoring the bioeconomy. A significant part of the chemical industry consists of well-implemented products based on mature technologies, that are mostly based on fossil resources. However, the sector also contributes to the bioeconomy more and more. There are already bio-based building blocks and polymers produced at larger scale. Also, many innovative technologies are currently being developed or in the pilot and demonstration phase with clear intentions to scale up where possible. It is driven by innovation in many fields. It is a hybrid between fossil-based and bio-based production and processing large amounts of feedstock into products, generating great value. Especially for socio-economic indicators, with a focus of transformation and innovation, the chemical sector offers a well-founded frame to look at closer in this case study. Since the chemical industry is one of the most diverse industries with a product line up, that ranges from basic and intermediate products to high technology products in many fields of application, it is rather difficult to make absolute statements.

To condense the broad product line up of the chemical industry down to a selection, that expresses mature and well-implemented products and innovative and currently developing markets, two products have been identified for the case study.

### 3.2.1 Lubricants

Firstly, the lubricant industry is a mature and well-implemented part of the chemical industry. While a large part of it is still based on fossil resources, a significant switch to bio-based resources has been observed lately. Lubricating products derived from bio-based resources and having a significant bio-based content were subsequently even allocated a newly implemented own code in the PRODCOM database. Lubricants are registered in PRODCOM with two specific codes:

1. **20.59.41.59**: Lubricants having a bio-based carbon content of at least 25 % by mass and which are biodegradable at a level of at least 60 %

2. **20.59.41.58**: Lubricating preparations obtained from petroleum or bituminous minerals […]

The main focus will be on the product code **20.59.41.59,** that is specifically acknowledged as (partly) bio-based. Testing a product group with its own distinctive product code for their bio-based versions allows this case study to point out, how helpful these bio-based product codes are for monitoring the bioeconomy reliably. However, since the threshold to fall into category 20.59.41.59 is a bio-based carbon content of at least 25 %, all lubricating preparations having a bio-based carbon content below 25 % are recorded elsewhere. This is why the code **20.59.41.58** must also be referenced.

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The assumption is that data availability for this mature product group with a dedicated PRODCOM code for bio-based lubricants is generally good.

The driving factors behind bio-based lubricant products can be broken down into two main aspects. Firstly, the price premium the consumers have to pay to use products with a higher bio-based content is a significant barrier. The prices of fully bio-based products compared to fossil-based products are up to five times higher which many consumers are not willing to pay. From a technical point of view up to 90 % of resources in the lubricant industry could be bio-based.
Secondly, binding quotas on bio-based contents or similar regulatory measures are not introduced by policymakers which then does not incentivise the use of bio-based alternatives or paying the green premium. Producing and using the fossil-based products is simply too cheap and comfortable for consumers.

### 3.2.2 Polyhydroxyalkanoates (PHAs)

Secondly, Polyhydroxyalkanoates (PHAs) have been identified as a fitting counterpart to lubricants. PHAs are biodegradable polyesters, that can be used in production of bio-based plastics. They can only be produced by microbial fermentation of any natural carbon resource making them fully bio-based by definition. However, PHAs fall into the category of innovative products currently establishing a market and being in the transformation process from the pilot phase to scaled-up production.

Given the position PHAs are in regarding a product's life cycle and their unique nature as a chemical product in the early stages of commercialisation, there is no dedicated PRODCOM code for PHAs in the Eurostat databases. In consultation with nova-internal experts we distinguished the following PRODCOM code as the product code, in which PHAs should be included at the moment:

**20.16.40.90** - Polyesters, in primary forms (excluding polyacetals, polyethers, epoxide resins, polycarbonates, alkyd resins, polyethylene terephthalate, other unsaturated polyesters)

Taking into account the high production volumes and values of this product group and the commercialization stage of PHAs, the challenge becomes quite clear. This product code includes a significant amount of other polyesters besides PHA making it difficult to derive specific numbers for specific polyester products. The assumption is that data availability for PHAs is generally poor based on these observations and the stage that PHAs are currently in.

By testing the quantification of the identified indicators in two cases, one with good and one with poor data availability, the boundaries, challenges and gaps of the methodology will be made obvious.

The major aspects driving the PHA industry and its future development can be found in policy and regulation. Initially, PHAs were and widely still are considered a great bio-based and biodegradable alternative to fossil-based plastics in many forms of application. Globally, the enthusiasm around

PHAs is still huge which can be seen in the much larger production capacities outside of the EU and also the much faster development of the sector. In the EU, the future of PHAs as a valid bio-based alternative to fossil-based plastics is in the hands of policy makers as e.g. the Single Used Plastics Directive may hugely influence how PHAs can be used from July 2021 on. Should PHAs, as stated in the latest guidelines draft to implement the SUPD into national law, be considered a plastic and therefore fall in the scope of the SUPD, future applications of PHAs as an alternative to fossil-based plastics are unlikely. This would likely see PHA production completely move away from Europe and grow further in North America and Asia.

## 3.3 Research questions

The case study follows predefined research questions in its process. The first and fundamental objective is to provide valuable lessons learnt and guidance to best practices for quantifying the indicators. The most crucial part in a hybrid sector as is the chemical industry, is to quantify the share of its bio-based part the best possible way. Only the bio-based parts contribute to the bioeconomy and are therefore crucial for a functioning, meaningful monitoring system.

The second fundamental objective is to test and validate the new bioeconomy indicators: An important driver towards bio-based chemicals is their environmental performance in terms of resource consumption, sustainability and climate change.

As examined above, it will be tested and validated in this case study whether these and other indicators can be quantified for the selected subsector of the chemical industry. Are the quantified indicators in line with expectations of experts from the selected chemical subsector? This will be examined and verified in interviews with stakeholders and experts to discover potential gaps in the methodology.

In order to provide valuable input to the modelling toolbox of BioMonitor, one objective of this case study is to examine: Can the indicators for the two selected parts of the bio-based chemical sector be quantified in such a way that they can meaningfully be used by WP5? The findings from testing the indicators, revealing possible limitations stemming from the given data availabilities and feedback from expert interviews can provide important information for the application of the indicators in the models. Subsequently, the outcomes of the Model Toolbox can be compared to the findings in this case study to see, if the results from the modelling approaches are in line with expectations that stem from the BioMonitor data platform and the findings from the case studies.

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# 4 Methodology

Prior to the case study reporting phase, the scope and methodological approach of the case studies have been determined. The scope of the case study was identified as specific products of the chemical sector and a set of indicators to be tested.

The methodological approach then defines how the case study is conducted in detail. Therefore, the socio-economic indicators selected for this study need to be introduced in more detail to point out the differences and similarities as well as the meaningfulness for the monitoring system.

## 4.1 Indicators

The list of indicators has been briefly mentioned before. Now, the descriptions, relevance and unique requirements of the indicators as well as the information they carry and express are further described.

### 4.1.1 Patents submitted

This indicator aims to show the number of patents linked to the respective sectors, that are submitted to the European Patent Office. The metric of this indicator is the total number of patents identified as relevant for the sector or product per year. Patents are generally linked to innovation and the inventive performance and the transformation from fossil to bio-based requires innovation in many aspects. Therefore, patents linked to a product or sector are a clear indicator to express innovation.

### 4.1.2 Private and public sector bioeconomy investments in R&D

Investments in research and development are a key figure to assess the transformation and innovation efforts in a sector. Also, the return on investment can be derived from the expenditure numbers. The goal is to monitor the expenditures of public bodies and the private sector in bioeconomy related research and development efforts with the metric being the absolute monetary value.

### 4.1.3 Turnover and value-added of sectors

The turnover of a sector, an industry or a product is the key figure to determine its importance and value in the bioeconomy in basic economic terms. It expresses the performance of a sector, industry, or product and is the key indicator considered in this regard. Many other indicators rely on turnover to be calculated or to be put in perspective. The metric for turnover is the monetary value in €.

The value added of a sector or a product takes the meaningfulness of turnover a step further. In deriving the value added by activities attributed to the bioeconomy, cross-sectoral comparisons regarding the economic performance can be performed. This leads to conclusions regarding economic competitiveness of sectors and can indicate how well an e.g. innovative bio-based sector performs compared to a well-implemented fossil-based sector.

Also, it allows to derive the added value per employment in a sector when combining it with employment data. The value added is expressed in monetary value in €.

### 4.1.4 Share of SMEs and large enterprises in the respective sectors

When looking at the economic characteristics of a sector or an industry, it is also important to distinguish between small/medium enterprises (SMEs) and large enterprises (HTEs) actively contributing to this industry. The composition of an industry regarding SMEs and HTEs offers general conclusions on the nature the industry. An industry mainly containing large/high-tech companies usually indicates being well established and historically profitable. The influence on shaping its own governance and future markets is bigger when coming from a strong position as a large enterprise. Also, the possible expenditures in research and development, fostering innovation in the industry, are usually higher for large enterprises.

SMEs are often proficient in very specific parts of an industry and provide valuable knowledge and experience as well as innovation in their niches. They are crucial for diversification of the product varieties and an indicator for an economically strong industrial sector. The metric to express this indicator is the share in % of SMEs and large enterprises of the sector or industry as a whole.

### 4.1.5 Bio-material replacing non-renewable resources

Every product containing bio-based resources contributes to the bioeconomy. To monitor its progress and development, it is crucial to observe how fossil-based resources are getting replaced by bio-based counterparts. Especially in sectors containing many products that are hybrids of fossil and bio-based resources and are in a process of transformation, this indicator is crucial. This indicator divides a sector into to its two subsectors: conventional and bio-based. The metric to express the indicator is tons of oil equivalent.

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### 4.1.6 Terms-of-Trade / export & import prices of sectors

The terms of trade of a product or sector are defined as the ratio between import and export prices. When the export prices are higher than the import prices, the terms of trade of a product in the monitored region are positive. Positive terms of trade signal an economically strong sector in the monitored region and a rather competitive nature compared to its trade partners. The metric for this indicator is an index **≤ or** ≥ one.

### 4.1.7 People employed by the sectors

In terms of socio-economic meaningfulness, the employment in an industry, sector or part of an economy is a key indicator to express its importance besides economic performance. The number of people employed in the bioeconomy is important in many regards. Various other indicators rely on employment data to be derived correctly, for example the productivity of a sector. Also, keeping employment numbers high is an important strategic policy goal and crucial for many policymakers. With the help of this indicator it can be shown how much tie bioeconomy contributes to the overall employment levels but also how the contribution to the bioeconomy per employee compares to other fields. The metric to express employment is employees in full time equivalents.

## 4.2 Data sources and collection

### 4.2.1 Statistical databases

As for many data sets used in BioMonitor, the first source of data is Eurostat's PRODCOM data base. Many of the indicators require data on production volume and value of the specific product to further calculate the socio-economic aspects. Also, export and import data is required in some cases. These data sets can be obtained from the PRODCOM data base on member state (NUTS 0) level on an annual basis up until 2017, which is therefore the latest year of observation for this case study.

Also, employment data is significant in terms of socio-economic observations. Eurostat provides another database, the structural business statistics database, which is used in this case study and which contains data on employment and other structural business aspects.

There is also a wide range of very specific data required for these indicators, that in some cases can be obtained from additional Eurostat databases or other similar databases from institutions other than EUROSTAT. The data availability and level of data, that is available, varies widely among these databases. To combine the different sources into the respective indicators and derive meaningful output is influenced by several factors. The greatest challenge when working with different

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databases is to find ways to overcome the distinctions and derive the indicators on a well-founded statistical base.

Whenever there is data required, that can not be found in the respective databases, other measures have to be taken to provide the missing data for the indicators.

### 4.2.2 Desktop research

One of the possible measures to overcome data gaps, that the databases do not cover, is an explorative desktop research regarding in the specific field. This can prove to be helpful when e.g. a specific coefficient is required to derive a production share or other shares of a hybrid data set. Also, when data is only available on a level of disaggregation, that does not fit the requirements of the indicator, desktop research may result in a better idea how to break down the available data so it can be more meaningful and comparable. Especially regarding the levels of disaggregation of the data further input on how to handle the data is often needed.

### 4.2.3 Expert interviews

Another approach to obtain valuable data, that can be used exemplarily or to test a specific method, is to conduct interviews with experts in the field that shall be monitored. In the course of this case study several experts have been contacted and asked for their willingness to provide input to our cases. Especially experts working in the respective industries often provide reliable and valuable information that is not at all or as clearly expressed in the data bases.

This information ranges from specific data values required to calculate an indicator and evaluations of approaches discussed and followed in the case study. Also, feedback on intermediate results and estimations resulting from the steps in the case study can be collected in interviews. For this case study, it was the aim to interview experts on lubricants as well as PHAs. Especially for PHAs and their expectedly poor data availability, feedback from the industry was much appreciated.

A total of nine experts have been contacted regarding an interview. Out of these nine, three agreed to provide us with information and feedback during an interview.
The contacted experts that agreed to an interview are:

1. Emery Oleochemicals GmbH
2. Fuchs Petrolub SE
3. GO!PHA

All of the interviews resulted in very helpful and important insights, which were subsequently incorporated into the testing and calculation processes. Also, the methodologies of the respective indicators as well as the challenges regarding data availability and calculation have been discussed

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with the interviewees to gather feedback on best practices and estimations on how meaningful the results of the different approximations and derivations can be.

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# 5 Data requirements and availability challenges

The data requirements for the various indicators are often heterogenous and all pose their own challenges and difficulties. The following table gives an overview of the specific data required to test and calculate the indicators in the scope of this case study.

## 5.1 Data needs of the indicators

The following table shows the specific data needs of each indicator as defined in its fact sheet. These fact sheets have been developed in BioMonitor WP3 as part of the development of the bioeconomy database. The functionality and also possible barriers of these fact sheets will be pointed out in the course of the case study.

| Indicator | Calculation of indicator | Data required | Main data sources |
|---|---|---|---|
| Patents submitted | $Number\ in\ total$ | Patents linked to specific product or sector | EUROSTAT - Patent applications to European patents office |
| | | | Patent database of EPO |
| Private and public sector bioeconomy investments in R&D | $expenditures \times product\ coefficient$ | Business expenditures in R&D | EUROSTAT - Business expenditure on R&D (BERD) by NACE Rev. 2 activity |
| | | Product coefficient derived from production data | EUROSTAT – Prodcom database |
| | | Public-sector expenditures | OECD – key biotechnology indicators database |

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| Turnover and value added of sectors | $turnover \times bio - based\ share$ | Turnover data | EUROSTAT – Prodcom database |
| | | Bio-based shares | Nova – BIC report |
| | $value\ added \times product\ coefficient \times bio - based\ share$ | Value added at factor costs | EUROSTAT - Annual detailed enterprise statistics for industry |
| | | Product coefficient derived from production data | EUROSTAT – Prodcom database |
| | | Bio-based shares | Nova – BIC report |
| Share of SMEs and large enterprises in the respective sectors | $\frac{number\ of\ SMEs}{total\ number\ of\ enterprises}$ | Number of SMEs or large enterprises in the field | EUROSTAT - Industry by employment size class |
| | $\frac{number\ of\ large\ enterprises}{total\ number\ of\ enterprises}$ | Total number of producers in the field | EUROSTAT - Industry by employment size class |
| Bio-material replacing non-renewable resources | $\frac{production\ volume \times bio - based\ share}{fossil\ input\ per\ kg\ of\ product}$ | Production volume | EUROSTAT – Prodcom database |
| | | Bio-based share | Nova – BIC report |
| | | Fossil resource input per output coefficient | |

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| Terms-of-Trade/export & import prices of sectors | $\frac{export\ price\ index}{import\ price\ index}$ | Export quantity | EUROSTAT – COMEXT Sold production, exports and imports by PRODCOM list |
| | | Export value | |
| | | Import quantity | |
| | | Import value | |
| People employed by the sector | $Employment\ in\ FTE\ \times\ bio-based\ share$ | Employment in FTE | EUROSTAT – Structural business statistics |
| | | Bio-based shares | Nova – BIC report |

## 5.2 Level of disaggregation

The data we are working with in BioMonitor and which is mainly provided by the various databases developed and maintained by EUROSTAT does not follow a common approach of provision and availability. Regarding their regionality, the most common level of disaggregation is the NUTS 0 level, which means that the data is available on member state level for the European Union.

The other critical factor depending on a level of disaggregation is the distinguishing of sectors, industries, and products. This is provided by the NACE rev. 2 classification system. Data taken from the Prodcom database is available at an 8-digit NACE rev. 2 level (e.g. **20.59.41.59**) which allows a look at specific products and product groups in this level.

Especially the highest level of disaggregation available for the different data sets is often a cause for concern. Generally, BioMonitor aims to monitor, process, and display the indicators on the NUTS 0 level regarding regionality, and on the 8-digit NACE rev. 2 level regarding product segmentation as these levels allow a meaningful monitoring of product-specific and member state specific part of the bioeconomy. However, apart from the Prodcom database, which operates on the desired NACE rev. 2 8-digit level, there are numerous databases only looking at less specified disaggregation levels. Several of the indicators in the scope if BioMonitor as a whole and in this case study in particular rely on data from the structural business statistics or similar sources. The level of disaggregation is often rather low when handling these kinds of data. One reason may be to provide a certain level of confidentiality for the industries, that report the data to EUROSTAT. Other reasons, e.g. more specific data being simply not reported to EUROSTAT yet or the reporting and collection of more specific data being too effortful, are also possible and may vary.

Since BioMonitor is focusing on the bioeconomy, another key aspect with a required level of disaggregation is the bio-based part of a product. What share of a data (set) can be attributed to the bioeconomy? Especially for hybrid sectors, industries, and products, the attribution to the bioeconomy is implemented poorly in the databases as of today. There are several methodologies already existing or currently being developed and tested, that aim to separate the bio-based and fossil-based shares in these hybrid sectors to have a clearer picture of the bioeconomy. The bio-based shares developed by nova Institut are one way to do this and the chosen method for this case study. These coefficients estimate the bio-based share of a final product and are available for the products of a broad list of sectors in the NACE class C (manufacturing of goods).

## 5.3 Data not collected by established instruments

Although a vast pool of data is available in the common EU databases and especially for the more basic indicators these data sets are often sufficient and meaningful, the data needs become more specific and complicated the more complex and novel the indicators become.

Basic market data and socio-economic data sets are usually readily available but the closer we want to look at different aspects of the bioeconomy and hence, want to create added value compared to existing methodologies, the harder it is to gather the necessary data sets.

In our case study we came across several specific data needs that would need improvement in order to express valuable information once applied to the indicators. The most common problem is the level of disaggregation desired by the indicators and made available by the databases as mentioned above. The more differences between the level of disaggregation required by the indicator and provided by the data source, the more estimation, derivation and general assumptions have to be made. In this case study, this was especially the case for the structural business statistics data, namely employment numbers and numbers of enterprises in a sector, also the kind of enterprises a sector comprises of. Also, the collection of patent data appears to be challenging given the way the data is provided. The user of the data can never be sure that all relevant patents are covered in the data extraction process as the results of the database heavily depend on the search request. Another data set of high interest for socio-economic analysis is the added value a sector generates. As products in e.g. the chemical sector are immensely heterogenous and hard to compare to each other, a simple derivation of the added value of a product group by share of production value of said product group of the total production value is not sufficient under scientific ambitions.

Other data is generally not available and needs to be implemented in the databases to be used successfully in a monitoring system of the bioeconomy. Here information on public investments

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made in the different sectors, industries and even better yet, product groups are essential to make valid statements on the role of the monitored subject in public perception.

# 6 Results of indicator analysis

## 6.1 Lubricant industry

### 6.1.1 General production overview

When monitoring the lubricant production and its related socio-economic indicators it has to be distinguished between two respective groups of lubricants. In the Prodcom database lubricants have been allocated their own distinctive codes and are separated in two groups of products: Lubricants with a bio-based content of more than 25 % by mass and below 25 % by mass. As both categories contain bio-based carbon both have to be accounted towards the bioeconomy with their respective contributions. This is where the more specific bio-based shares are critical to derive the bio-based content and account it towards the bioeconomy.

According to the EUROSTAT Prodcom database the production quantity of lubricants in general in 2017 was at a total of 575.584.083,00 kg of which roughly 17.5 % are falling into the category of lubricants with a bio-based content of more than 25 % by mass. This translates to 100.629.339,00 kg. The remaining 82.5 %, or 474.954.744,00 kg, fall into the category of lubricants with a bio-based content of less than 25 % by mass.[1]

As Prodcom only distinguishes between more or less than 25 % bio-based content more precise bio-based shares are necessary to make reliable and meaningful statements about their impact on the bioeconomy. The nova-developed bio-based shares for lubricant products were once again validated with stakeholders and experts and feedback from the interviews was included. This results in estimations of the bio-based share of each of the product groups that are utilised in this case study.

For the Prodcom code **20.59.41.58 – Lubricants with a bio-based content of less than 25 % by mass** the average bio-based share is in the range of 5 % - 10 % and 7.5 % will be used in the calculations in this case study.

[1] EUROSTAT Prodcom database: **Sold production, exports and imports by PRODCOM list (NACE Rev. 2) - annual data**

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For the Prodcom code **20.59.41.59 – Lubricants with a bio-based content of more than 25 % by mass** the average bio-based share is at 50 % which will subsequently be used in the calculations.

### 6.1.2 Application of the indicators

When applying the methodology of the patents submitted indicator, the database of the European Patent Office provides various information on the patents, that have been submitted in the EU. Several filters have to be applied to access the relevant patent (numbers) of the lubricant industry. As key words the combination of "lubricant" and "bio" was applied to find the relevant patents. In 2017, 101 patents have been submitted to the Patent Office by EU countries that include the respective key words in its content. However, it is impossible to claim completeness of data with this methodology, as it is uncertain if all relevant patents are covered by this search filter.

Investments in research and development can either come from the public and the private sector and have to be monitored separately. In general, data on public sector investments in research and development is not available at a level that is required to make meaningful statements on investments in the chemical industry let alone in the lubricant industry.

Regarding private sector investments, an approximation can be made based on investment data in the chemical industry sector. Therefore, it is necessary to estimate the share of investments made in the lubricant sector of the overall investments in the chemical sector.

For this approach, we assume that the private sector investments into a product group are in relation to its share of turnover of the whole chemical sector. This share is expressed by the product coefficient mentioned in chapter 5.

The production value of lubricants in the EU makes up roughly 0.354 % of the whole chemical industry sector C20. This coefficient is then applied to the overall business expenditures in research and development in the chemical industry to derive the lubricant-related share. This leaves us with 0.354 % of the 7.534 billion EUR invested in lubricant research and development in 2017 which add up to 26.65 million EUR. Breaking these numbers further down into the bio-based shares would alter the meaningfulness of the indicator even more and we therefore do not recommend to apply the bio-based shares here. It is more or less impossible to tell, what percentage of these investments are linked to the bio-based content of lubricants.

The turnover of the lubricant industry can be directly taken from EUROSTAT's Prodcom database. To derive the relevant share for the bioeconomy, the bio-based shares have subsequently to be applied. This results in the following values for the two lubricant groups, respectively. The turnover of lubricants with less than 25 % bio-based content by mass was 1.003.877.741,00 € in 2017, which leaves us with 75.290.830,58 € when applying the actual average bio-based share of this product group which is estimated at 7.5 %.

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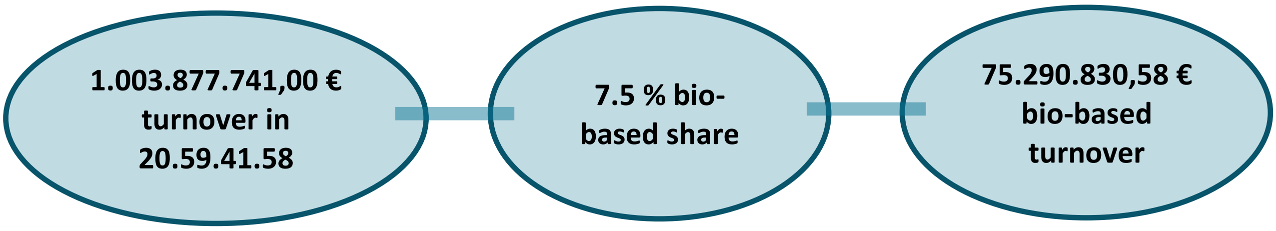


The same approach is then applied to lubricants with a bio-based content of more than 25 %, whose turnover in 2017 accumulated to 267.511.718,00 € and of which 50 % can be counted towards the bioeconomy. This results in 133.755.859,00 € bio-based turnover.

The value added at factor costs is taken from EUROSTAT structural business statistics[2] and shows a value of 16.352 billion EUR for the sector 20.59. The share of both lubricant groups of the whole 20.59 group is then calculated as the coefficient for deriving their value-added estimates. Lubricants with a bio-based content of less than 25 % make up roughly 1.9 % of the total 20.59 group whereas lubricants with a bio-based content of more than 25 % account for 0.5 % of the same group. These coefficients combined with the value added for 20.59 and subsequently multiplied with the average bio-based shares of both lubricant groups then result in 23.3 million EUR value added by lubricants with less than 25 % bio-based content and 40.881 million EUR value added for lubricants with more than 25 % bio-based content respectively.

The share of SMEs and large enterprises in the lubricant sector has been addressed quite unanimously in the interviews which is tremendously helpful given that EUROSTAT does not report data on a more disaggregated level than 20.5. Deriving data from this level of disaggregation on a product level would not yield in meaningful and usable indicators. However, the information we collected from the interviews shows, that the lion's share of turnover is generated by only a small group of large enterprises while a large number of SMEs generate the remaining turnover. It is estimated that for every large enterprise in the lubricant industry there are at least three SMEs leaving us with a share of 25 % of large enterprises and 75 % of SMEs in the lubricating industry.

In terms of bio-materials, that replace non-renewable resources the conversion rate of fossil oil to lubricants is somewhere in the range of 0.6 to 0.8 meaning for one kilogram of lubricant formulation 0.6 to 0.8 litres of fossil resources are required. To show, how much fossil resources are replaced by renewable resources, the renewable quantity of production has to be calculated and multiplied by this factor.

The production quantity in kilogram in 2017 are reported by EUROSTAT Prodcom at 474.95 million kilograms for lubricants with a bio-based content of less than 25 % which results in 35.62 million kilograms when the bio-based share is applied.

[2] EUROSTAT – Structural business statistics: Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E)

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The production quantity in kilogram in 2017 for lubricants with a bio-based content of more than 25 % is reported at 100.63 million kilograms which results in 50.31 million kilograms when the bio-based share is applied.

When these bio-based quantities are now multiplied with the conversion rate of fossil resources into lubricants, the results show what amount of fossil resources is replaced exactly.
Applying a conversion rate of 0.7 in the first case this results in 24.93 million kilograms of replaced fossil resources. In the second case respectively, this results in 35.22 million kilograms of replaced fossil resources.

To derive the terms of trade of the European lubricant industry the import and export values as well as quantities are required. By dividing the export value by the export value, the average export price results. The same approach is used for imports respectively. To express the terms of trade of a region and a production sector, we have to see the export and import prices in relation to each other. For both lubricant groups the terms of trade turned out to be negative, meaning that the import prices are respectively higher than the export prices.

The first case of lubricants having a bio-based content of less than 25 % shows the following.

Export price:

$$\frac{995.946.710\ EUR}{284.126.400\ kilograms} = 3.50$$

Import price:

$$\frac{130.727.120\ EUR}{28.647.700\ kilograms} = 4.56$$

The second case of lubricants having a bio-based content of more than 25 % shows the following:

Export price:

$$\frac{30.486.420\ \ EUR}{6.944.200\ kilograms} = 4.39$$

Import price:

$$\frac{3.686.960\ EUR}{100.700\ \ kilograms} = 6.82$$

The employment numbers are reported in the EUROSTAT structural business statistics on the same level as value added data, that is a 4-digit NACE code level at 20.59. Therefore, the same approach is used to derive the data for the lubricant industry.

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The whole sector of 20.59 has reportedly 127.614 persons in full-time equivalents employed. Applying the respective coefficients for both lubricant codes, that have been calculated at 1.9 % for lubricants with a bio-based content of less than 25 % and 0.5 % for lubricants above, this leaves us with 2424 FTEs for lubricants below 25% and 638 FTEs above 25 %.

To derive the employment solely for the bio-based part of the lubricant industry the bio-based shares need to be applied respectively. This results in roughly 501 FTEs that can be counted towards the bio-based part of the lubricant industry.

### 6.1.3 Findings of the analysis

Even though the lubricant sector is overall considered to have a good data availability performing the analysis of the different indicators in this sector showed how crucial solid and reliable data sets are to achieve meaningful results. The more estimations and vague derivations have to be performed in order to achieve a result, the less well-founded the results usually are. This applies to this case study in various aspects. While the well-established databases in some cases provided excellent data that can be applied directly to the indicators and do not need significant amounts of alteration, there is also a lot of data in the databases lacking necessary detail. Especially the levels of disaggregation often pose barriers and challenges to the successful calculation of the indicators. To overcome these disaggregation differences often estimations and derivations are required which alter the outcome of the indicator application significantly. When working on a scientific level, these inaccuracies are not desired and need to be addressed critically. On the other hand, often times these estimations and derivations are the best practice available and, when distributed with respective annotations regarding the data challenges, these indicators can still be very meaningful and valuable for a general monitoring of the bioeconomy.

### 6.1.4 Expert feedback on procedure and derivations

The feedback we received from experts on the different methodologies and approaches to measure the bioeconomic parts of the lubricant industry was overall very fruitful and helped us to see the challenges the different indicators pose from a different point of view. Often times the approaches of the indicators are very data-driven and run the risk of losing touch to the actual complexity of the aspect the indicator aims to express. Some of the derivations and estimates that have been made in order to achieve a data set that can be applied to the indicators have been seen critically by the industry. Assumptions made for the chemical sector as a whole do not always translate fully to the lubricant sector and vice versa. Overall, the experts interviewed were aware of the data availability problems and understood the efforts to overcome these in other ways but warned that often the validity of the indicators is not given on a high enough level when too many estimations within the data set are being made.

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# 6.2 PHA industry

## 6.2.1 General production overview

The Polyhydroxyalkanoate market is fairly small, given its status as an emerging technology. As the interest in PHA technology increases and the market grows, new companies emerge and start developing production facilities and processes to meet this demand. Pilot plants and small-scaled demonstration plants are the first step on the road to industrial-scale chemical production.

Given the innovative nature of PHA technology the vast majority of PHA production facilities can be described as being in the demonstration stage or as pilot plants. Overall, even globally the current production volume of PHA is almost minuscule compared to other plastics or products in the chemical sector. Solid statistical data on PHA production volumes are not available as of right now as many companies in the field are not reporting numbers so far for various reasons. Therefore, PHA production can only be expressed in the overall production capacity of the existing plants.

In 2017, the year of observation in this case study and simultaneously the latest year of data available in many of the utilised data sources, the global production capacity of PHA was at a grand total of just over 5000 tonnes. Of these 5000 tonnes only 10 tonnes of production capacity can be attributed to the EU–28. However, the PHA production capacity is expected to increase significantly in the foreseeable future. A trend, which can already be observed in the years following 2017.
The global production capacity of PHAs in 2020 is roughly six times the size of 2017's production capacity at more than 31000 tonnes. Not only globally, but also in Europe, the production capacity increased. In 2020 Europe's capacity comprised of 2005 tonnes which depicts a considerable increase compared to the 10 tonnes in 2017 but can still be considered minuscule.[3]

Data exceeding these of production capacities in the given timeline between 2011 and 2020 are hard to come by. In our interview with GO!PHA it became clear that the current demand for PHAs is greater than the overall production capacity. This is leaving us with the justified conclusion, that the production capacity is fully exploited by the market and therefore equals the supply.
The total supply multiplied with the estimated market prices of PHAs yields an estimation of the overall market volume in monetary units. PHA polymer prices are currently in the range of 3 € to 7,50 € per kilogram and expected to drop significantly once production is successfully scaled up to industrial standards, according to expert information.

Subsequently, the production value of Europe's PHA industry in 2020 is somewhere in the range of 6 million € to 15 million € considering the above-mentioned market prices and production quantities.

One reason for the lack of enthusiasm when it comes to PHA production in the EU is the highly uncertain regulatory framework. The current EU legislation efforts do not particularly encourage

[3] Skoczinski et al.; Bio-based Building Blocks and Polymers – Global Capacities, Production and Trends 2020 – 2025 (2021)

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the use of PHAs and hence, curb the investments and further developments into this technology. The latest interpretation of the Single Use Plastics Directive classifies PHA as an unnatural polymer which would make it fall into the scope of the directive and restrict its use heavily in the EU. Therefore, scaling up the production has been targeted quite hesitant so far.

### 6.2.2 Application of the indicators and findings

A product with a market as small PHAs and in a stage of development as early as PHAs are currently in lacks most of the required data to successfully and meaningfully apply any socio-economic indicators. In this early stage of technological and market development, there is great competitiveness between the different companies which requires a high level of confidentiality. The best practice to gather market data is to interview experts and stakeholders, which yields in valuable exchange of information but is far from being the best option when it comes to monitoring mechanisms.

Also, universal assumptions suitable for well-implemented and scaled up industries and partly utilised during the application of the indicators to the lubricant industry cannot simply be used likewise for an industry as novel and unique as PHAs.

Hence, most indicators examined in this case study are not feasible to be calculated for PHAs as of today. This clearly shows the barriers and challenges one has to overcome for the successful monitoring of hybrid sectors in the bioeconomy.

However, some statements regarding the indicators in this case study can be made based on information gathered by interviews and literature.
The lion’s share of production is currently not happening in the EU and will also not happen in the EU in the foreseeable future.

While outside of Europe the companies are slowly moving from the early stages of development, the so-called embryonic stage, to an early growth stage, the European based companies are still going to be operating on the embryonic stage for a while.

This embryonic stage is characterised by high investment costs and opposed by little to no profits which makes it impossible to derive the actual investments in research and development from any annual turnover or profit data as attempted in the case of lubricants. Based on announcements from the respective stakeholders it is assumed that globally there will be investments in PHA technology and production in the amount of about 500 million USD in the next years.[1] However, what share of these investments will happen in Europe cannot be estimated.

The few companies currently operating in Europe are heavily dependent on private and public investments in order to stay in business. This leads us to the conclusion, that European PHA producers can all be classified as SMEs and hence, result in a share of 100 % SMEs in this sector.

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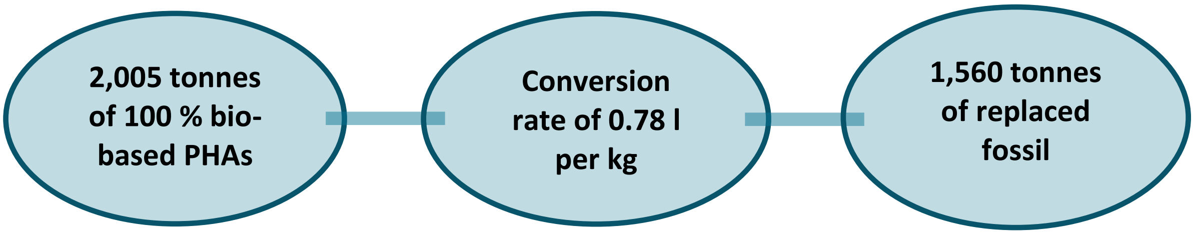
In terms of bio-material, that replaces non-renewable resources, a calculation as described in chapter 5.1 can be executed. It is assumed that the average conversion rate from oil to plastics is 0.78 l/kg.[4]

Taking into account the production data for 2020 and that PHAs are fully bio-based, roughly 1560 litres of oil were replaced by bio-materials.




Another methodological approach from the fact sheets, that can be applied for PHA is that of the patents submitted to the European Patent Office. However, the proposed approach has its weaknesses as well.

To access data from the patent database the search engine has to work with key words to filter the patents according to the sector of interest. There is no guarantee, that the key words entered in the database are covering all of the relevant patents for a sector.

However, when selecting the EU countries, the year 2017, and searching for the keyword 'polyhydroxyalkanoate,' the database finds 74 results. Therefore, 74 patents on PHAs have been submitted to the European patent office in 2017. Applying the same filters and changing the year to 2020 the database finds 34 results resulting in 34 PHA-related patents in 2020.[5]

Following the methodological approach of the turnover indicator an overall turnover in the range of 6 million € to 15 million € for 2020 can be assumed depending on the actual market prices that had been achieved. This turnover can fully be attributed to the bioeconomy, as PHAs are considered fully bio-based.

### 6.2.3 Expert feedback on procedure and derivations

As indicated before, the most reliable and meaningful sources for data on PHA production are interviews with experts and stakeholders. Most of the data used for the derivation and calculation of the indicators for PHA production in this case study originates directly from interviews with experts. Other information found in literature and by desktop research was validated with experts

[4] F. ENGELBEEN, Plastics Environnemental Aspects. (http://ces.iisc.ernet.in/hpg/envis/plasdoc612.html)

[5] European Patent Office – Espacenet patent database

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and the general feedback was similar to our findings. Data availability for PHA production is expectedly poor and not going to improve as long as production and technology developments remain on the stage they are in at the moment. This applies especially to Europe, where the future of the PHA market is heavily dependent on the interpretation and enforcement of the Single Use Plastics Directive starting in July 2021. Only once production is scaled up to industrial levels PHAs are able to compete with alternative materials and significantly take part in the chemical industry of the EU. This is also when more reliable and useful data should become available as competitiveness and the associated confidentiality decrease.

As PHAs are not one single material but a whole group of polymers, the feedback we received on monitoring and tracking socio-economic developments in the sector is to not focus on PHAs as a whole but to look at the different relevant polymers the group of PHAs consists of. It was proposed to focus on the three most promising polymers from the PHA group, namely PHBH, PHBV, and P3HB4HB.

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# 7 Conclusions and outlook

***A valid, meaningful and scientifically well-founded monitoring methodology of the bioeconomy is an endeavour, that has to cope with various challenges and has to overcome data availability issues on a daily basis.***

Overall, the indicators proposed in BioMonitor, and especially those that have been tested in this case study, promise to be a well-functioning tool to express relevant socio-economic information on the European bioeconomy. These indicators cover a vast landscape of information and show are able to show the developments in the bioeconomy in many facets. However, they fully rely on data sets provided by sources, that do not work uniformly and do not provide consistent and complementary information. Especially in a sector as the chemical industry, that is diverse, well-established, yet still innovative and object of steady change and development, the uniformity of the data provided for the monitoring system is crucial. In general, the indicators are able to paint a clear picture of the movements, shifts and also the status quo of the industry and how different external and internal factors may influence it. The drivers of change often originate from regulation and policy institutions. If the change to a larger and better performing bioeconomy is desired, which would be supported by a functioning monitoring system, these monitoring measures have to be supported by implementing better data reporting measures, lay a special focus on data matters of the bioeconomy and provide information required for these undertakings uniformly and processed to a level at which they can be directly used.

This case study had the aim to test the chosen indicators regarding feasibility, meaningfulness and validity and hence, to provide feedback on the methodologies developed in work package 3 of the BioMonitor project. Many of the findings of this case study will be taken to work package 3 and help provide valuable feedback that will subsequently be implemented in the efforts of creating and filling the bioeconomy database. These findings also may be used by the modelling efforts of BioMonitor as the data needs and challenges became obvious in the course of this case study.

Also, the importance of a tool to distinguish between the fossil-based and bio-based parts of the industry, especially in a hybrid sector as the chemical sector, became clear. Without the application of such a tool the provided data by EUROSTAT can not be processed to show the parts relevant for the bioeconomy. A way to distinguish between bio-based and fossil-based parts of the economy, that is based on the same methodology of the data in EUROSTAT's databases, would be a valuable tool for better reporting and monitoring system of the EU bioeconomy.

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