Cleaner and Circular Bioeconomy 5 (2023) 100044

Contents lists available at ScienceDirect

Cleaner and Circular Bioeconomy

journal homepage: www.elsevier.com/locate/clcb

Article

Opportunities and challenges of the European Green Deal for the chemical industry: An approach measuring circularity

Lisa Thormann, Ulf Neuling*, Martin Kaltschmitt

Institute of Environmental Technology and Energy Economics (IUE), Hamburg University of Technology (TUHH), Germany

ARTICLE INFO

Keywords:
Circular economy
European Green Deal
Chemical industry
Sustainability
Resource efficiency
Governance

ABSTRACT

The European Green Deal aims to address the challenges of climate change and environmental degradation and plans to transform the EU into a modern, resource-efficient and competitive economy, ensuring, among other things, that there are no net emissions of greenhouse gases by 2050 and economic growth is decoupled from resource use. The European Commission has issued a Circular Economy Action Plan. The action plan announces initiatives along the entire life cycle of products. What opportunities and challenges can be expected from the implementation of the European Green Deal for the chemical industry in the EU? A circular economy offers innovative solutions to sustainability challenges by moving from a take-make-use-dispose economy to an improved resource management. However, the implementation of a closed loop economy for the chemical industry is not only reflected in the value chain within its own production processes but also in possible changes in customer demand due to circularity. Based on this observation, a methodology is developed to assess the impact of the circular economy on the customers of products provided by the chemical industry. The methodology developed is applied within a case study using the EU chemical industry as an example. The results of this case study show an increase in demand for chemicals compared to the baseline due to circular economy trends; for example, in the medium-term (2030), the circular economy drivers will lead to around 18 Bn. € of increased demand compared to today (2020). In the long-term (2045), the effects of circular economy will be softened to a certain extent and an increase in demand of around 6 Bn. € is expected. For example, demand for plastics as well as paints and inks in the automotive industry will increase in the medium-term. This is directly related to the growing demand for electro mobility, the trend towards lightweight materials and the increasing use of plastics (composite materials) in automotive construction. The methodology presented here provides a future perspective of the impact of circularity on the respective product demand of customers in the chemical industry and attempts to inspire discussions that support the transition to a sustainable circular economy.

1. Introduction

In December 2019, the European Commission (EC) published measures to meet the European Green Deal to drive Europe's ambition to become a world leader in a resource-efficient and sustainable economy by 2030 and beyond. It outlines the investments required and the financial instruments available. Additionally, it explains how to ensure a fair and inclusive transition to promote the efficient use of resources through the transition to a clean, circular economy with a view to achieving the goal of a climate-neutral European Union (EU) by 2050 (European Commission The European Green Deal, 2019). Therefore, the EC has developed a roadmap providing an overview of the respective measures documented within the European Green Deal to be defined by 2021. The Circular Economy Action Plan being part of this roadmap and relevant also to the chemical industry, was already published in March 2020 as one of the actions placed within this roadmap. The overarching aim of this Circular Economy Action Plan is to produce sustainable products to be provided to the European and global markets (European Commission A New Circular Economy Action Plan for a Cleaner and More Competitive Europe, 2019).

Accordingly, the chemical industry is faced with the questions of (i) how far it can promote its own manufacture of sustainable products and (ii) what effects these circularity demands have on the respective product demand of customers in the chemical industry. Against this background, this article develops and presents an assessment methodology to answer the second question. The first question is addressed in a previously published article (Thormann et al., 2021). With regard to the evaluation of the circular economy, the focus of this article is on the demand for products of the chemical industry. In order not to overload the scope of the article, only the chemical industry has been considered,

* Corresponding author.
E-mail address: ulf.neuling@tuhh.de (U. Neuling).

https://doi.org/10.1016/j.clcb.2023.100044
Received 24 August 2022; Received in revised form 12 April 2023; Accepted 12 April 2023

but the methodology developed can be transferred to other industries. This leads to the main research questions of this article: How can opportunities and challenges of circular economy on the demand of products from the chemical industry be evaluated in the medium- and long-term?

Previous work has conceptualized circular economy in the chemical industry (Kümmerer et al., 2020; Vennestrøm et al., 2011) and described approaches in the area of changing business models (Bocken et al., 2019; Antikainen et al., 2017; De Angelis, 2018). While recent studies analyze the importance of circular economy in the chemical industry in terms of sufficiency (Bocken et al., 2022) and bring it more to the forefront of the discourse on circular economy (Snihur and Bocken, 2022), there is a lack of conceptual methodologies to assess impacts in terms of demand. Furthermore, while research has included business cases (Bocken and Konietzko, 2022), it has lacked a comprehensive approach linking changes in demand from chemical industry customers due to circular economy trends. Here we develop a methodology to assess the opportunities and challenges of demand as a driver of the circular economy. The effects of circularity on the chemical industry include, e.g., products that enable partners in the value chain to increase their recycling quota, to provide more durable products for increased reuse and/or to convert plastic waste into chemical building blocks (improved recycling). The principle of circular economy aims to optimally use and recycle available materials throughout their overall life cycle. Examples of this are (Hirsch and Schempp, 2020; Woltjer et al., 2018):

- Product design. Rethinking the product design by, e.g., reusing and recovery of components or recycling materials after the use of the product;
- Business model. Developing innovative business models by, e.g., keeping products in a clearly longer use by reuse or redistribution and improve the collection of the products;
- Reverse cycle skills. Using feedstock from reused or recycled sources by improved treatment methods;
- Cross-cycle and cross-sector collaboration. Making more intensive use of products, e.g., via service or performance models.

The EC has summarized the drivers of the circular economy in the '9 R's': refuse, rethink, reduce, re-use, repair, refurbish, remanufacture, repurpose, and recycle (Hirsch and Schempp, 2020). These nine drivers and the demand for alternative raw materials is within the focus of the developed methodology.

The framework conditions of the European Green Deal are both demanding and supportive for the chemical industry. It is therefore essential for the achievement of the objectives of the Green Deal that innovations (novel and sustainable processes and products) towards a sustainable chemical industry can be evaluated across the various sectors. Thus, the development of an assessment methodology is necessary for technology prioritization with regard to advanced materials and advanced processes as well as the implementation and joint development of digital technologies. This will require identifying all circular economy impacts of the innovation ecosystem, across value chains and technologies.

The consequence is that the methodology to be developed here has to include several parameters to assess the impact of the circular economy on the chemical industry. Essentially, there are three parameters to be considered:

(i) The industries to that the chemical industry essentially supplies its products,
(ii) The specific products (chemicals or chemical groups) that the chemical industry supplies to the respective market segment or customer and
(iii) The impact of circular economy on customer demand per market segment and chemical group in the medium- and long-term compared to today's demand.

The methodology thus has to provide an outlook on the impact of the circular economy on the respective product demand of customers in the chemical industry and seeks to stimulate discussions that support the transition to a sustainable circular economy. To reach this goal, a baseline needs to be defined (i.e., evaluation of relevant market segments and chemicals/ chemical groups) and, based on this, an assessment of circular economy drivers need to be performed. Following this, a perspective for the future, indicating what chemical groups or chemicals will experience changes in demand due to circular economy, can be identified. The methodology developed is based on literature research and on expert interviews.

2. Methodological approach

The methodology is based on investigating the current situation and extrapolating the situation (as-is) as an assessment of the baseline. The necessary data are provided by an analysis of relevant market segments and chemical groups as well as their respective market shares. The resulting development with regard to a circular economy demands are analyzed then in a subsequent step. In this context, it is analyzed how demand per market segment and chemical group develops due to the influence of the measures to be implemented to realize a circular economy. The results are then compared to the baseline (Fig. 1).

A detailed explanation of the methodological approach follows later in the chapter. To assess the baseline, we have identified the relevant market segments of the chemical industry and assessed them without the influence of circular economy. In doing so, we have differentiated between chemical groups, regions and the time frame. In the circular economy impact assessment, we determined the demand for products of the chemical industry and analyzed it in terms of chemical groups, market segments, regions, time horizon and the circular economy perspective.As a basis for assessing demand, we have added the circular economy impact and a relevance factor. The circular economy impact results from the market segments, the regions, selected circular economy parameters and the time horizon. The relevance factor describes the extent to which the circular economy parameters have concrete application for the respective market segment. The determined relevant demand has subsequently been converted into indexed demand for improved presentation.

2.1. Baseline evaluation

The baseline evaluation first assesses the market segments where the chemical industry currently supplies chemicals or groups of chemicals. The next step is to evaluate the chemicals or chemical groups supplied per market segment for the medium- and long-term in a region (here: the EU).

As a basis for this, a clear delimitation of the investigated area with regard to the chemicals or chemical groups is necessary by clearly defining the respective system boundaries. As soon as it has been determined what chemicals or groups of chemicals are to be analyzed, the region (*re*) to be included in the analysis needs to be clearly defined. This is relevant for the evaluation of the sales market.

In order to determine the relevant market segments for the chemical industry, the chemicals or groups of chemicals produced according to defined classes, a segmentation strategy is carried out based on the demand (i.e., sales). Segmentation should lead to the formation of sufficiently large homogeneous customer groups, whereby a segment should be located somewhere in between the two extremes of the total market and the individual customer. Industries or customer segments with less than 2% demand per chemical group are typically not evaluated individually, but are grouped together under 'Other' (Langner, 1991).

2.1.1. Current status

Eq. (1) describes the respective market segment ($MS_{1...n,CG_{1...n},re,t_0}$ describes themarket segment (share) in% ($MS_{1...n}$) of the chemical group ($CG_{1...n}$) in a region (*re*) for the current status (t_0), D stands for the

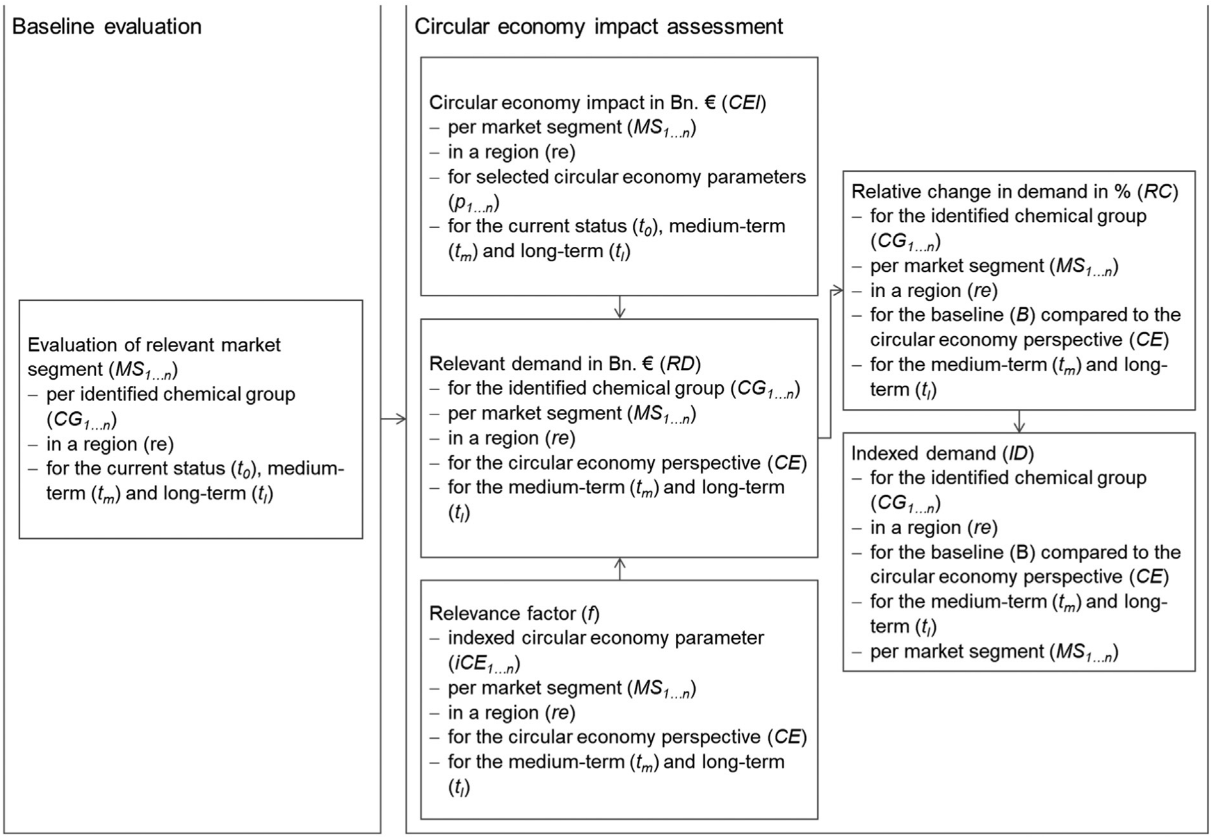

Fig. 1. Simplified illustration of the methodological approach to the evaluation and assessment of the indexed demand of the chemical industry by circular economy drivers.

demand (sales) in a region (*re*) for the current status (t_0), and$CG_{1\ldots n}$ describes the identified chemical or group of chemicals).

$$MS_{1\ldots n, CG_{1\ldots n}, re, t_0} = D_{re,t_0} CG_{1\ldots n} \quad (1)$$

2.1.2. Medium- and long-term perspective

For the calculation of the future market share per market segment and chemical group, the average of a certain amount of years is used as a basis for the extrapolation into the future; for example, the past five years (i.e., 2016 till 2020) can been used for that. Based on this approach, for simplicity reasons it is assumed that no new market segment will be developed in a medium- to long-term perspective. If the methodology is to show more granularly what market segments are involved, e.g., beyond the automotive segment and a differentiation of electric and fuel cell propulsion is required, market segment expected to emerge in the medium- and long-term can easily be included into the methodology.

2.2. Circular economy impact assessment

The future demand under the conditions of circular economy for chemicals or group of chemicals is represented by an index (Eq. (2), $ID_{CG_{1\ldots n} re, CE, t_{m,l} MS_{1\ldots n}}$ described the indexed demand (*ID*) for the identified group of chemicals ($CG_{1\ldots n}$) in a region (*re*) for the circular economy perspective (*CE*) for the medium-term (t_m) and long-term (t_l) per market segment ($MS_{1\ldots n}$), $CEI_{MS_{1\ldots n} re, p_{1\ldots n}, t_{m,l}}$ stand for the circular economy impact (*CEI*) per market segment ($MS_{1\ldots n}$) in a region (*re*) for selected circular economy parameters ($p_{1\ldots n}$) for the medium-term (t_m) and long-term (t_l), $RD_{CG_{1\ldots n} MS_{1\ldots n} re, CE, t_{m,l}}$) describes the relevant demand (*RD*) for the identified chemical group ($CG_{1\ldots n}$) per market segment ($MS_{1\ldots n}$) in a region (*re*) for the circular economy perspective (CE) for the medium-term (t_m) and long-term (t_l), $f_{iCE_{1\ldots n} MS_{1\ldots n} re, CE, t_{m,l}}$ is a relevance factor (*f*) indexed circular economy parameter ($iCE_{1\ldots n}$) per market segment ($MS_{1\ldots n}$) in a region (*re*)for the circular economy perspective (CE) for the medium-term (t_m) and long-term (t_l), $RC_{CG_{1\ldots n} MS_{1\ldots n} re, B, CE, t_{m,l}}$ stand for the relative change in demand (*RC*) for the identified chemical group ($CG_{1\ldots n}$) per market segment ($MS_{1\ldots n}$) in a region (*re*) for the baseline (*B*) compared to the circular economy perspective (*CE*) for the medium-term (t_m) and long-term (t_l)). Eq. (2) thus represents the overall calculation, and the individual components of the calculation method are explained in more detail in Eq. (3) till 6 (see below).

$$ID_{CG_{1\ldots n} re, CE, t_{m,l} MS_{1\ldots n}} = CEI_{MS_{1\ldots n} re, p_{1\ldots n}, t_{m,l}} \times \left(RD_{CG_{1\ldots n} MS_{1\ldots n} re, CE, t_{m,l}} \; f_{iCE_{1\ldots n} MS_{1\ldots n} re, CE, t_{m,l}} \right) \times \left(-RC_{CG_{1\ldots n} MS_{1\ldots n} re, B, CE, t_{m,l}} \right) \quad (2)$$

2.2.1. Circular economy impact

To evaluate the circular economy drivers on a specific market segment to be assessed, the influence of the relevant circular economy parameters in a specific region on this respective market segment needs to be analyzed. Thus, based on the parameters defined above indices are formed.

In March 2020, the EC published a sector-agnostic approach for activities contributing to the circular economy. For the identification of relevant circular economy drivers the nine 'R's of the EC are applied and evaluated for relevance. In principle, the following nine 'R's can be used for categorization (according to Hirsch and Schempp 2020, Bocken et al.).

- Refuse; i.e., make a product redundant by abandoning its function or by offering the same function by a radically different product or service;

- Rethink; i.e., make product use more intensive (e.g. mobility as a service);
- Reduce; i.e., increase efficiency in product manufacture as well as reduction of the number of products on the market;
- Re-use; i.e., re-use of a product which is still in a good condition and fulfills its original function (and is not waste) for the same purpose for which it was conceived;
- Repair; i.e., repair and maintenance of a defect product so it can still be used with its original function;
- Refurbish; i.e., restore an old product and bring it up to date;
- Remanufacture; i.e., use parts of a discarded product in a new product with the same function;
- Repurpose; i.e., use a redundant product or its parts in a new product with different function(s);
- Recycle; i.e., recover materials from waste to be reprocessed into new products, materials or substances whether for the original or other purposes.

Based on this categorization, the identified market segments are analyzed. The analysis calculates to what extent the demand for specific products or product groups within a market segment changes due to circular economy parameters. Eq. (3) is valid ($CEI_{MS_{1\ldots n}PG_{1\ldots n}re,t_{m,l}}$ describes the circular economy impact (*CEI*) per market segment ($MS_{1\ldots n}$) and more precisely per product group within the market segment ($PG_{1\ldots n}$) in a region (*re*) for the medium-term (t_m) and long-term (t_l); $p_{1\ldots n}$ is the selected circular economy parameters; $RD_{t_{0.m,l}}$ stand for therelevant demand).

$$CEI_{MS_{1\ldots n}PG_{1\ldots n}re,t_{m,l}} = PG_{1\ldots n}p_{1\ldots 9}RD_{t_{0.m,l}} \tag{3}$$

The selection of the 'R's therefore refers to the effect on the changing demand per market segment. For example, changing legislation is used as a basis for assessing the impact on demand per market segment.

The relevance factor connects the demand for the chemicals or groups of chemical with the circular economy impacts to identify the intensity the circular economy parameter has on the respective market segment as well as on the respective chemical or group of chemicals. This is defined within Eq. (4) ($f_{MS_{1\ldots n}PG_{1\ldots n}re,t_{m,l}}$ is therelevance factor per market segment $MS_{1\ldots n}$ and per product group $PG_{1\ldots n}$, per region (*re*) for the medium-term (t_m) and long-term (t_l); $CG_{1\ldots n}$ describes theidentified chemical group; $iCE_{1\ldots .n}$stand for the indexed circular economy parameter).

$$f_{MS_{1\ldots n}PG_{1\ldots n}re,t_{m,l}} = CG_{1\ldots n}iCE_{1\ldots .n} \tag{4}$$

The relevance factor can be determined from data on the basis of market shares for the respective chemical or group of chemicals.

2.2.2. Relevant demand

The relevant demand (*RD*) per market segment is the expected baseline demand for the medium- and long-term including circular economy impacts. This is described by Eq. (5) ($RD_{CG_{1\ldots n}re,CE,t_{m,l}MS_{1\ldots n}}$ describes therelevant demand per identified chemical group ($CG_{1\ldots n}$) per region (*re*) for the circular economy perspective (*CE*) for the medium-term (t_m) and long-term (t_l) per market segment ($MS_{1\ldots n}$); $CEI_{MS_{1\ldots n}re,PG_{1\ldots n}CG_{1\ldots n}p_{1\ldots n},t_{m,l}}$ is thecircular economy impact (*CEI*) per market segment ($MS_{1\ldots n}$) in a region (*re*) and more precisely per product group within the market segment ($PG_{1\ldots n}$) per identified chemical group ($CG_{1\ldots n}$) per selected circular economy parameters ($p_{1\ldots n}$) for the medium-term (t_m) and long-term (t_l); $f_{iCE_{1\ldots n}MS_{1\ldots n}re,CE,t_{m,l}}$ stand for the relevance factor per indexed circular economy parameter ($iCE_{1\ldots .n}$) per market segment ($MS_{1\ldots n}$) per region (*re*) for the medium-term (t_m) and long-term (t_l)).

$$RD_{CG_{1\ldots n}re,CE,t_{m,l}MS_{1\ldots n}} = CEI_{MS_{1\ldots n}re,PG_{1\ldots n}CG_{1\ldots n}p_{1\ldots n},t_{m,l}} \times \left(RD_{CG_{1\ldots n}re,t_{m,l}MS_{1\ldots n}}\ f_{iCE_{1\ldots n}MS_{1\ldots n}re,t_{m,l}} \right) \tag{5}$$

The baseline demand excluding the circular economy impacts is calculated on the basis of the demand given within a certain time frame in the past used as a basis to be extrapolated it further. The *CAGR* (Compound Annual Growth Rate) is used as the key indicator (Eq. (6)) (PV_{t0} is the initial, present or starting value of the asset, FV_{tn} is the final, ending or future value, t_n is the end time period, and t_0 is the first time period) (Chan, 2009).

$$CAGR = \left(\frac{FV_{t_n}}{PV_{t_0}} \right)^{\frac{1}{t_n - t_0}} - 1 \tag{6}$$

3. Case study

In the following explanations, the described methodological approach is applied within a case study.

3.1. Definition

The investigated time horizon is the current status (2020), the medium-term (2030), and the long-term (2045). The regional system boundaries include the EU-28. The focus is set on the chemical industry, i.e. basic inorganics (fertilizers and other inorganics), consumer chemicals, polymers (plastics, synthetic rubber, man-made fibres), and specialty chemicals (dyes & pigments, crop protection, paints & inks). The market segments or consumer of the chemical industry considered are agriculture, automotive, building & construction, household, leisure & sports, electrical & electronics, packaging, publishing &printing and textile.

3.2. Baseline evaluation

The evaluation of the relevant market segment is based on public available data. This is true for reports from chemical companies providing an overview of market segments per chemical group, and the EC provides statistical data on the chemical industry and its customer markets. Additionally, annual business reports from the European chemical industry are used to identify relevant market segments. In addition, the European Chemical Industry Council (CEFIC) provides an annual report providing an overview of the market segments of the European chemical industry.

Within these sources, chemicals are typically classified in commodities, specialties and fine chemicals, where commodities and fine chemicals are single pure chemicals and specialties are mixtures. Nevertheless, the borderline between the different classes of chemicals is often not clear-cut. Thus, the data sources mentioned above need to be allocated to the various classes based on clearly defined allocation rules.

The CEFIC categorization differentiates between four categories and data based on these categories is already available (Bartels et al., 2020; Hadhri, 2020; American Chemistry Council 2019 Guide to the Business of Chemistry, 2020x). Therefore, this categorization is also used within the subsequent analysis.

1. Basic inorganics; i.e., fertilizers (e.g., nitrogen fertilizers, phosphate fertilizers, potassium fertilizers) and other inorganics (chlorine, caustic soda (sodium hydroxide), acids (nitric, phosphoric, sulphuric, etc.), aluminum sulfate, lime, soda ash (sodium carbonate), sodium bicarbonate, sodium chlorate, sodium sulfate, and sulfur;
2. Consumer chemicals (e.g., glycolic acid, silicone, surfactants);
3. Polymers; i.e., plastics (e.g., polypropylene (PP), low density polyethylene (LDPE), linear low density polyethylene (LLDPE), high density polyethylene (HDPE), polyvinyl chloride (PVC), polyurethane (PU), polyethylene terephthalate (PET), polystyrene (PS), expanded polystyrene (EPS), other polymers), synthetic rubber (e.g., butyl rubber, ethylene-propylene-diene monomer (EPDM), terpolymers, neoprene, nitrile rubber, styrene-butadiene rubber (SBR), specialty elastomers), man-made fibres (e.g. acrylic, nylon, polyester, polyolefin);

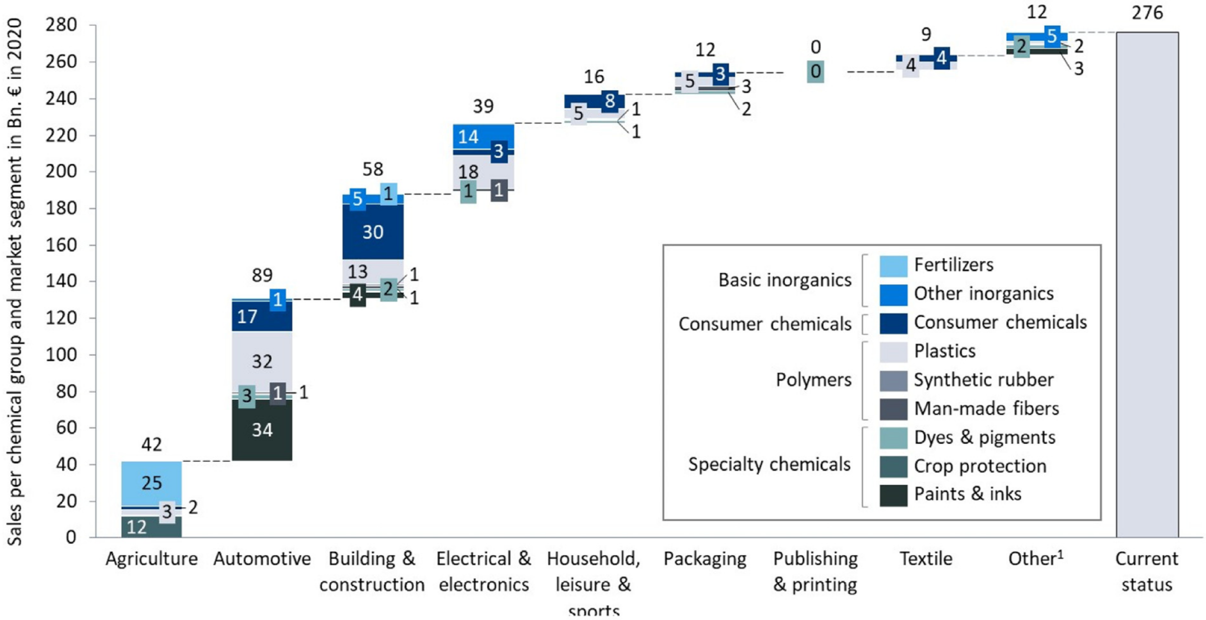

Fig. 2. Current status of sales per chemical group and market segment (first/direct customer industry) (intra-industry sales not included); excluding petrochemicals, industrial gasses and auxiliaries; values below 0.5 Bn. € are not represented by the exact value.; [1] others includes appliances, mechanical engineering, furniture, medical etc.; calculations and approximations are based on (Hadhri, 2020; American Chemistry Council 2019 Guide to the Business of Chemistry, 2020; Chemiewirtschaft in Zahlen Online - Verband Der Chemischen Industrie e.V, 2020; PlasticsEurope Plastics – the Facts, 2019; European Commission Polymers, 2007; BASF SE BASF Factbook, 2020; Farn, 2006).

4. Specialty chemicals; i.e., dyes & pigments (e.g. colorants), crop protection (e.g. fungicides, herbicides, insecticides, miticides, pesticides), paints & inks (e.g. liquid dispersions of dyes (or pigments)).

Current status. Once the chemicals or chemical groups have been defined, the market shares of the chemicals and chemical groups as well as the relevant market segments are determined. Here, the nine subcategories of the four CEFIC categories are reported individually to provide more granular results.

Following these data, sales of chemical products within the EU-28 in 2020 amounted to 499 Bn. € (Hadhri, 2020, 2022). The share of sales in the categories "basic inorganics", "consumer chemicals", "polymers" and "specialty chemicals" amounted to about 276Bn.€ (Fig. 2 and Supplementary Materials Table 1). This excludes petrochemicals, industrial gasses and auxiliaries. The chemical group of polymers comprises ca. 34%, specialty chemicals roughly 23%, consumer chemicals a bit more than 24% and basic inorganics a bit less than 19%.Plastics (ca. 30%) and paint & ink (ca. 15%) are in particular demand from the market segments. Four market segments (i.e. (i) agriculture, (ii) automotive, (iii) building & construction, (iv) household, leisure & sports) together represent over 82% of the sales of the chemical groups. The distribution of the chemical groups in relation to the customer segments shows a rather heterogeneous proportion.

Medium-and long-term perspective. The outlook on future sales development in the chemical industry is based on the average of the last five years (i.e. 2016 till 2020). Fig. 3 shows the expected changes in demand per market segment and chemical group, comparing the current-status with the future perspectives (as a baseline without the influence of the changes due to the envisaged circular economy). When looking at the total sales in the chemical industry in the EU-28 up to and including petrochemicals, a Compound Annual Growth Rate (CAGR) of 0.6% can be seen over the years 2013 to 2018 (Hadhri, 2020). Based on the individual analysis of market segments and chemical groups, a Compound Annual Growth Rate (CAGR) of 0.08% is expected for the chemical industry in the EU-28 for the future perspective based on the last five years (Supplementary Materials Tab. 1).

3.3. Circular economy impact assessment

With regard to the assessment of the effects of the circular economy, different parameters have been used for each market segment. The parameters used in the assessments are described in detail in Table S2.The parameters that are expected to have an impact on the respective market segment in the future have been taken into account.

The relevance factor combines the demand for the chemicals or the respective groups of chemicals with the impact of the circular economy to determine the intensity that the circular economy might have on the respective market segment as well as on the respective chemical or group of chemicals. This allows a weighting of the factors (Fig. 4).

For the selected market segments of the chemical industry in the EU-28, an assessment has been made on the basis of the nine 'R's' according to the methodology described in Section 2.2.1. This provides a detailed overview of the key performance indicators identified for each market segment. Below, the circular economy impacts are discussed in detail clustered in market segments (Fig. 5) and the respective results are described per market segment. In addition, the differentiation between the various chemical groups is depicted in Figs. 6 and 7.

The results of the projected impact of the European Green Deal on the chemical industry in the medium- and long-term show significant changes in the demand based on circular economy (Fig. 6). There is a clear increase obvious in the demand for chemicals in the medium-term (~8%). In the long-term, however, this trend is abating, but remains positive (~2%). Below the various sectors are discussed individually.

The following explanations show that the differences in the characteristics of the effects of circular economy impacts for the respective chemical groups vary strongly. Nevertheless, in average a significant increase in the overall demand can be seen especially in plastics, consumer chemicals and paints & inks, while the demand for dyes & pigments is clearly decreasing (Figs. 6 and 7).

Agriculture. The chemical groups relevant to the agriculture market segment include (i) fertilizers, (ii) crop protection, (iii) plastics and (iv) consumer chemicals (Fig. 4). Within the framework of the European

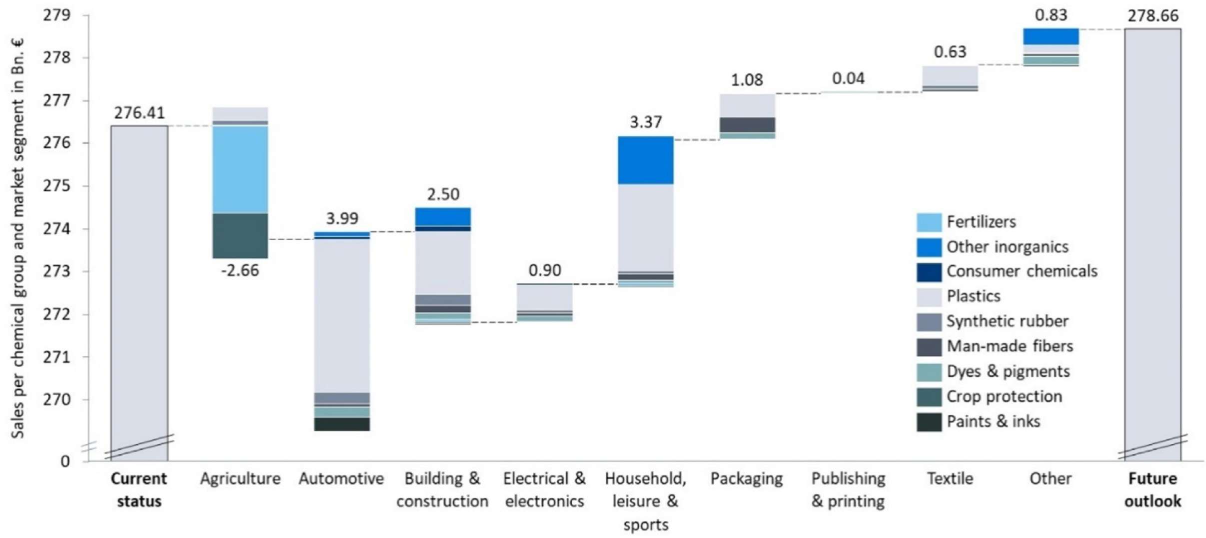

Fig. 3. Medium- and long-term perspectives of sales per chemical group and market segment for the baseline (excl. the influence of circular economy); calculations and approximations are based on (Chemiewirtschaft in Zahlen Online - Verband Der Chemischen Industrie e.V, 2020).

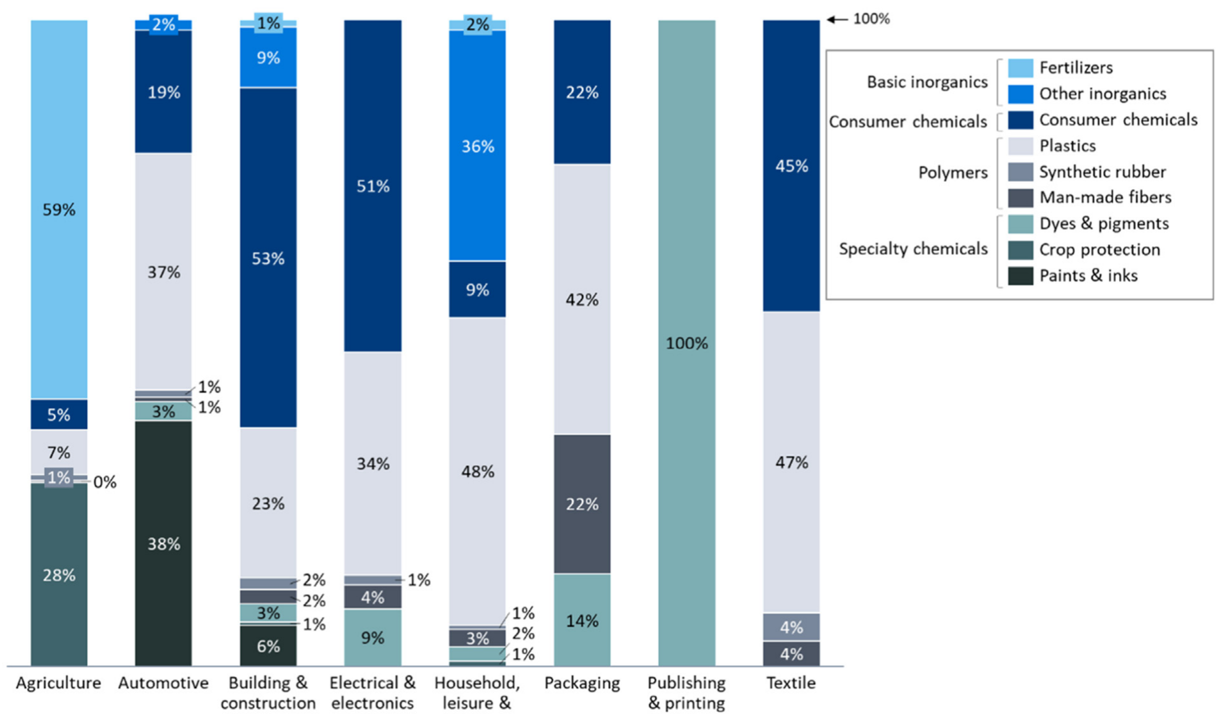

Fig. 4. Percentage of sales per market segment and chemical group for the current status (Hadhri, 2020; American Chemistry Council 2019 Guide to the Business of Chemistry, 2020; Chemiewirtschaft in Zahlen Online - Verband Der Chemischen Industrie e.V, 2020; PlasticsEurope Plastics – the Facts, 2019; European Commission Polymers, 2007; BASF SE BASF Factbook, 2020; Farn, 2006).

Green Deal many initiatives are aiming at the agricultural sector. The initiative "From Farm to Fork" plans during the years 2021 till 2027: (i) better informed citizens, (ii) more efficient food production systems, (iii) better storage and packaging, (iv) healthy consumption and reduce food loss and waste, and (v) more sustainable processing and farm transport. The overall goal of these activities is to contribute to achieve a circular economy – from production to consumption (European Commission; Directorate-General Communication, 2019). The following four circular economy indicators for the agricultural industry were identified (Ragonnaud, 2013; European chemicals agency microplastics - Registry of restriction intentions until outcome - ECHA, 2020; European Commission Sustainable Agriculture in the EU, 2020; Schrijver et al., 2016; Takácsné György et al., 2018; Alexandratos, 2012; Food and Agriculture Organization of the United Nations, 2015; Tilman et al., 2011; Priefer et al., 2016; Vox et al., 2016; Kumar et al., 2020; Huang et al., 2020; Bertling et al., 2021; Mammana, 2014).

1. Reusability and recycling of agricultural applications. Plastic materials used for crop covering, soil mulching, packaging, containers, pots, plastic irrigation and drainage pipes, can become a source of pollution if they are improperly disposed of, left on the ground, or burned. In this regard, reduction and recycling of plastics in agricultural applications addresses the aim for more sustainable processing. In Europe, 1.51 Mt/a of agricultural plastics are currently pro-

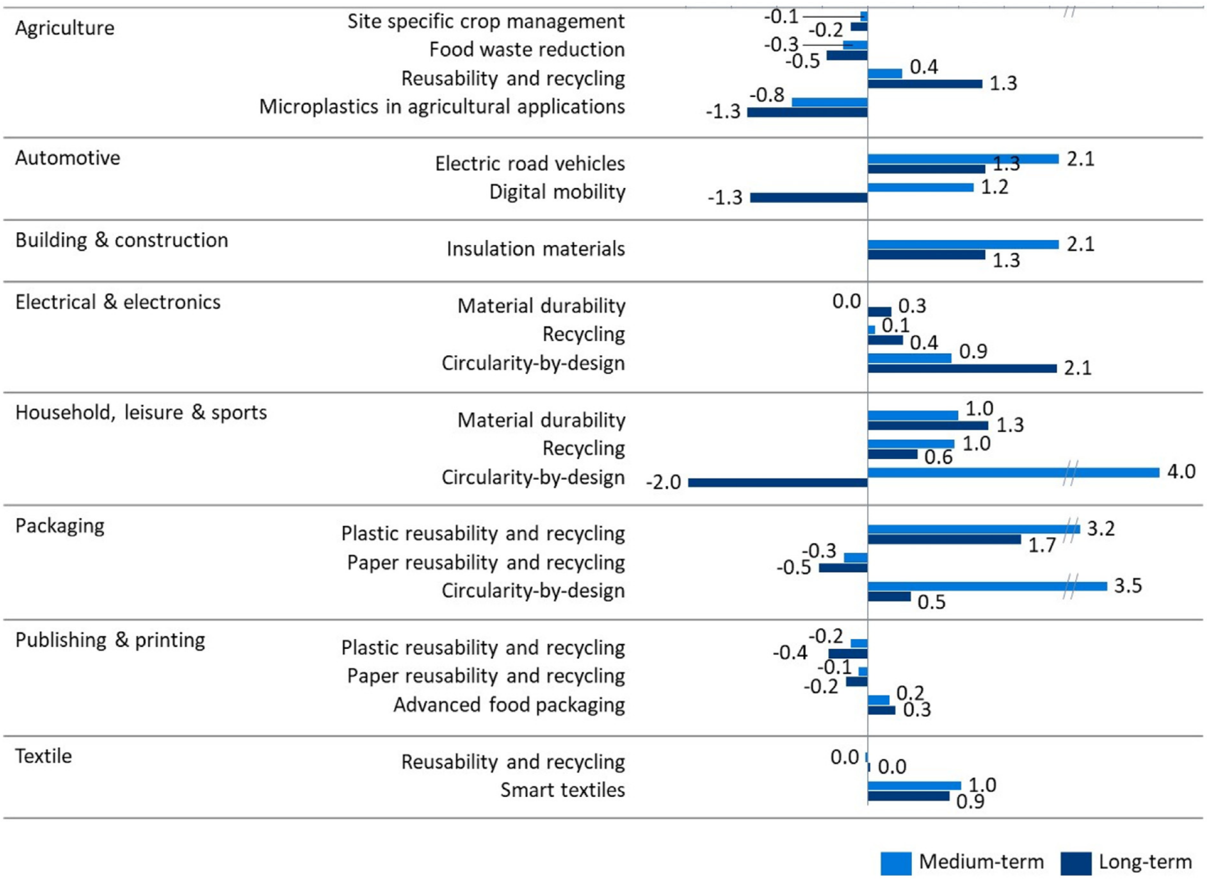

Fig. 5. Effect of circular economy parameter on sales for the medium- and long-term compared to the baseline.

cessed. This value corresponds to about 3.0 to 3.4% of the processed plastics in Europe (51.2 Mt/a, e.g. thermoplastics, thermosets, and polyurethanes). Of this, 22.1% come from crop production (mulch films, protective nets, irrigation systems, etc.), 25.6% from biomass production (silage films), 10.2% from agricultural equipment, and 42.0% from horticulture and gardening (plant containers, planting aids, decorative items). Horticulture and gardening are not included in the calculations of the agricultural sector. The agricultural sector achieves currently a recyclate use rate of 22% within the EU. For the baseline observations, a stable recycling rate is assumed in the medium- and long-term. The agricultural sector in some European countries (i.e. Germany) achieves already a recyclate use rate of 36.5% at present. The EU-wide averaged recyclate use rate for circular economy are expected in the medium-term to be between 26.8 to 34.2%. Based on this, an increase in demand is developing in the medium-term and also in the long-term (Fig. 5).

2. Site-specific crop management. The aim is to reduce significantly the dependency, risk and use of chemical pesticides, as well as of fertilizers and antibiotics. Based on this, the increased use of precision agriculture / satellite farming has been derived (e.g., reduction of fertilizer required per hectare). The parameters used for this analysis are (i) the size of the European seed market and (ii) the share of arable land where site-specific crop management is applied. Based on this, a slight decline in demand is developing in the medium-term and also in the long-term (Fig. 5).
3. Food waste reduction. The amount of food wasted is analyzed. Levers for the reduction of such food waste considered are (i) improvement of process- and market-based standards, (ii) avoidance of non-compliance with food safety requirements, (iii) abolition of the expiry / best-before date for food products, (iv) improvement of marketing standards, and / or (v) logistic constraints. Based on this, a decline in demand results in the medium-term and also in the long-term (Fig. 5).
4. Microplastics in agricultural applications. In view of a forthcoming restriction regarding the avoidance / refusal of intentionally added microplastics (expected in 2022), a reduction of the polymer seed coatings is assumed. Based on this, a decline in demand is developing in the medium-term as well as in the long-term (Fig. 5).

Fig. 6 shows that a decline in demand can be expected in the agricultural sector for fertilizers. This trend will be driven both by the reduction in food waste and by the optimized management of agricultural land through site-specific crop management.

Automotive. The chemical groups important for the automotive sector are (i) plastics, (ii) paints & inks, and (iii) consumer chemicals (Fig. 4). A sustainability goal valid within the mobility sector is a clear reduction in greenhouse gas (GHG) emissions by 2050 (European Commission Sustainable Mobility, 2019). Two main trends are obvious for the automotive sector's demand for chemical industry products (American Chemistry Council 2019 Guide to the Business of Chemistry, 2020; International Energy Agency Global EV Outlook, 2020; Automotive News Europe Volvo Sets Goal of 25% Recycled Plastics in Cars, 2020; European Bioplastics Bio-Based Plastics in the Automotive Market – Clear Benefits and Strong Performance, 2020; Witzke, 2016; Mock, 2018; Weymar and Finkbeiner, 2016; Hurtig et al., 2014; Niestadt and Bjornavold, 2019; SusChem - The European Technology Platform for Sustainable Chemistry Strategic Innovation and Research Agenda - Innovation Priorities for EU and Global Changes, 2020; Carus et al., 2020; Csonka and Csiszar, 2016; Liao et al., 2020; New Registrations of Electric Vehicles in Europe, 2022).

1. Electric-driven road vehicles. Changing demand for e-mobility based on customer requirements, changing regulations in the EU-28 is an-

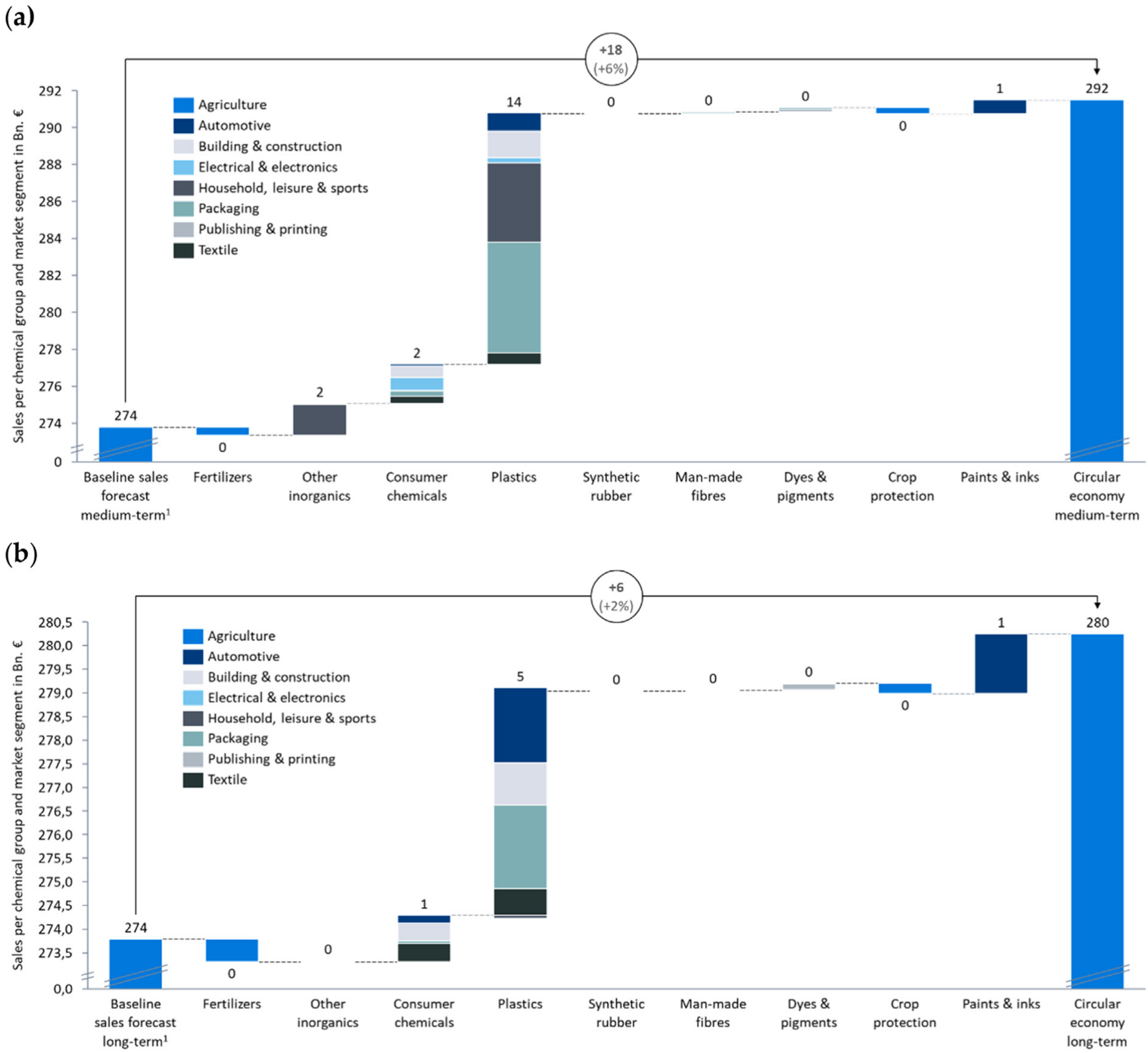

Fig. 6. Circular economy impact on sales by chemical group; baseline perspectives compared to circular economy perspectives for the (a) medium- and (b) long-term; [1]Baseline sales forecast medium- and long-term excluding 'Others'.

alyzed, and accordingly, changing demand for chemicals utilized in this sector. This assessment based on new registrations of private vehicles results in the fact that the circular economy demands on the automotive industry shows a significant increase in the demand for chemicals (Fig. 5).

2. Digital mobility. The demand for chemicals will change based on digital mobility (i.e. shared mobility, automated, autonomous driving) and increasing technological advantages (i.e., enhanced functionalities, durability and recyclability of composites and cellular materials in increasingly demanding applications). Relevant parameters are, among others, number of new built vehicles, average number of passengers per trip, vehicle lifetime, average weight of a passenger vehicle, change for chemicals in private and shared vehicles, recycling rates of chemicals from vehicles. Fig. 5 shows that the efforts towards digital mobility will lead to a decline in demand for chemicals in the long-term. The trend towards lightweight vehicles results in an increasing demand for chemicals, e.g., to replace other materials in the construction of a vehicle (e.g. steel) in the medium-term. However, the trends based on shared mobility are directing into declining figures in the demand for vehicles in the long-term.

Building and construction. The chemical groups relevant to building and construction are (i) consumer chemicals, (ii) plastics, (iii) other inorganics, and (iv) paints & ink (Fig. 4). Renovation of both public and private buildings is a key initiative of the European Green Deal driving energy efficiency. At present, ~75% of the building stock is energy inefficient, and ~80% of today's buildings will still be in use in 2050 (European Commission Renovation Wave August, 2020). The implementation of the European objectives will require the use of numerous chemicals being various components of improved construction materials (European Commission Buildings, 2019; Klaassens, 2020; D'Agostino et al., 2017; Artola, 2016; European Commission The Macro-Level and Sectoral Impacts of Energy Efficiency Policies, 2017).

1. Insulation materials. The demand for chemicals utilized for such materials based on, i.e., lightweight foams and materials for thermal insulation are thus evaluated based on parameters such as average renovation rate and / or average rate of new buildings (energy efficient / passive house). The results show that the demand for chemicals for the thermal insulation of houses will increase strongly in the medium-term, e.g. in order to achieve the European climate tar-

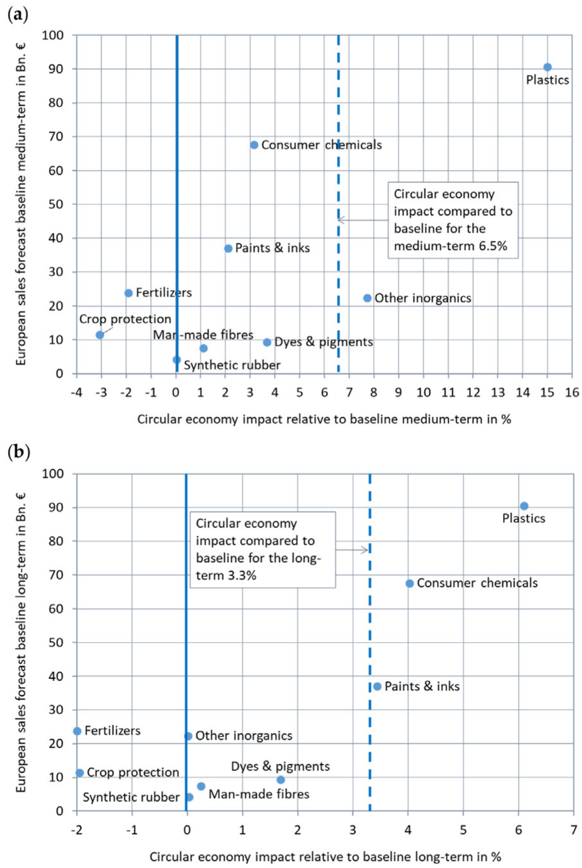

Fig. 7. Circular economy impact on sales by chemical group; baseline perspectives compared to circular economy perspectives for the (a) medium- and (b) long-term.

gets. However, this trend is expected to weaken in the long term, since it can be assumed that houses in need of renovation will be renovated for energy efficiency within the next decade and that the total number of houses in need of renovation will decrease thereafter.

Electrics and electronics. The chemical groups most important for the respective industry are (i) consumer chemicals, (ii) plastics, and (iii) dyes & pigments (Fig. 4). Concerning composites, for example, the growing use creates a high demand for improving circularity-by-design for resins. Applications for materials for electronics include, among others, organic light emitting diodes (OLEDs), printed biosensors, printed conductive ink (predominately for photovoltaics), stretchable and wearable electronics, flexible batteries and capacitive sensors. The demand for chemicals by the electrical industry market segment is not only influenced by the European Green Deal, but also by Horizon Europe, supporting the development of the production of a wide range of new electronic devices based on chemicals with applications in healthcare, consumer electronics, energy, buildings, and mobility (SusChem - The European Technology Platform for Sustainable Chemistry Strategic Innovation and Research Agenda - Innovation Priorities for EU and Global Changes, 2020; European Commission Implementation Strategy for Horizon Europe, 2020; Franquesa et al., 2019).

1. Material durability. Longevity, reliability, and robustness of the electronic device product needs to be ensured when novel chemicals and / or materials are introduced; accordingly, material durability / product lifetime is a decisive criterion for future demand. The results show that in the medium-term there is not yet an increase in demand for life extension chemicals, but in the long-term chemicals supporting this goal are expected to increase in demand.
2. Recycling. The demand for chemicals (e.g., plastics) in the electrical and electronics industry that are suitable for recycling will rise in the medium-term. During recycling it is often very difficult to separate within mechanical recycling processes between different types of materials; this is especially true in the case of composite materials. In the long term, however, it is assumed that the demand for chemicals that enable subsequent recycling will increase even further.
3. Circularity-by-design. A change in behavior of the end-user in terms of reusability is assessed. In the electrics and electronics industry, a significant increase in the demand for chemicals can be seen to allow an increased reusability. This trend is expected to continue to grow in the long term, following the principle of circularity-by-design of products.

Household, leisure and sports. The relevant chemical groups are essentially (i) plastics, (ii) other inorganics, and (iii) consumer chemicals. For new business models a shift to renting goods and services and reduce consumption patterns away from single or limited use products is essential. On this basis, below the lifetime of household, leisure and sports goods, the material quality and the recyclability of plastics is analyzed (European Commission Packaging and Packaging Waste - Environment - European Commission, 2020; Rigall and Wolters, 2019; European Commission, 2019).

1. Material durability. Longevity, reliability and robustness of the household, leisure and sports products needs to be ensured when novel chemicals or materials are introduced; accordingly, material durability / product lifetime is a decisive criterion for the respective demand. This sector will see a significant decrease in demand for chemicals within a circular economy due to longer product life cycles in average both in the medium- and long-term.
2. Recycling. The demand for chemicals (i.e. plastics) for products in the household, leisure & sports market segment that are suitable for the concepts of recycling (e.g. mechanical, thermo-chemical, and chemical recycling) will lead to an increase in demand for the relevant chemical groups, especially in the medium-term. In the long-term, however, the share of recycled materials will decrease, as the share of biogenic materials is expected to increase due to GHG reduction goals and thus recyclable products based on fossil fuel energy / fossil materials will decline in demand.
3. Circularity-by-design. For new business models, the shift to renting goods and services and the reduction of consumption patterns away from single-use or limited-use products is crucial. A change in behavior of the end-user in terms of reusability as well as waste processing for products in the household, leisure, and sports market segment is assessed. In the medium-term, however, demand is expected to rise, as consumer demand from end users for products defined by circularity-by-design will only in the long-term result in products that meet this characteristic and accordingly, reduce the demand within this sector by enhancing the product lifetime.

Packaging. The chemical groups that are most relevant for the packaging industry are (i) plastics, (ii) man-made fibres, (iii) consumer chemicals, and (iv) dyes & pigments.

Packaging materials gain a lot of attention in European regulations. One example of the regulation of packaging is the food industry. In France, 30 types of fruit and vegetables will gradually be offered only without packaging from 2022 onwards. What initially only applies to less sensitive varieties such as cucumbers, carrots or oranges, will be extended to goods such as grapes or berries over the next five years (PlasticsEurope Plastics – the Facts, 2019; European Commission Packaging and Packaging Waste - Environment - European Commission, 2020; World Economic Forum Plastics, the Circular Economy, and Global Trade, 2020; Environmental Protection Agency Plastics, 2016;

Babader et al., 2016; Ewijk et al., 2018; Food and Agriculture Organization of the United Nations, 2013; European Commission A European Strategy for Plastics in a Circular Economy, 2018; Lendal et al., 2019; Detzel et al., 2013; Arbeitsgemeinschaft Verpackung + Umwelt, 2022; Ncube et al., 2021).

1. Plastic reusability and recycling. The demand for chemicals (i.e., plastics) in packaging that are applicable to the concepts of reuse and / or recycling is increasing in the medium- and long-term. It can be observed that the trend has a stronger influence in the medium-term than in the long-term, mainly reflecting the trend to replace chemicals of recycled or reusable origin with chemicals of biogenic origin.
2. Paper reusability and recycling. The demand for chemicals for paper packaging will be lower in the circular economy. This is mainly due to the reduced demand for packaging materials overall, driven strongly by EU regulations.
3. Circularity-by-design. Especially in the medium-term, the trend towards an increased demand for chemicals can be shown, explained by the increased demand for high performance food packaging. The end consumers are paying more attention to the packaging materials and therefore the demand for chemicals that enable high performance food packaging is also increasing.

Publishing and printing. The chemical group most relevant to the publishing and printing industry is dyes & pigments.

The demand for chemicals in this segment is based on the possibilities of reusability and recycling (World Economic Forum Plastics, the Circular Economy, and Global Trade, 2020; Babader et al., 2016; Food and Agriculture Organization of the United Nations, 2013; European Commission A European Strategy for Plastics in a Circular Economy, 2018; Lendal et al., 2019; Detzel et al., 2013; Arbeitsgemeinschaft Verpackung + Umwelt, 2022; Ncube et al., 2021). Thus, for example, the demand for packaging labeling chemicals is decreasing in the medium- and long-term due to the expected and enforced decline in the demand for packaging materials.

1. Paper reusability and recycling. The same trend that can be seen for plastic-based packaging materials can also be seen for paper-based materials. Both, in the medium- and long-term, a decline in demand is expected.
2. Advanced food packaging. The need for chemicals for publishing and printing changes with the replacement of plastics in packaging with paper. There will be an increased demand for chemicals that meet customers' needs for high performance food packaging.

Textile. The chemical groups relevant for the textile industry are (i) plastics and (ii) consumer chemicals.

Performance and durability of critical and structural parts leads to increased system efficiency (e.g., fire resistance and dimensional stability) (SusChem - The European Technology Platform for Sustainable Chemistry Strategic Innovation and Research Agenda - Innovation Priorities for EU and Global Changes, 2020; Rigall and Wolters, 2019; Resyntex A New Circular Economy Concept - From Textile Waste towards Secondary Raw Materials, 2020; Kupfer, 2019; Hemkhaus et al., 2019; Manshoven et al., 2021).

1. Reusability and recycling. It seems, that end customers are not adapting their purchasing behavior to reuse or recyclability.
2. Smart textiles. Innovations in textiles such as textiles with functional finishes, with long-lasting properties and resistance to washing conditions are developed and accordingly, the demand for chemicals will be affected (e.g., anti-microbial and anti-biofilm nano-functionalized material used in specialty textiles for e.g. for public areas and hospitals). In the textile industry, the demand for chemicals will therefore increase in the medium- and long-term as chemicals are used to improve the resistance and durability of textiles.

4. Discussion

Our developed methodology can provide companies with a starting point for identifying which chemical groups will be affected by the impact of the European Green Deal on consumer demand in the future. The results show that the developed methodology for a circular economy impact assessment is an effective tool to assess to what extent developments in circular economy have an impact on the European chemical industry at an early stage. The evaluation based on the presented assessment method is only the first step, allowing a first estimation of the areas in particular in need of further technical development. We suggest that future research should focus on bringing together the evaluation criteria already presented. Bocken et al. (2021), (2022) provides a variety of approaches for evaluating business models and Niessen et al. (2023) regarding sufficiency strategies on consumer practices. The methodology we have developed complements previous work and should be further developed and synthesized in the context of the results of the research just mentioned. In particular, the aspect of monetary evaluation of our developed methodology should be complemented by accompanying research, as it is quantitatively well measurable, but leaves out, for example, technical parameters. Kümmerer et al. (2020) discussed the challenges the chemical industry faces in using non-fossil input materials and recycled materials of lower quality. In particular, they point out the increasing complexity of chemicals and initiate a rethink in order to achieve recycling and sustainable manufacturing goals in the chemical industry.

5. Conclusion

The aim of the methodology developed is to measure the impact of the circular economy on the demand per market segment for the chemical industry. In this context, the transition from a take-make-use-dispose economy to improved resource management is to be measured and/or assessed. The nine 'R's' of the circular economy are used as a basis and are evaluated and applied for each market segment and chemical group in terms of their applicability. The current status is compared with the medium- and long-term developments (i.e., 2030 and 2045, respectively) within the EU-28.

Basically, the efforts of the circular economy aim to use resources to their full extent aiming of conserving resources and thus to reduce the demand for new / unused resources. The extent to which demand reduction in the chemical industry is achieved by the trends of the circular economy for each chemical group or market segment can be clearly analyzed with the methodology developed and presented. For example, a reduction in demand is expected in the medium-term in the packaging as well as within the publishing and printing sector. Both will be driven by changing end-user expectations for modified packaging materials or the reduction of plastics for packaging (relevant for plastics, dyes and pigments). However, the methodology also shows increases in demand due to circular economy trends. The drivers for an increase in demand can be clearly identified. For example, demand for plastics and paints and inks in the automotive industry will increase in the medium-term. This is directly related to the growing demand for electro mobility, the trend towards lightweight materials and the increasing use of plastics (composite materials) in automotive construction. These components in turn need to be colored, explaining the demand for paints and inks.

Thus, the methodology developed can be used to make transparent what circular economy trends will trigger increases or decreases in demand in the chemical industry in the medium- and long-term. This reveals dependencies that are not directly recognizable when introducing regulations, for example, or when developing trends. Thus, market segments relevant for the chemical industry are clearly recognizable and can be further developed accordingly.

Funding

This research received no external funding.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Lisa Thormann: Conceptualization, Methodology, Validation, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Supervision. **Ulf Neuling:** Formal analysis, Visualization. **Martin Kaltschmitt:** Conceptualization, Formal analysis, Visualization, Writing – review & editing.

Data availability

No data was used for the research described in the article.

Acknowledgments

The authors would like to thank the reviewers for their valuable comments that have significantly developed the article.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.clcb.2023.100044.

References

Alexandratos, N.; Bruinsma, J. World Agriculture towards 2030/2050 (FAO) 2012. https://www.fao.org/3/ap106e/ap106e.pdf.
American Chemistry Council 2019 Guide to the Business of Chemistry 2020. https://www.americanchemistry.com/GBC2019.pdf 30.08.2020.
Antikainen, M., Aminoff, A., Kettunen, O., Sundqvist-Andberg, H., Paloheimo, H., 2017. Circular economy business model innovation process – case study. Sustainable Design and Manufacturing. Springer International Publishing Campana, G., Howlett, R.J., Setchi, R., Cimatti, B., Eds.; Smart Innovation, Systems and TechnologiesCham, 2017; Vol. 68, pp. 546–555 ISBN 978-3-319-57077-8.
Arbeitsgemeinschaft Verpackung + Umwelt; Industrievereinigung kunststoffverpackungen E.V mandatory requirements on recycled content for plastic packaging? Available online: https://newsroom.kunststoffverpackungen.de/wp-content/uploads/2020/06/discussion-paper-agvu-ik-mandatory-recycled-content.pdf (accessed on 15 June 2022).
Artola, I. *Boosting building renovation what potential and value for Europe?*; European Parliament: Brussels, 2016; ISBN 978-92-846-0309-1.
Automotive News Europe Volvo Sets Goal of 25% Recycled Plastics in Cars Available online: https://europe.autonews.com/article/20180618/ANE/180619754/volvo-sets-goal-of-25-recycled-plastics-in-cars (accessed on 23 August 2020).
Babader, A., Ren, J., Jones, K.O., Wang, J., 2016. A System Dynamics approach for enhancing social behaviours regarding the reuse of packaging. Expert Syst. Appl. 46, 417–425. doi:10.1016/j.eswa.2015.10.025.
Bartels, R.; Elser, B.; Ulbrich, M. Winning in a circular economy: practical steps for the european chemical industry 2020. https://www.accenture.com/_acnmedia/PDF-117/Accenture-Winning-In-A-Circular-Economy-Executive-Summary.pdf.
BASF SE BASF Factbook Available online: https://www.basf.com/global/documents/en/investor-relations/calendar-and-publications/Factbook/BASF_Factbook_2020.pdf (accessed on 30 August 2020).
Bertling, J.; Zimmermann, T.; Rödig, L. Kunststoffe in der umwelt: emissionen in landwirtschaftlich genutzte böden. 2021, doi:10.24406/UMSICHT-N-633611.
Bocken, N., Konietzko, J., 2022. Circular business model innovation in consumer-facing corporations. Technol. Forecast. Soc. Change 185, 122076. doi:10.1016/j.techfore.2022.122076.
Bocken, N., Strupeit, L., Whalen, K., Nußholz, J., 2019. A review and evaluation of circular business model innovation tools. Sustainability 11, 2210. doi:10.3390/su11082210.
Bocken, N.M.P., Weissbrod, I., Antikainen, M., 2021. Business model experimentation for the circular economy: definition and approaches. Circ. Econ. Sustain 1, 49–81. doi:10.1007/s43615-021-00026-z.
Bocken, N.M.P., Niessen, L., Short, S.W., 2022. The Sufficiency-based circular economy—an analysis of 150 companies. Front. Sustain. 3, 899289. doi:10.3389/frsus.2022.899289.
Bocken, N.; Miller, K.; Evans, S. Assessing the environmental impact of new circular business models.; Toulouse, France, June 19 2016. https://research.tudelft.nl/en/publications/assessing-the-environmental-impact-of-new-circular-business-model.
Carus, M., Dammer, L., Raschka, A., Skoczinski, P., 2020. Renewable carbon: key to a sustainable and future-oriented chemical and plastic industry: definition, strategy, measures and potential. Greenh. Gases Sci. Technol. 10, 488–505. doi:10.1002/ghg.1992.
Chan, E, 2009. Harvard Business School Confidential: Secrets of Success. John Wiley & Sons (Asia) ; John Wiley & Sons, Singapore ; Hoboken, NJ ISBN 978-0-470-82239-5.
Chemiewirtschaft in Zahlen Online - Verband Der Chemischen Industrie e.V. (VCI) Available online: https://www.vci.de/die-branche/zahlen-berichte/chemiewirtschaft-in-zahlen-online.jsp (accessed on 22 August 2020).
Csonka, B.; Csiszar, C. The future of car usage: quality analysis and assessment method for carsharing. 2016, 63, 13–23.
D'Agostino, D., Zangheri, P., Castellazzi, L., 2017. Towards nearly zero energy buildings in Europe: a focus on retrofit in non-residential buildings. Energies 10, 117. doi:10.3390/en10010117.
De Angelis, R., 2018. Business models and circular business models. In: Business Models in the Circular Economy. Springer International Publishing, Cham, pp. 45–73 ISBN 978-3-319-75126-9.
Detzel, A., Kauertz, B., Derreza-Greeven, C., 2013. Study of the Environmental Impacts of Packagings Made of Biodegradable Plastics. ifeu – Institut für Energie- und Umweltforschung Heidelberg GmbH, Heidelberg, pp. 1–130. https://www.umweltbundesamt.de/sites/default/files/medien/461/publikationen/4446.pdf (30.08.2020).
Environmental Protection Agency Plastics: Material-Specific Data 2016. https://www.epa.gov/sites/default/files/2019-11/documents/2016_and_2017_facts_and_figures_data_tables_0.pdf (30.08.2020).
, 2020. European Bioplastics Bio-Based Plastics in the Automotive Market – Clear Benefits and Strong Performance.
European chemicals agency microplastics - Registry of restriction intentions until outcome - ECHA Available online: https://echa.europa.eu/de/registry-of-restriction-intentions/-/dislist/details/0b0236e18244cd73 (accessed on 22 August 2020).
European Commission *Sustainable industry: the European green deal*; Brussels, 2019; ISBN 978-92-76-13680-4.
European Commission Buildings 2019. https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-performance-of-buildings (30.08.2020).
European Commission Packaging and Packaging Waste - Environment - European Commission Available online: https://ec.europa.eu/environment/waste/packaging/legis.htm (accessed on 22 August 2020).
European Commission Renovation Wave Available online: https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en (accessed on 22 August 2020).
European Commission Sustainable Agriculture in the EU Available online: https://ec.europa.eu/info/food-farming-fisheries/sustainability_en (accessed on 22 August 2020).
European Commission The European Green Deal 2019. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:640:FIN.
European Commission; Directorate-General Communication *From farm to fork: the European Green Deal*; Brussels, 2019; ISBN 978-92-76-14006-1.
European Commission A European Strategy for Plastics in a Circular Economy 2018. https://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy.pdf (30.08.2020).
European Commission A New Circular Economy Action Plan for a Cleaner and More Competitive Europe 2019. https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1™format=PDF.
European Commission Implementation Strategy for Horizon Europe 2020. https://research-and-innovation.ec.europa.eu/system/files/2020-04/ec_rtd_implementation-strategy_he.pdf (30.08.2022).
European Commission Polymers 2007. https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/pol_bref_0807.pdf.
European Commission Sustainable Mobility 2019. https://ec.europa.eu/commission/presscorner/detail/en/fs_19_6726.
European Commission The Macro-Level and Sectoral Impacts of Energy Efficiency Policies 2017. https://energy.ec.europa.eu/system/files/2017-07/the_macro-level_and_sectoral_impacts_of_energy_efficiency_policies_0.pdf (30.08.2020).
Ewijk, S.V., Stegemann, J.A., Ekins, P., 2018. Global life cycle paper flows, recycling metrics, and material efficiency. J. Ind. Ecol 22, 686–693. doi:10.1111/jiec.12613.
Farn, R.J., 2006. Chemistry and Technology of Surfactants. Blackwell Pub, Oxford, Ames, Iowa Ed.ISBN 978-1-4051-2696-0.
Food and Agriculture Organization of the United Nations *Food wastage footprint: impacts on natural resources: summary report*; FAO: Rome, 2013; ISBN 978-92-5-107752-8.
Food and Agriculture Organization of the United Nations *FAO statistical pocketbook 2015: world food and agriculture.*; 2015; ISBN 978-92-5-108802-9.
Franquesa, D.; Navarro, L.; Fortelny, S.; Roura, M.; Nadeu, J. Circular consumption and production of electronic devices: an approach to measuring durability, upgradeability, reusability, obsolescence and premature recycling 2019. https://people.ac.upc.edu/leandro/pubs/294.pdf (30.08.2020).
Hadhri, M. 2020 Facts and figures of the European Chemical Industry Available online: https://cefic.org/app/uploads/2019/01/The-European-Chemical-Industry-Facts-And-Figures-2020.pdf (accessed on 9 August 2020).
Hadhri, M. 2022 Facts and figures of the European Chemical Industry Available online: https://cefic.org/a-pillar-of-the-european-economy/facts-and-figures-of-the-european-chemical-industry/ (accessed on 15 June 2022).
Hemkhaus, M.; Hannak, J.; Malodobry, P.; Janßen, T.; Griefahn, N.S.; Linke, C. *Circular economy in the textile sector*; GIZ, 2019.
Hirsch, P.; Schempp, C. *Categorisation system for the circular economy: a sector-agnostic categorisation system for activities substantially contributing to the circular economy*; 2020; ISBN 978-92-76-10527-5.

Huang, Y., Liu, Q., Jia, W., Yan, C., Wang, J., 2020. Agricultural plastic mulching as a source of microplastics in the terrestrial environment. Environ. Pollut. 260, 114096. doi:10.1016/j.envpol.2020.114096.

Hurtig, O., Leible, L., Kälber, S., Kappler, G., Spicher, U., 2014. Alternative fuels from forest residues for passenger cars - an assessment under German framework conditions. Energy Sustain. Soc. 4, 12. doi:10.1186/2192-0567-4-12.

International Energy Agency Global EV Outlook 2020 2020. https://iea.blob.core.windows.net/assets/af46e012-18c2-44d6-becd-bad21fa844fd/Global_EV_Outlook_2020.pdf.

Kümmerer, K., Clark, J.H., Zuin, V.G., 2020. Rethinking chemistry for a circular economy. Science 367, 369–370. doi:10.1126/science.aba4979.

Klaassens, E. Sustainable buildings available online: https://ec.europa.eu/environment/eussd/pdf/Resource%20efficiency%20in%20the%20building%20sector.pdf (accessed on 23 August 2020).

Kumar, M., Xiong, X., He, M., Tsang, D.C.W., Gupta, J., Khan, E., Harrad, S., Hou, D., Ok, Y.S., Bolan, N.S., 2020. Microplastics as pollutants in agricultural soils. Environ. Pollut. 265, 114980. doi:10.1016/j.envpol.2020.114980.

Kupfer, M., 2019. Natural fibres and the world economy july. Renewable Carbon News. (30.08.2020) https://renewable-carbon.eu/news/natural-fibres-and-the-world-economy-july-2019/.

Langner, H. Die abgrenzung von marktsegmenten auf dem europäischen markt. In *Segmentierungsstrategien Für Den Europäischen Markt*; Langner, H., Ed.; Neue betriebswirtschaftliche Forschung; Gabler Verlag: Wiesbaden, 1991; pp. 55–102 ISBN 978-3-322-87980-6.

Lendal, A.; Lindeblad Wingstrand, S. Reuse – rethinking packaging 2019.

Liao, F., Molin, E., Timmermans, H., van Wee, B., 2020. Carsharing: the impact of system characteristics on its potential to replace private car trips and reduce car ownership. Transportation 47, 935–970. doi:10.1007/s11116-018-9929-9.

Mammana, I., 2014. Concentration of market power in the EU Seed Market. European Parliament- EFA. https://www.greens-efa.eu/files/assets/docs/concentration_of_market_power_in_the_eu_seed_market.pdf.

Manshoven, S.; Smeets, A.; Arnold, M.; Mortensen, L.F. *Plastic in textiles: potentials for circularity and reduced environmental and climate impacts*; European Environment Agency, 2021.

Mock, P. European vehicle market statistics 2018/2019 2018. https://theicct.org/wp-content/uploads/2021/06/ICCT_Pocketbook_2018_Final_20190408.pdf.

Ncube, L.K., Ude, A.U., Ogunmuyiwa, E.N., Zulkifli, R., Beas, I.N., 2021. An overview of plastic waste generation and management in food packaging industries. Recycling 6, 12. doi:10.3390/recycling6010012.

New Registrations of Electric Vehicles in Europe Available online: https://www.eea.europa.eu/ims/new-registrations-of-electric-vehicles (accessed on 15 June 2022).

Niessen, L., Bocken, N.M.P., Dijk, M., 2023. The impact of business sufficiency strategies on consumer practices: the case of bicycle subscription. Sustain. Prod. Consum. 35, 576–591. doi:10.1016/j.spc.2022.12.007.

Niestadt, M.; Bjornavold, A. European parliament - electric road vehicles in the European Union 2019. https://www.europarl.europa.eu/RegData/etudes/BRIE/2019/637895/EPRS_BRI(2019)637895_EN.pdf (30.08.2020).

PlasticsEurope Plastics – the Facts 2019 Available online: https://www.plasticseurope.org/application/files/1115/7236/4388/FINAL_web_version_Plastics_the_facts2019_14102019.pdf.

Priefer, C., Jörissen, J., Bräutigam, K.R., 2016. Food waste prevention in Europe – A cause-driven approach to identify the most relevant leverage points for action. Resour. Conserv. Recycl. 109, 155–165. doi:10.1016/j.resconrec.2016.03.004.

Ragonnaud, G., 2013. The EU seed and plant reproductive material market in perspective. A Focus on Companies and Market Shares doi:10.2861/46869.

Resyntex A New Circular Economy Concept - From Textile Waste towards Secondary Raw Materials Available online: http://www.resyntex.eu/images/downloads/RESYNTEX-Leaflet-2018.pdf (accessed on 30 August 2020).

Rigall, J.; Wolters, G. VCI - expectations of customer industries for the Chemical Industry 2019. https://www.vci.de/vci/downloads-vci/publikation/2019-09-26-expectations-customer-industries-english-final.pdf (30.08.2020).

Schrijver, R.; Poppe, K.; Dewar, D.; Kempenaar, C.; Lokhorst, K.; Bogaardt, M.-J.; van der Wal, T.; de Baerdemaker, J.; Quinn, J. *Precision agriculture and the future of farming in Europe: annex 1 : technical horizon scan : study*; European Parliament: Brussels, 2016; ISBN 978-92-823-9556-1.

Snihur, Y., Bocken, N., 2022. A call for action: the impact of business model innovation on business ecosystems, society and planet. Long Range Plan. 55, 102182. doi:10.1016/j.lrp.2022.102182.

SusChem - The European Technology Platform for Sustainable Chemistry Strategic Innovation and Research Agenda - Innovation Priorities for EU and Global Changes 2020.

Takácsné György, K., Lámfalusi, I., Molnár, A., Sulyok, D., Gaál, M., Keményné Horváth, Z., Domán, C., Illés, I., Kiss, A., Péter, K., 2018. Precision agriculture in hungary: assessment of perceptions and accounting records of FADN arable farms. Stud. Agric. Econ. 120, 47–54. doi:10.7896/j.1717.

Thormann, L., Neuling, U., Kaltschmitt, M., 2021. Opportunities and challenges of the european green deal for the chemical industry: an approach measuring innovations in bioeconomy. Resources 10, 91. doi:10.3390/resources10090091.

Tilman, D., Balzer, C., Hill, J., Befort, B.L., 2011. Global food demand and the sustainable intensification of agriculture. Proc. Natl. Acad. Sci. 108, 20260–20264. doi:10.1073/pnas.1116437108.

Vennestrøm, P.N.R., Osmundsen, C.M., Christensen, C.H., Taarning, E., 2011. Beyond petrochemicals: the renewable chemicals industry. Angew. Chem. Int. Ed. 50, 10502–10509. doi:10.1002/anie.201102117.

Vox, G., Loisi, R.V., Blanco, I., Mugnozza, G.S., Schettini, E., 2016. Mapping of agriculture plastic waste. Agric. Agric. Sci. Procedia 8, 583–591. doi:10.1016/j.aaspro.2016.02.080.

Weymar, E., Finkbeiner, M., 2016. Statistical analysis of empirical lifetime mileage data for automotive LCA. Int. J. Life Cycle Assess. 21, 215–223. doi:10.1007/s11367-015-1020-6.

Witzke, S., 2016. Carsharing Und Die Gesellschaft von Morgen. Springer Fachmedien Wiesbaden, Wiesbaden ISBN 978-3-658-11840-2.

Woltjer, G.; Smits, M.; Duin, L.; Best, A.; Hasenheit, M.; Drabik, E.; Rizos, V. Insights from the circular impacts case studies 2018. https://www.ecologic.eu/sites/files/publication/2018/2809-case-study-insights_2018-09-20_final.pdf.

World Economic Forum Plastics, the Circular Economy and Global Trade 2020. https://www3.weforum.org/docs/WEF_Plastics_the_Circular_Economy_and_Global_Trade_2020.pdf (30.08.2022).