David Schönmayr

Automotive Recycling, Plastics, and Sustainability

The Recycling Renaissance

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David Schönmayr
University of Graz
Graz/Linz
Austria

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To my dear parents. May your loving care continue in perpetuity.

Foreword

Humanity is shaping earth's geology and ecosystems on a scale which has not been seen before in history, which leads to the debate to name our epoch "Anthropocene." As of 2016, more than 7.5 billion people are living on our planet, and it is expected that global population will reach up to 10 billion in 2050. This will have consequences. The challenge is to meet the needs of all people living on Earth now and in the future while ensuring the stability of our ecosystems—this is the basic definition of Sustainable Development published in the famous Brundtland Report in 1987. The United Nations issued 17 Sustainable Development Goals to boost the global progress toward a sustainable society providing good living conditions for all while respecting ecological limits. All societal actors have a responsibility to contribute to Sustainable Development.

The automotive industry forms one of the most productive economic sectors and thus has also to take up this responsibility to contribute to Sustainable Development. One important aspect hereby is the amount of resources used for products and services. Up to now, we have to a large extent a linear industrial system where resources are extracted, used for products, and disposed after the use phase. An important element in any transition toward sustainability will therefore be to use resources much more efficiently and to develop a circular economy where waste is used as new resource input. This background underpins the relevance of this book. One strategy of the automotive industry to reduce energy demand and CO_2 emissions is to reduce the weight of vehicles. This leads to an increasing demand of lighter materials including plastics. On the other hand, recycling rates for plastic are lower as, for example, for steel. The relevant question is then, how recycling rates for plastic can be increased in the automotive sector as contribution to a sustainable and circular economy. David Schönmayr gives actual, competent, and comprehensive insights to answer this question. He first provides the big picture of this topic from a sustainability perspective. This is the basis for the discussion of the status quo regarding plastic use in the automotive industry. By bringing in expert's knowledge based on a survey, he is able to develop a road map for the "recycling renaissance" as a core result of this book. This book deserves many readers and is relevant to all who are interested in the topic of sustainability transitions in the automotive sector.

Univ.-Prof. Dr. Rupert J. Baumgartner (Head of institute)
Institute of Systems Sciences, Innovation and
Sustainability Research
University of Graz

Preface

Plastics are one of the most inexpensive and at the same time valuable materials made by humankind. The production of plastics is well established, and the virgin material is virtually adaptable to any requirement rendering them impressively versatile. The omnipresence of plastics establishes most people's constant contact with this material. In fact, one could not imagine a life without plastics. These materials have helped develop our economy, our society, and our life, because plastics are truly valuable.

However, during the work for this book, it became clear that many companies are not (yet) rational and far sighted enough, or are too focused on money and growth to realize their chance to transform their business for the better through implementing holistic ecological sustainability. The current path is very unlikely to be sustainable in the long term. In fact, we have to act right now, because nature will continue to thrive, likely in new forms, despite humanity changing the circumstances. Will we continue to thrive as well? Environmental degradation might not be the end result, but human degradation.

The enormous garbage patches in the oceans, plastic waste in the streets of India, and even microscopic plastic particles in your own body. Humanity has still to learn how to treat plastics, since the current usage is very unfortunate indeed. Now, we need to step up and change the way we deal with plastics. Let us start by introducing the recycling renaissance, starting with the automotive sector.

Graz/Linz, Austria David Schönmayr

> Change will not come if we wait for some other person or some other time. We are the ones we've been waiting for. We are the change that we seek.
>
> —Barack Obama

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While doing research for this book, I was fortunate to have amazing companions along my intensive, challenging, and rewarding path. I want to thank the following people:

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- Prof. Dr. Elmar Kulke for helping me to focus and narrow my book to develop a common theme viewed from a fresh perspective
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- Mike Biddle Ph.D. and Dr. Brian Riise, MBA Polymers
- DI Sabine Seiler and Mag. Alfred Ledersteger, Saubermacher
- Dipl.-Ing. Heinz G. Schratt, PlasticsEurope
- Dr. Peter Kunze, ACEA—European Automobile Manufacturers' Association
- DI Nina Kieberger, voestalpine Steel Division

- Michael Plamann, Ammer Entsorgung
- Mag. (FH) Peter Maierl, Clariant
- Hans Zimmer and his motivational audio support, because music is simply one of the best mental stimulators
- And ultimately, I am very glad to have such a supporting partner Stefanie, motivating family members, and dear friends—I couldn't have done it without you!

Contents

Abbreviations

ASR	Automotive Shredder Residue
CAGR	Compound annual growth rate
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	CO_2 equivalent
CSR	Corporate Social Responsibility
DIN	Deutsches Institut für Normung (German Institute for Standardization)
EC	European Commission
EIA	Environmental Impact Analysis
ELV	End-of-life vehicle
EOL	End-of-life
EPR	Extended Producer Responsibility
EU	European Union
Eurostat	Statistical office of the European Union
FSSD	Framework for Strategic Sustainable Development
GDP	Gross domestic product
GHG	Greenhouse Gases
In-house in-line recycling	Recycling of production waste within the company
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
KPI	Key Performance Indicator
LCA	Life-Cycle Assessment
LDC	Less Developed Countries
MSW	Municipal Solid Waste
OECD	Organization for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
OPEC	Organization of the Petroleum Exporting Countries
Post-consumer recycling	Recycling after the usage phase
RCBA	Risk–Cost–Benefit Analysis

REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RoHS	Restriction of Hazardous Substances Directive
SCOT	Analysis including Strengths, Challenges, Opportunities, Threats
TA	Technology Assessment
Tier 1, 2, …n	Suppliers for OEMs (varying commercial distance)
WEEE	Waste Electrical and Electronic Equipment…

Plastic Types

ABS	Acrylonitrile Butadiene Styrene
ASA	Acrylonitrile Styrene Acrylate
CE	Cellulose
CFRP	Carbon Fiber-reinforced Plastics
GRP	Glass-reinforced Polyester
GFRP	Glass Fiber-reinforced Plastics
HDPE	High-density Polyethylene
HIPS	High Impact Polystyrene
LDPE	Low-density Polyethylene
LLDPE	Linear Low-density Polyethylene
PA	Polyamide (nylon)
PBT	Polybutylene Terephthalate
PC	Polycarbonate
PE	Polyethylene
PET	Polyethylene Terephthalate
PMMA	Polymethylmethacrylat
POM	Polyoxymethylene
PP	Polypropylene
PS	Polystyrene
PUR	Polyurethane
PVC	Poly Vinyl Chloride
SMA	Styrene Maleic Anhydride…

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Chapter 1
Origin and Design of This Book

Abstract What is the purpose of this book, and which (non-)scientific methods were used to achieve representative, real-world results? These questions are answered in this chapter, including a short depiction on the inspiration for this work, including an outline of the book design and its logical structure.

Darwin's 1859 "On The Origin of Species" was originally published on the 24th of November (Dupree 1988, p. 267), the same day I came into the world in 1986. Coincidence or not, I consider the topic of this book to also be about evolution—evolution concerning society achieving sustainability, starting with a circular economy, because this evolution is a prerequisite for the health of humanity. Nature will continue to exist, but will we?

However, since I have been truly interested in the topic of sustainability for numerous years now, including research and lectures on this broad topic, it was only a question of the right time to focus on contributing to this field. Moreover, I have invested increasingly more time in research and quickly came to a number of possible fields for intensive study. The one most interesting was and still is the topic of automotive plastics recycling concerning the production and the end-of-life phase. As a result, the author held fruitful discussions across sciences and settings that ultimately led to this book.

The first motivating and inspiring impulse for this book was mainly initiated by Martin Dupal, co-owner of the plastics and plastics recycling company Walter Kunststoffe GmbH in Wels, Upper Austria. He made reference to the rather non-existent amount of information on plastics recycling and the non-transparent recycling status of plastics in the automotive sector. During an extended interview, he reflected on the scientific pool of available information in the area of plastics recycling and argued that the quality and quantity of data of plastics packaging, for example, PET-recycling was comparably sophisticated and developed. Regrettably, this was not the case in the area of plastics recycling in the automotive sector. Mr. Dupal indicated that this scientific field was poorly assessed and analysed. The second impulse for this book was provided by an EU publication which stated that automotive plastics from end-of-life vehicles (ELVs), which accounted for 1.5 Mt in 2008, are hardly recycled. As a matter of fact, they are mostly landfilled or thermally treated (Euro-

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pean Commission DG ENV et al. 2011). The third impulse came from the former CEO of the plastics recycling company MBA Polymers, Mike Biddle, who gave a talk on their advanced possibilities to recycle virtually any plastics, even if the most complex compounds, like the ones used in automobiles (Biddle 2011, 2012). The final impulse was the fact that there is a high probability that demand for plastics will grow significantly in the next 10 years. This is because the quantity of automotive plastics is rapidly increasing, in relative and absolute terms, because of the increasing share of plastics in new cars and the increase in the number of cars on the globe (see Chap. 3). Furthermore, the "academic 'call to arms'" by Orsato and Wells (2007, p. 993) to inspire research for making "one of the most influential industries in the world more sustainable" truly has inspired and motivated me.

For these reasons, I decided to start a research project in form of a PhD thesis as a basis for this book in order to foster innovative solutions to tackle the obvious insufficiency of automotive plastics recycling and the use of recyclates in the automotive sector. This book provides solutions and options for car manufacturers and suppliers, recyclers, virgin plastics producers, politicians and scientists in order to spur on a circular flow economy to establish a more sustainable automotive industry with the focus on ecological aspects. Overall, the intention is to develop advanced concepts and holistic solutions to current unsustainable practices regarding plastics materials and raise awareness in the European automotive sector through critical, rigorous and integrative research. The project promotes the decoupling of economic growth from waste generation, and has already triggered and will continue to trigger economic rethinking through the empirical research including the survey, expert workshops and lectures by the author alongside personal communication. For these reasons, this book provides research results for strategies to establish synergy effects to drive sustainable development and generate a vital impulse in the direction towards a circular automotive plastics industry on a global scale to take a turn for the better.

Purpose of This Book

Intensive literature research revealed that there is a lack of topical scientific books and papers dealing holistically with the issue of the ecological sustainability of the automotive plastics production and recycling system, including the key players. Orsato and Wells (2007, p. 993) in particular inspired research into making "one of the most influential industries in the world more sustainable", which was continued for automotive plastics recycling, for example by Miller et al. (2014, p. 5896) who stated that "future efforts should look to increase the proportion destined for recycling" and "future research is critical to determining what the ideal combination of [treatment] alternatives might be for long term sustainability". Current research does not provide a holistic analysis of the overall system, because predominantly narrow sections within this field of automotive plastics and sustainability are being treated. For these reasons, the holistic research of this book provides a novel overarching analysis of the system as well as conceptual solutions. As Baumgartner (2011, p. 785) summarised, "...sustainability science should help to identify sustainability problems and should help society to solve them". This book does offer help.

Book Design

In this book, you will find answers to the following questions:

- What is corporate sustainability and how can it advance a circular economy?
- How ecologically sustainable is the automotive life-cycle (production, life-phase, and end-of-life) in terms of plastics?
- ...and what are the reasons for this?
- What are the benefits and drawbacks of virgin and recycled plastics in terms of ecological, economic and technical performance?
- What are the challenges of this system?
- What are the best solutions to improve this system in terms of ecological sustainability, with a focus on the recycling aspect in particular?
- How will this system have developed by 2020 and beyond?
- How will the behaviour of consumers have changed by 2020?
- What are tools and methods to achieve corporate sustainability, and thus circular automotive plastics?

Why Not Focus on Plastics Other Than Automotive?

The focus on the automotive industry was chosen because it is considered a superimposed branch, which can serve as a basis for top-down knowledge transfer to branches with lower requirements in terms of material performance. As the global automotive industry is deeply concerned with safety, reliability and design, the materials have to fulfil very high standards. For this reason, the idea behind this book being to offer solutions to stimulate the plastic recycling industry, it is assumed that the knowledge gathered in this top level branch can be transferred to numerous other branches, which have lower material performance requirements. Orsato and Wells (2007, p. 989) highlight the superimposed status of the automotive sector by stating that it is a branch with significant influence especially on society and the environment, as well as other industrial sectors. In addition to these complex challenges, the plastics and especially the automotive plastics sector is very dynamic and enjoys strong growth. In fact, automotive plastics are rapidly increasing in relative and absolute quantity, because of the increasing share of plastics in new cars and the increase of cars on the planet (Kremlicka 2012; Sperling and Gordon 2009; Worldbank 2013). In addition, a possible trend towards eco-efficient lightweight design and electric mobility renders plastics highly relevant, if not even more relevant due to the required compensation of heavy batteries and comparably low range.

Methods

In order to perform research on a firm scientific foundation, I chose a mixed methods approach including qualitative and quantitative techniques in combination, adapted to the respective phase of this book. The entire book is based on mixed method guidelines by Creswell and Clark (2011, p. 11) combined with analysis techniques focused on preconditions, laws and connections between phenomena by Hempel (1965) and Hempel and Oppenheim (1948).

The theoretical matter which makes up Chaps. 2 and 3 consists firstly of reactive or primary data such as expert interviews for understanding and discussing the state to date, to optimise the research focus and questions, and to validate findings mainly during the literature research phase in the beginning, and additionally in later stages of the book. Then secondly, non-reactive or secondary data such as literature as well as process produced data and behavioural traces including statistics, as outlined by Fink (2009), were utilised.

In the empirical part, which will be described in more detail in Chap. 8, I hosted two expert workshops for developing and validating gathered data together with the Autocluster Styria and the Department of Geography and Regional Science at the University of Graz. The first workshop was held to discuss and improve a pre-developed SCOT analysis together with chosen experts and outline suggestions to improve the book. Most importantly, I also conducted an online survey involving key players and stakeholders of the automotive plastics production and recycling system throughout Europe to gather real-world data from key players to achieve relevant results. Additionally, this survey served as a basis for a validation, interpretation and critique conducted in the second workshop, which is featured in Chap. 4, in direct succession of the factual, unaltered and clinical outline of the results. Thus, the survey and the workshop methodologies are blended together for concise information. Furthermore, future perspectives were developed relying on literature research mainly including reports from key companies, data from the survey, and information gathered through expert interviews. Subsequently, the development of scenarios with the generated data and knowledge from the preceding research stages is the basis to enhance and expand the concepts for solutions developed by experts in the second workshop. Through these selected methods and research stages, a well-founded scientific analysis was achieved.

Book Structure

This book is divided into two parts: firstly, the theory and secondly, the empirical part. The first deals with the theoretical foundations of this research, which is subdivided into two logically connected chapters. We will begin with the theory approach which investigates the relevant scientific approaches to this research. This is designed to achieve the theoretical background necessary for fully understanding the subsequent chapter, the controversial industry reality investigating the status quo in the economy. Through this approach, it is possible to analyse a variety of aspects of the automotive sector resulting in a holistic understanding of the system, the subsystems and related influences. The combination of these two chapters generates a broad and deep knowledge foundation required for the critical analysis in the second part, the empirical section. This approach was chosen because theory determines our observation, in this case the empirical section. It is divided into the exploration of the automotive plastics production and recycling system in the EU to discover the drivers of change, followed by a SCOT analysis. The next phase concerns modelling future perspectives by investigating basic trends and key uncertainties and developing multiple scenarios by analysing the rules of interaction, finally leading to concepts for solutions. The approach of the empirical section is based on Schoemaker (1995).

Funnel-Logic Distillation

The sections in this book are logically structured to extract the essence of the respective topic by distillation, where appropriate. This process, based on Baade et al. (2010) is comparable to working with a theoretical funnel for scientific research, where the broad and general information is investigated at the start, which is followed by narrowing down the relevant information until the core, or the essence is extracted or revealed, in other words, 'from general to specific'. This funnel-logic distillation approach can be reversed, depending on the nature of the topic, depending on the respective logic to ensure maximum understanding of the written work.

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Chapter 2
The Scientific Sustainability Approach

Abstract Read, rethink, refine, reform. In this chapter, you will learn that sustainability is the next big thing. For you, for your company, and for society. After reading this chapter, you will be able to rethink your world, be able to refine it, and ultimately reform it. First, however, you need to understand sustainability, and you have to recognise that it is a holistic and trans-disciplinary matter. Especially considering that the topic of plastics recycling in the automotive sector is associated with a large number of different disciplines, it can and should be analysed from several scientific and non-scientific points of view, including various approaches and their respective tools and methods. As a consequence, it is a prerequisite to understand the related fields such as systems sciences, sustainable development, ecology, economy, geography, as well as environment research, society, ethics, psychology, politics, and technology, which are briefly depicted in this chapter. Through this approach, it is possible to analyse a variety of aspects of the automotive sector resulting in a holistic understanding of the system, the subsystems, and related influences. This approach generates the broad and at the same time deep knowledge foundation required for the empirical analysis in the subsequent chapters offering the holistic basis for corporate sustainability management concerning automotive plastics and recycling.

2.1 Transdisciplinarity

As this book is dedicated to looking at automotive plastics recycling as a whole, and following the definitions of multi-, inter-, and transdisciplinarity by Choi and Pak (2006), a holistic and transdisciplinary approach was selected to mark the basis of this book in order to generate more value, because according to Klein et al. (2012), transdisciplinarity offers an optimised approach to overcome challenges by combining know-how from multiple sources, as required in the field of sustainability. However, because transdisciplinarity can be defined in various wide and narrow ways (Lang et al. 2012) such as including scientific experts from other disciplines in the research team, which is not the case in this book, and to circumvent possible unclear definitions, it is to be highlighted that the notion of transdisciplinarity in this book is implemented in the sense of an intensive and consecutive inclusion of assorted relevant

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insights from diverse disciplines, sources, and actors in this book, following the notion of Jahn et al. (2012). The chosen transdisciplinary setting focusses on human ecology within geography in close collaboration with systems sciences, sustainability and innovation research. The issue concerning specific disciplines which are relevant for this book to varying degrees is that those are focussed solely and understandably on merely one aspect of the topic of plastics recycling in the automotive sector. Of course, these disciplines are vital to understand and ultimately analyse this field of research, but it remains highly important to take a holistic approach in order to combine the knowledge generated by each of the mentioned disciplines. With this broad transdisciplinary approach implemented in the sense of including different relevant insights from various related disciplines and sources in this book, this research can conceive of the countless relations including cause and effect across disciplines within the globalised automotive branch.

For these reasons, the most significant sciences relevant to this research and their interrelations are briefly outlined on the subsequent pages. The disciplines refer to academic disciplines and are arranged from meta- to specific levels, resulting in an investigation of varying intensity into human ecology, systems sciences, sustainable development, ecology, economy, society, ethics, psychology, politics, and technology.

2.2 Human Ecology

Besides the declared approach of transdisciplinarity in Sect. 2.1, it is of great importance to find scientific fields which are capable of managing the various additional required disciplines from a meta-position. Through this approach, is it possible to further increase the substantial value and relevance of this research. The chosen scientific fields capable of this task of taking the meta-position, of serving as a superstructure, are first of all, the human-environment geography (see Gebhardt 2011; Knox et al. 2008; Turner 2002; Weichhart 1993) with human ecology as well as systems sciences and sustainable development, which will be dealt with within Sects. 2.3 and 2.4.

Geography and sustainable development are to date pursuing similar goals in their respective sub-areas. Their difference lies mainly in their differing history and their approach, which is the reason for choosing geography as the first science for the meta-position. Human-environment geography emerged largely from academic scholars limited by the institutions, while environmental studies, including the notion of systemic sustainability, evolved through the driving force of occurrences and stakeholders within large sections of society (Sneddon 2009, p. 559). However, geography is experienced in managing the interaction between humanity and the environment, and not to forget, geographers have successfully empirically verified the influence of industrial production on the natural environment (Braun 2003, p. 1). Recent scholars state that the multiple sciences of geography (physical and human) render the geographer capable of taking on the role as a valuable link vital to achieving a

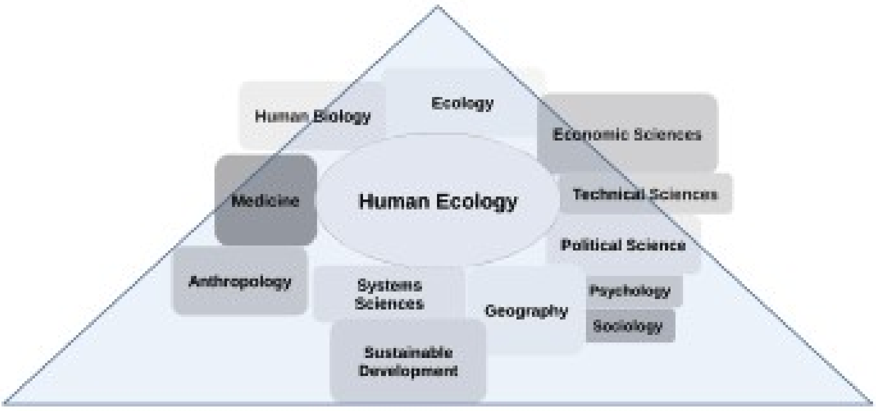

Fig. 2.1 Human ecology—a transdisciplinary approach, adapted with kind permission from Weichhart (1995)

connection between the natural environment and humanity for the purpose of understanding complex issues arising from this relation (see Knox et al. 2008, p. 755). This meta-approach is entitled 'human ecology' and serves as the main transdisciplinary meta-approach for this book. However, despite subtleties of the definition due to different approaches, human ecology in the geographical context is predominantly concerned with sustainability in terms of the relationship between society and the environment which renders human ecology perfectly suitable as a meta-position to answer the research questions in this book (see Sect. 1). Human ecology in this book is primarily based on Peter Weichhart's explanations (Weichhart 2011), alongside Weichhart (1993), Meusburger and Schwan (2003), Glaeser (2013) and Nentwig (2013). Generally, human ecology can be seen as a field of sustainability research focused on transdisciplinarity and the relationship between the global stakeholders as defined below, without a predefined structure as it is basically not an independent science but is a meta-approach managing and accessing diverse human sciences. Human ecology is a new scientific discipline researching the interrelationships and interactions between society, the environment and humanity. Its core is a holistic approach that incorporates physical, cultural, economic and political aspects (Deutsche Gesellschaft für Humanökologie e.V. 2013).[1] Although human ecology emerged from the geographic discipline, it emancipated itself and became a firmly established, transdisciplinary area of research far-reaching across multiple sciences (see Fig. 2.1).

This transdisciplinary approach of human ecology (Fig. 2.1) is an attempt to connect the various disciplines which represents the theoretical foundation of this

[1] Translated and paraphrased original German passage: "Die Humanökologie ist eine neuartige wissenschaftliche Disziplin, deren Forschungsgegenstand die Wirkungszusammenhänge und Interaktionen zwischen Gesellschaft, Mensch und Umwelt sind. Ihr Kern ist eine ganzheitliche Betrachtungsweise, die physische, kulturelle, wirtschaftliche und politische Aspekte einbezieht" (Deutsche Gesellschaft für Humanökologie e.V. 2013)

book. Human ecology and its transdisciplinarity offer the idea of coupled knowledge, although this is often not the case in reality. The most important sciences connected through human ecology which are relevant to plastics recycling in the automotive sector are geography, systems sciences, and sustainable development, followed in a descending order by ecology, economic sciences, sociology and ethics, psychology, political science, and technical sciences. Following this notion of human ecology, the interaction between the two main participants, namely the physical-material world and society, is of especially high importance. In this 'model of interaction', the physical-material world (nature) and society (culture) overlap and this area is defined through 'hybrid systems' [see Weichhart (2008, p. 65), adapted from Fischer-Kowalski and Weisz 1999].

Returning to the paramount topic of geography (Knox et al. 2008, p. 730), further proposes that numerous aspects of future geographies will depend almost certainly on the demand for particular resources and the utilisation of new technologies. Reconsidering the facts about the high demand for oil necessary for the production of virgin plastics and the "end of cheap oil" as stated by Campbell and Laherrère (1998) and outlined in Sect. 3.1, Knox's statement highlights the necessity of geographic approaches toward the current and future plastics production due to the high dependency on a particular resource - oil. Furthermore, the utilisation of new technologies, such as new materials, and technological changes in a globalised economy have global effects (see Malecki 1997).

Taking a brief look on the life-cycle of products, as outlined in Sect. 3.1.2, it becomes clear that geographic factors are essential in a globalised economy. Focussing on the automotive sector, on the required resources for production, the automotive components, and ultimately the car itself as outlined in Sect. 3.2, the life-cycle of those is characterised through numerous spatially relevant features and is a reflection of the relationship between society and the environment:

- The geographic location of the source of the natural resources (e.g., determines the work environment and is relevant for the ecological impact).
- The geographic location of production (locations can be at different stages of development and can have different laws leading to different environmental impact).
- The geographic location of the usage (determines to a great extent where and how the ELVs are treated, causing varying ecological impacts).
- The geographic location of the final destination of untreated end-of-life vehicles.

The relationship of the above-mentioned geographic locations of stages throughout the life-cycle of products, or in this case cars, underlies the basic relations within economic geography according to Ritter (1991, p. 24). This model shows that the resources of the natural milieu and resources of the societal and cultural milieu are used to satisfy human needs, which are modified by ethics and morality. These resources are situated at a geographic position. Finally, the resources, their geographic location and the human needs define the functional relations of economy. Additionally, the relationship between the actors comprised of the consumer, the politicians, and the supplier company is relevant in an economic systems such as the automotive and plastics industry, which is called 'group of actors approach' according to Kulke (2013, pp. 18–20). In this approach, the financial and work trade between the supplier and the consumer, the power distribution between the consumer and politics, the lobbying and structural policy between politicians and the supplier, and finally the sharing of information establish a system of actors which is influencing the structure and dynamics of location systems and areas as well as spacial systems of economic activities. This approach highlights that in an economy, several actors or actor groups are interconnected significantly. In short, environmental issues and their geographic research are generating a huge momentum within the field of sustainability concerning materials in the economy, regardless of varying definitions of scientific (sub-)fields. However, there are more disciplines besides geography that are investigating environmental issues.

2.3 Systems Sciences

Because this research in the automotive sector deals with a complex system regarding a vast number of elements and disciplines as outlined above, it is advisable to take a systemic approach for improving our understanding of the inherent complexity of the topic. The principles of systems science are relationships between elements including cause and effect, as illustrated in the following example linked to sustainability by OECD (2003, p. 21), which states that "human activities exert pressures on the environment and affect its quality and the quantity of natural resources ('state'); society responds to these changes through environmental, general economic and sectoral policies and through changes in awareness and behaviour ('societal response')" (see Fig. 2.2).

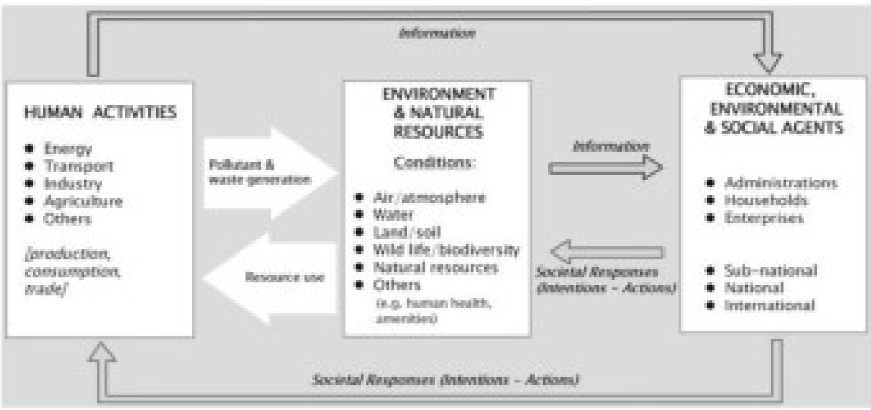

Fig. 2.2 The "Pressure-State-Response Model" highlighting the systemic relationships of sustainability, used with kind permission from OECD (2003, p. 21)

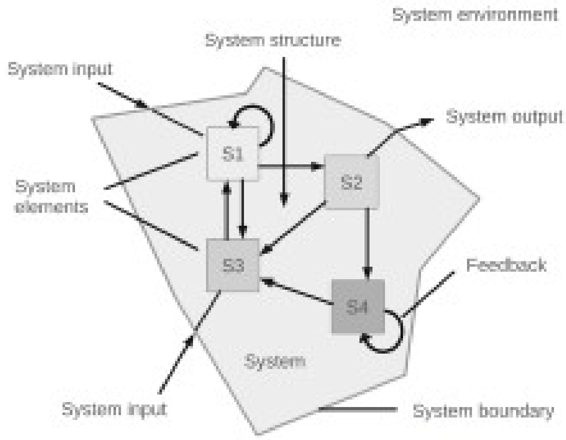

Fig. 2.3 The basic principles of a system, adapted from Mrotzek (2012) and Ossimitz (2000, 1997)

With systems sciences, it is easier to comprehend the system elements and the structure of effects related to automotive plastics when following the principles developed by authors such as Bertalanffy (1968), Checkland (1999), Rosnay (1979) and Willke (2006). Thus the necessary insight to discover the most promising system elements, which can be altered to enhance economic and ecological performance, can be achieved. This notion was also followed by Graedel et al. (1998) who claimed that the automotive industry had to be understood as a system including its surrounding elements and other systems. The principle of systems science is defined as follows: "A system is a set of objects together with relationships between the objects and between their attributes" (Hall and Fagen 1956, p. 18). Consequently, a system consists of system elements, which are structured through connections thus creating relationships, and possibly feedback. In general, the elements of a system are situated within a certain boundary, which should be created in order to achieve a high level of autonomy of the system within the system environment. This system environment influences the system (input) and vice versa (output). Furthermore, feedback is possible within the system, even without input from the environment (Mrotzek 2012). The basic principles of a system are illustrated in Fig. 2.3.

By thinking in terms of such systems, it is possible to perform analysis right down to the last detail as well as regarding the far-reaching synthesis of causal relations (Ropohl 2009, p. 77). Furthermore, this 'systems thinking' is, according to Ossimitz (1997, 2002) defined by four essential dimensions, which were adapted by the author:

- Model thinking: explicitly comprehended modeling, and awareness of the real-world the model is referring to
- Interrelated thinking: thinking in interrelated, systemic structures.

- Dynamic thinking: thinking in dynamic processes (delays, feedback loops, oscillations).
- Systemic action: the ability for practical system management and system control.

These dimensions are considered key to practical systems thinking as performed in this book. Now that the basics of systems thinking are outlined, we can apply this essential systemic knowledge to the science of 'sustainable development'.

2.4 Sustainable Development

The science of sustainability[2] is obligatory to fully understand the ecological dimensions of automotive plastics along the whole life-cycle of cars. For this reason, scientific exploration of sustainable development figures into the theoretical concepts of this book as it facilitates strategic thinking and taking action to overcome urgent challenges (see Baumgartner and Korhonen 2010; Carroll and Buchholtz 2011; Kates and Clark 2001).

Defining sustainable development is difficult, although the term is to date widely used, eliciting a variety of responses. According to Hopwood et al. (2005, p. 38), "the concept of sustainable development is an attempt to combine growing concerns about a range of environmental issues with socio-economic issues." Another and probably the most famous definition is from the report "Our common future", also known as 'Brundtland report': "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Gro Harlem 1987, p. 41).

2.4.1 Levels, Types and Principles of Sustainable Development

In this section, a brief outline of the goals of sustainability and sustainable development will be provided. Following the idea of the 'Framework for Strategic Sustainable Development' (FSSD) by The Natural Step (2013),[3] we must "eliminate our contributions to ...

- ... the systematic increase of concentrations of substances extracted from the Earth's crust (for example, heavy metals and fossil fuels),
- ... the systematic increase of concentrations of substances produced by society (for example, plastics, dioxins, PCBs and DDT),

[2] A detailed up-to-date outline on sustainability is provided by Zimmermann (2016) (in German).

[3] These goals are a reformulation of the initially developed goals by Robèrt (2002) and Robèrt et al. (2002, pp. 198, 199)

- ... the systematic physical degradation of nature and natural processes (for example, over harvesting forests, destroying habitat and overfishing); and ...
- ... conditions that systematically undermine people's capacity to meet their basic human needs (for example, unsafe working conditions and not enough pay to live on)."

Besides these goals for a sustainable society which do not incorporate certain aspects, five principles for sustainable development of which some are linked to the goals mentioned above expand this notion (Deutscher Bundestag 1998):[4]

- "The degradation rate of renewable resources should not overcome their regeneration rate. This rule requires the maintenance of ecological productivity."
- "Non renewable resources should only be used to the extent to which a physically and functionally equivalent replacement in the form of renewable resources or of higher productivity of renewable as well as of non-renewable resources is achieved."
- "Element inputs into the environment should not overcome the absorption capacity of the environmental medium, considering all functions of the environmental medium."
- "The period of time in which anthropogenic inputs or interferences in the environment occur must be in a balanced relation with the period of time needed by the natural processes related to the reaction capacity of the environment."
- "Dangers and unjustifiable risks for human health due to anthropogenic interferences have to be avoided."

Additionally, sustainability contains economic, ecological, and social dimensions that are not separate, but create via an integrated view the three pillars or dimensions of sustainable development (see Adams 2006), illustrated in Fig. 2.4. The dimensions of sustainability with respect to this research will be dealt with in detail subsequently to this section.

Taking the pillars of sustainability, it becomes obvious that one is missing: the institutional pillar. Through this approach, initially developed by Valentin and Spangenberg (2000, p. 383), the institutional aspect of sustainability (which strengthens participation) as well as the linkages between the certain points of sustainability and their imperatives are taken into consideration, as illustrated in the following tetraheder (see Fig. 2.5). Additionally, Janschitz and Zimmermann (2010, p. 137) incorporated logical levels to achieve a concept originally developed for sustainable regional development, but is perfectly suitable for various research in the field of sustainability. The core of the logical levels is to consider the fields in need of change from identity to the environment, which are relevant according to the respective pillar or in this case the vertices of sustainability, and to achieve solutions ranging from visions to concrete actions. The main aim of the concept is to integrate a holistic strategy in sustainable development with the focus on the ecological aspect for the

[4] Translation from German passage in Umweltbundesamt (2010, p. 15), additional translation available from Gleich et al. (2006, p. 355)

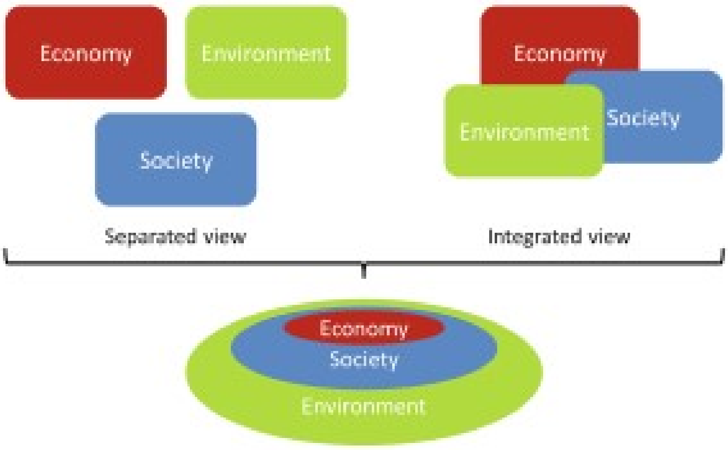

Fig. 2.4 The dimensions of sustainability, adapted from Adams (2006)

Fig. 2.5 The prism of sustainability (Valentin and Spangenberg 2000, p. 383), used with kind permission. All rights reserved

reason to develop valuable and practicable solutions for transdisciplinary challenges, which is key to this book primarily concerned with ecology.

Because one pillar of sustainability is concerned with economy, it is necessary to first investigate corporate sustainability and secondly, the relationship between sustainable development and corporate sustainability. In this case, the macro-level

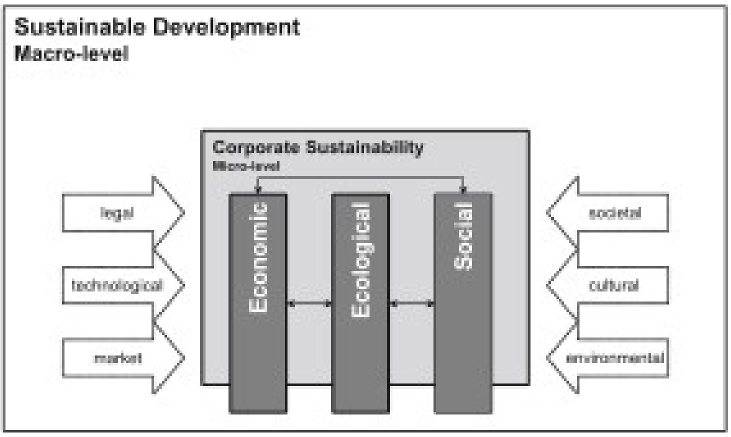

Fig. 2.6 Levels and relationships of sustainability, used with kind permission from Baumgartner and Ebner (2010, p. 77)

(sustainable development) influences the micro-level (corporate sustainability, see section "Corporate sustainability and CSR") through legal, technological, market, societal, cultural, as well as environmental factors (see Fig. 2.6). The micro-level is again based on the three pillars of sustainability. Additionally, society can benefit from corporate sustainability as illustrated by the columns in grey extending from the micro-level into the macro-level (Baumgartner and Ebner 2010, p. 77).

On a holistic examination of sustainability science, four aspects are vital of importance, creating a full outline of the notions of sustainability, which was adapted from Baumgartner (2011, p. 785) and Ömer-Rieder and Tötzer (2004, pp. 6, 7): Sustainability...

- ... is about achieving adequate living for all people on earth within the planetary boundaries, still enabling tomorrow's society to do so likewise.
- ... is dynamic with constantly shifting short-term goals in the course of less dynamic long-term goals.
- ... has to develop strategic contributions (thinking+action) for constructive improvement for society and nature.
- ... contributions have to be rigorous in terms of approaches and strategies.
- ... is to be dealt with in traditional disciplines, and holistic disciplines (such as sustainability science) to achieve an integral way of viewing things.
- ... is about sustainable innovation through new products, as well as institutional, societal and system innovations

Continuing with the approach 'from holistic to specific', we will move on to outline the pillars of sustainability. First of all, the ecological aspects will be dealt with, followed by the economic and the societal aspect including ethics, psychology, politics and the technical theory regarding automotive plastics recycling.

2.4.2 Ecological Aspects

The most important aspect of sustainability in this research is ecology. Essentially, the connection between geography, sustainable development, and ecology is highlighted by Siebert (2008, pp. 99, 283) and Siebert (2007, p. 378) because they state that human activities are always linked to the environment, which is still considered a free good marked by overconsumption to date. It is for these reasons that the environmental impact by human and especially corporate activities has been growing ever since, leading to unsustainable practices (IPCC 2007; Labuschagne et al. 2005; Pachauri et al. 2014) which are measured and compared, for example by DJSI (2013), FTSE (2006) and GRI (2011). Due to this impact of humanity on the environment, the era succeeding the Holocene from the late eighteenth century until today can be labelled as the 'Anthropocene' (Crutzen 2002; Steffen 2007). However, the term Anthropocene has a variety of definitions, depending on the educational and professional background of the respective author (Ruddiman 2012; Zalasiewicz et al. 2008). Crutzen's definition was considered the most suitable, because of his atmospheric chemistry approach, which considers the industrial revolution and the usage of fossil fuels as the beginning of the 'Anthropocene' era. In that era, humanity has been transgressing the planetary boundaries which "define the safe operating space for humanity with respect to the Earth system and are associated with the planet's bio physical subsystems or processes" (Rockström et al. 2009, p. 472).

With this background of the environmental impact of human activities, and the principles of sustainability provided above, we now have to assess the practical ecological aspects or impacts regarding life within the planetary boundaries based on Baumgartner and Ebner (2010, p. 79): The ecological aspects of sustainability include "Resources (materials, energy) including recycling", "Emissions into the air", "Emissions into the water", "Emissions into the ground" as well as "Waste and hazardous waste", impact on "biodiversity" and "Environmental issues of the product" over the whole life-cycle. These ecological aspects are diversely applicable to investigate adverse environmental impacts. In fact, especially the link between global warming and humanity has been confirmed by extensive research on 11,944 papers by Cook et al. (2013, p. 1) which showed that "97.1% endorsed the consensus position that humans are causing global warming", although this number is being debated and challenged in the scientific community. However, to provide countermeasures against the human-caused environmental degradation, one can deduce rules for sustainability, as outlined in Sect. 2.4. When considering the rules and the ecological aspects of sustainable development, it is to be highlighted that during the investigation of ecological impacts of, for example, a product, a life-cycle approach is necessary in order to achieve a holistic view. This life-cycle is defined through three phases: the production phase, the life phase, and the end-of-life phase (Maudet et al. 2012, p. 23), see Sect. 3.2.3. During these phases, certain environmental impacts have to be considered, for example demand for raw materials and energy, the production of waste, and the release of emissions (for more details see Sect. 3.1.3).

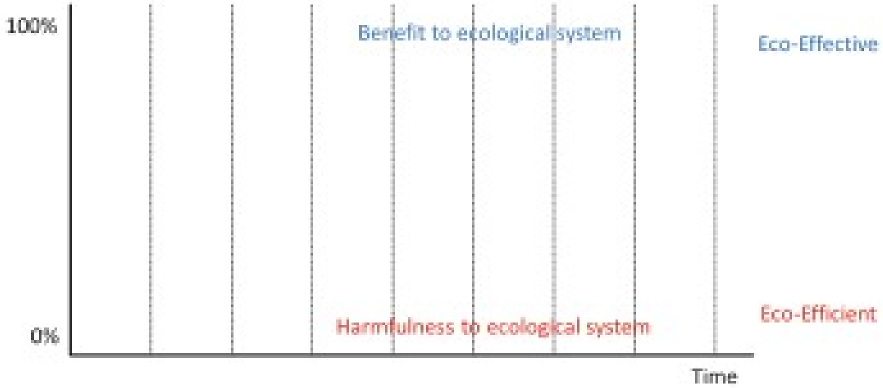

Fig. 2.7 Eco-effectiveness and eco-efficiency, adapted with kind permission from Braungart et al. (2007, p. 1343)

Sustainability science has developed two levels of sustainability, namely 'weak' and 'strong' sustainability. Weak sustainability suggests that natural capital can be replaced by manufactured capital, that depleting natural resources is justifiable if human-made capital is generated in exchange. For example, extracting oil, thus extracting green house gases whose emissions are measured in CO_2 equivalents (CO_2e) (Pachauri et al. 2014), is acceptable if enough plastic products are being produced. In contrast, strong sustainability suggests that natural capital is irreplaceable, that natural capital is finite and certain natural functions are irreversible (Neumayer 2010, pp. 1, 2).

The idea of sustainability leads to additional concepts, such as eco-efficiency and eco-effectiveness. According to Braungart et al. (2007), eco-efficiency sees the economic flow in a linear way, from raw material extraction, to the production of goods and finally to waste (cradle-to-grave). In this linear succession, it is possible to enhance efficiency through, for example, a decrease of raw-material and energy consumption for the production, or little recycling. In fact, only downcycling[5] is possible, since the linear economy does not implement design-for-recycling strategies. In contrast, eco-effectiveness sees the economic flow not as linear but as circular (cradle-to-cradle). With this approach, materials do not end up as waste, as their status as a valuable resource is never lost, through design-for-recycling and actual recycling strategies (upcycling[6]) (Braungart et al. 2007). Moreover, eco-efficiency is intended to decrease the harmfulness to the ecological system, whereas eco-effectiveness is intended to increase the benefit to the ecological system (see Fig. 2.7).

[5]Downcycling describes the process when the recycled product is of inferior value than the initial product, for example, if high-tech automotive plastics is being downcycled to become a waste paper basket.

[6]Upcycling describes the process when the recycled product is of equal or superior value than the initial product, for example if high-tech automotive plastics is being recycled to become high-tech automotive plastics again.

However, a critical analysis reveals that the concept of cradle-to-cradle has to be seen from a holistic life-cycle viewpoint. Thus, the hierarchy of aims might conclude that recycling is deemed unworthy because it is too energy-consuming and the recovery of energy through incineration might be preferable. However, this has to be analysed in each individual case. The next relevant scientific field of sustainability is concerned with the economic aspects related to this research.

2.4.3 Economic Aspects

Research on plastics recycling in the automotive sector is heavily dependent on economic factors, simply due to the fact that it is the economy that drives the world. With this in mind, it is clear that "... the resolution of environmental issues has to proceed alongside the many economic challenges currently facing the automotive industry: notably over-capacity; saturated and fragmenting markets; capital intensity; and persistent problems with achieving adequate profitability" (Orsato and Wells 2007, p. 989). This notion refers to firstly, 'impact decoupling', which "requires increasing economic output while reducing negative environmental impacts" and secondly, 'resource decoupling', which is defined as "reducing the rate of use of (primary) resources per unit of economic activity" (Fischer-Kowalski and Swilling 2011, p. 4). As illustrated in Fig. 2.8, resource decoupling refers to the idea that the intensity or success of economic activity is to be decoupled from resources. And impact decoupling refers to the notion that the economic activity is to be decoupled from the environmental impact. Moreover, the aim is to decouple human well-being, which is presently coupled to economic growth, from environmental impact and resource use.

Additionally, Deutscher Bundestag (2013, p. 156) points out that 'green growth' will not be defined by high growth rates. The benefit lies in the stability and

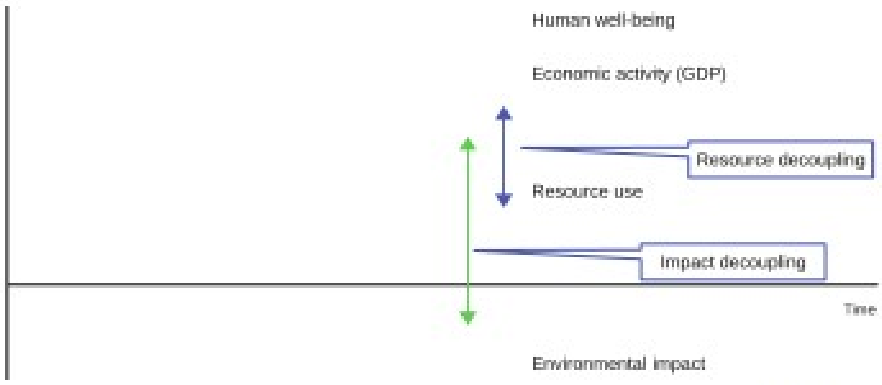

Fig. 2.8 Two aspects of 'decoupling', adapted from Fischer-Kowalski and Swilling (2011, p. 15)

long-term sustainability of economic development. Despite these notions of green growth and decoupling, several additional economic aspects have to be considered as well. According to Deutscher Bundestag (1998, pp. 26, 27), the following aspects[7] have to be taken into account:

- *The economic system is to meet individual and social needs efficiently. For this, the economic system must be so designed that it promotes personal initiative (self-responsibility) and the self-interest in the service of the common good (usually responsibility) is to secure the well-being of current and future society.*
- *Prices must permanently perceive the essential guiding role in markets. They are to reflect to a large extent the scarcity of resources, lowering, factors of production, goods, and services.*
- *The conditions of competition are to be designed so that functioning markets emerge and are sustained, and innovations stimulated in order to achieve a state in which a long-term orientation is worthy and that the social change necessary to adapt to future needs is encouraged.*
- *The economic efficiency of a society and its productive, social, and human capital must be at least maintained over time. These should not only be increased in terms of quantity, but also constantly improved in terms of quality.*

Corporate Sustainability and CSR

The aspects above now have to be implemented within companies through corporate sustainability, which is "Sustainable development when incorporated by the organisation ... and it contains, like sustainable development, all three pillars: economic, ecological and social" (Baumgartner and Ebner 2010, p. 77) and corporate social responsibility 'CSR',[8] which is defined as "the responsibility of enterprises for their impacts on society" (European Commission 2011, p. 6), although CSR is often defined by multidimensionality not just concerning the social aspect. This broad corporate social responsibility is comprised of integrating environmental, ethical, social, and human rights, and concerns of the consumer into the corporate strategy, "with the aim of ... maximising the creation of shared value for their owners/shareholders and for their other stakeholders and society at large" and "identifying, preventing and mitigating their possible adverse impacts." Another term for corporate sustainability is "Corporate Responsibility", which is defined similarly through a business management with sustainability as the major focus to achieve long-term success.

United Nations (2010, p. 15) developed a more detailed guideline for companies, to achieve a higher level of sustainability. These 'ten principles of the global compact' include besides principles about human rights, labour standards, and anti-corruption, three environmental principles (7 to 9) that "[b]usinesses should support a precautionary approach to environmental challenges", "undertake initiatives to promote greater environmental responsibility" and "encourage the development and

[7] Translated and paraphrased from German.

[8] Please note that CSR and corporate sustainability are still not clearly distinguished (Baumgartner 2014, p. 259) and this is why both terms are used to prevent confusion.

diffusion of environmentally friendly technologies." To find out how to implement sustainability at corporate level, please see Sects. 6.1 and 6.1.3.

However, (corporate) sustainable development requires assessment, which is difficult. More than 41 sustainability indices offer various approaches, from integrated and holistic to specific and narrow, including, for example, life-cycle assessments (LCAs) (Singh et al. 2012) with respective standards such as the ISO 14040:2006 (ISO 2006a) and 14044:2006 (ISO 2006b). The mentioned LCA is a holistic and systematic analysis of a product from the cradle to the grave including the initial raw material extraction up to the disposal at the end-of-life (Owens 1997, p. 37), or a "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life-cycle" (Shrader-Frechette 2012). Several LCA methods, which have been developed and improved in the last years, are applicable for achieving a rigour and holistic life-cycle assessment also to "avoid problem-shifting from one part of the life-cycle to another, from one geographical area to another" (Finnveden et al. 2009, p. 17).

Now focusing on the social aspect of corporate sustainability, CSR can be outlined in various ways and very simply, such as done by Carroll and Buchholtz (2001, p. 36) who state four components of social responsibility, which suggest that a company which incorporates CSR should be profitable, conforming to the law, act ethically and be a good member of society. As the concept of CSR is, as the definition suggests, deeply linked to societal aspects, the next section will draw on this and other remaining aspects of sustainability, but not just focused on the corporate level.

2.4.4 Societal, Ethical, Psychological, Political, and Technological Aspects

Sustainability in general also incorporates social aspects including ethics and psychology, which are of equal importance to the ecological and economic aspects. Starting with society and following the notion of Dillard et al. (2008, p. 4), it is to be highlighted that sustainability in social terms is divided into sustainable processes and social facilities, which foster the former.

Within the social aspects of sustainability, also ethics emerge as a field of interest, as they are the foundation of responsible acting. According to Kant (1993), ethics are defined as the following imperative: "Act only according to that maxim whereby you can at the same time will that it should become a universal law without contradiction." Formulated very simplistically, this imperative suggests that what evokes social benefit is positive, and what evokes social disadvantage is negative. Additionally, Kant (1993, p. 5) argues that society has the duty to incorporates efforts to improve freedom, peace, justice, and human rights, and to preserve the natural environment.

As a result, these notions establish and drive the implementation of a new paradigm or consensus called the 'global ethic' (Küng 1993, p. 6). Further, it is time to pursue responsible economic practices concerning the present world, the natural world and the future world (Küng 2010, p. 126). Consequently, the global ethic can be utilised to channel these required practices. Now, in order to understand how we can pursue such responsible economic practices, we have to briefly assess the political and psychological aspects as well. Within this book, the social (and also the economic) aspect of sustainability is only indirectly of relevance due to the link to the ecological sustainability, for example, when increasing the circular economy in terms of plastics which can cause a reduced need for waste exports to countries that have less strict regulations concerning landfilling, including manual treatment of (toxic) waste.

However, sustainability is also concerned with psychology, simply for the reason that humans are involved. The decision-making process performed in companies, the government and in the mind of each individual human being is especially relevant for automotive plastics recycling, for example due to a possible change of material sources. According to University of Massachusetts Dartmouth (2017), the steps of decision making are:

1. "Identify the decision"
2. "Gather information"
3. "Identify alternatives"
4. "Weigh the evidence."
5. "Choose among alternatives"
6. "Take action"
7. "Review your decision."

However, this decision making process can be influenced heavily by cognitive and personal biases (Manktelow 2012), which can lead to serious failures regarding decisions within a complex system that requires a rigorous and holistic analysis of the system elements and their relationships. One relevant aspect in this case is the possibility of egoistic action by the individual in the system which can lead to seriously negative outcome, and this usual actor is called "limited homo oeconomicus" (Kulke 2013, p. 55).

Besides society and the economy represented by businesses, politics and political decision-makers represent an additional key player in the changing and environmentally critical system of automotive plastics, because "... science and technology developments are challenging existing public policies and legislation due to the impact that they may have in terms of environmental sustainability ..." (Klüver et al. 2015). In fact, politicians can influence this system through impeding, promoting, and stalling action by means of legislative measures, incentives, lobbying, and simple action, inaction, or even counter measures. Through these options of influence, politics represent another actuator for improving sustainability within companies. More importantly, the mentioned key players (politics, companies and society) do act accordingly to certain decision making processes and are influenced by biases.

In the field of plastics recycling in the automotive sector, the technical aspect is of particular interest. This is because the available and future technologies determine the paths we can choose from when pursuing sustainable development. When thinking about technology to improve the level of sustainability, it is necessary to evaluate technology. However, current practice is to focus on the economic and technical characteristics. If new technology is intended to be designed humane and environmentally sound, ecological, social and political dimensions ought to be included in the system of aims within the development of this new technology (see Ropohl 2009). This notion is called 'eco-technological systems knowledge' or 'eco-socio-technological systems knowledge[9] (Ropohl 2009, p. 277). This concept builds on the assumption that nature, human beings, and society create the conditions to which technology is subject. Vice versa, consequences induced by technology influence nature, human beings and society (see Ropohl 2009).

Now, to develop future conscious strategies in line with nature and society, an examination of technology and its possible issues is required. Prominent examinations are the holistic 'technology assessment' or 'TA' (United States Congress 1995) to analyse the impact of technology on society (Coates 1976), or the focussed 'environmental-impact analyses' 'EIA' (Shrader-Frechette 2012). A popular TA method is for example the 'risk-cost-benefit analysis' 'RCBA'. Concerning these types of assessments, the biggest challenge is forecasting and anticipating "higher-order" consequences of high complexity (Shrader-Frechette 2012).

2.5 Conclusion: Sustainability as Schrödinger's Cat

Is sustainability dead or alive? I am not so sure. But reflecting on the gathered information in the preceding sections concerning plastics recycling in the automotive sector with the focus on ecological sustainability, one is led to these main findings:

- Humankind is the determining factor on the globe in the era of the Anthropocene (Crutzen 2002; Steffen 2007).
- Certain boundaries of the earth have been transgressed or are being transgressed (Rockström et al. 2009).
- Solutions and strategies exist in theory, such as

– Resource and impact decoupling (Fischer-Kowalski and Swilling 2011, p. 4).
– Eco-efficiency and eco-effectivity (Braungart et al. 2007).
– Concepts for holistic and transdisciplinary strategies for sustainable development including the FSSD (Janschitz and Zimmermann 2010; Robèrt et al. 2002, p. 137).
– Corporate sustainability and CSR (Baumgartner 2014; Baumgartner and Ebner 2010; European Commission 2011).
– Ecotechnical systems knowledge and technology assessment (Ropohl 2009; Shrader-Frechette 2012; Singh et al. 2012).

[9] Translated and paraphrased original German passage: "ökotechnologisches Systemwissen" and "öko-sozio-technologische Systemwissen" (Ropohl 2009, pp. 214, 215).

As a intermediate result, the scientific sustainability approach revealed that in order to develop sustainability with strategies as mentioned above, first the key elements including the key players, resources and goods, as well as their relationships within the automotive plastics production and recycling system have to be understood (Fischer-Kowalski and Weisz 1999; Knox et al. 2008; OECD 2003; Ossimitz 2002; Weichhart 2008). Furthermore, it is necessary to gather knowledge and data on the above-mentioned system aspects suitable for the normative, the strategic, and the operational management level in companies (see Baumgartner 2014). Consequently and foremost, information about the economic branches and goods in the focus of this book is required, which is done in the following Sect. 3 and the subsequent empirical analysis.

When going back to the beginning of this book and reflecting on the research questions (see Sect. 1), the theoretical outline in the preceding sections provided reasons and criteria for the selection and formulation of research questions following the overarching question: What can we do to advance the ecological sustainability of plastics in the European automotive sector? But first, when thinking beyond the main findings above and especially the section about sustainability, it was discovered that companies do think differently. Sustainability is 'good' and a requirement, but in fact, the only thing companies really understand are key performance indicators (KPIs). Therefore, a new definition was required. And this is why it was decided to adapt the notions of sustainability science for companies by creating a new approach.

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Chapter 3
Automotive Plastics and Sustainability

Abstract Plastics, cars, and sustainability—how do those three concepts even go together? To explain, I will now present a short outline on the global development of both the plastics and automotive industries, each with a comprehensive analysis of the environmental challenges and sustainable chances of the automotive plastics production and recycling system. In this system especially, the notions and ideas depend heavily on the perspective, or in this case, rather the perspective of the companies. This creates numerous and often conflicting opinions and even facts that clash, generating controversy in particular when analysing plastics in terms of ecological sustainability. In this chapter, this controversy is brought forward in an objective, scientific manner, based on the theoretical ideas and notions from Chap. 2 to reflect on the reality in the industrial sector. Through the combination of these two chapters, we can break the surface and evaluate the current development of the automotive plastic production and recycling system.

3.1 Plastics

3.1.1 Definition and Development of Plastics

Plastics are omnipresent, yet are hard to define. The term plastics is commonly known yet not easy to describe for most people, ever since plastics were developed (Meikle 1995, p. 5). Nevertheless, there are several definitions, some very detailed and thus more restrictive than others:

> [Plastic is a] material which contains as an essential ingredient a high polymer[1] and which, at some stage in its processing into finished products, can be shaped by flow. Elastomeric[2] materials, which are also shaped by flow, are not considered to be plastics. (ISO 2013)[3]

[1] A polymer is a "high molecular weight molecule, natural or synthetic, whose chemical structure can be represented by repeated small units which collectively form molecular chains. …This material class has three main sub-groups: elastomers, thermoplastics and thermosets." (ISO 2011).

[2] An elastomer is a "macromolecular material which returns rapidly to its initial dimensions and shape after substantial deformation by a weak stress and release of the stress. …The definition applies under room temperature test conditions." (used with kind permission from (ISO 2013)).

[3] By permission. From the International Organization for Standardization.

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However, for this research, the following definition is considered best as it refers to the organic roots of the vast majority of plastics:

> [Plastic is] a plastic substance; specifically: any of numerous organic synthetic or processed materials that are mostly thermoplastic[4] or thermosetting[5] polymers of high molecular weight and that can be made into objects, films, or filaments (Merriam-Webster's Collegiate© Dictionary 2017)[6]

As natural materials such as bitumen might also fit the definition of plastics, one has to differentiate between natural plastics and synthetic plastics (Brydson 1999). Moreover, plastics are made from petrochemicals such as crude oil, coal, and natural gas[7] (Chanda and Roy 2010). Focussing on synthetic plastics in this book, the historical data of the plastics discovery in literature found varies depending on the detailed definition of plastics. Brydson (1999, Chap. 1), one of the most prominent authors dealing with plastics in general, highlights the discovery of rubber in the 19th century as a mere starting point of plastics, as this material was a vital yet neglected predecessor of the plastics industry. Inventors such as Charles Goodyear and Thomas Hancock did extensive research on rubber resulting in the development of materials such as vulcanite, ebonite, and hard rubber. In the years following, numerous plastics materials, for example parkesine, celluloid, gutta percha, and shellac expanded the range of plastics. However, Brydson (1999, pp. 3, 4) also highlights that Alexander Parkes was the first to market plastics after developing a material called 'Parkesine', introduced in 1862 at the 'Great International Exhibition' in London (Brydson 1999, Chap. 1). Therefore, Parkes can be considered the father of plastics.

A different view on the history of plastics is expressed by Thompson et al. (2009b), as he declares a certain material the starting point of plastics: the first fully synthetic plastics material 'Bakelite', developed by Leo Bakeland, a Belgian chemist, in 1907, set off further developments.

However, it is even more remarkable that the success of plastics materials did not start off immediately after their discovery. In fact, there was a period of reduced activity until the beginning of mass production in the 1940s and 1950s, launching the rise of plastics used on a daily basis (Thompson et al. 2009b). Since this start of industrial plastics production, the usage of plastics has been growing extensively (see Fig. 3.1). The economic relevance of the plastics industry on the globe and in Europe has therefore been growing in the EU-28 in 2012 to generate a turnover of €215 billion from manufacturing "plastic products" (processed and shaped plastics), additionally 93.6 billion from manufacturing "plastics in primary forms" (Eurostat 2015) (such as plastic flakes and granulates). Furthermore, in 2012 there were 2546 enterprises

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[4] "Plastic which, when cured by heat or other means, changes into a substantially infusible and insoluble product" (ISO 2011).

[5] "Plastic that has thermoplastic properties" (ISO 2011).

[6] By permission. From Merriam-Websters Collegiate Dictionary, 11th Edition 2017 by Merriam-Webster, Inc. (http://www.Merriam-Webster.com).

[7] For more details on plastic materials and production, please refer to Chanda and Roy (2010), and http://www.plasticseurope.org.

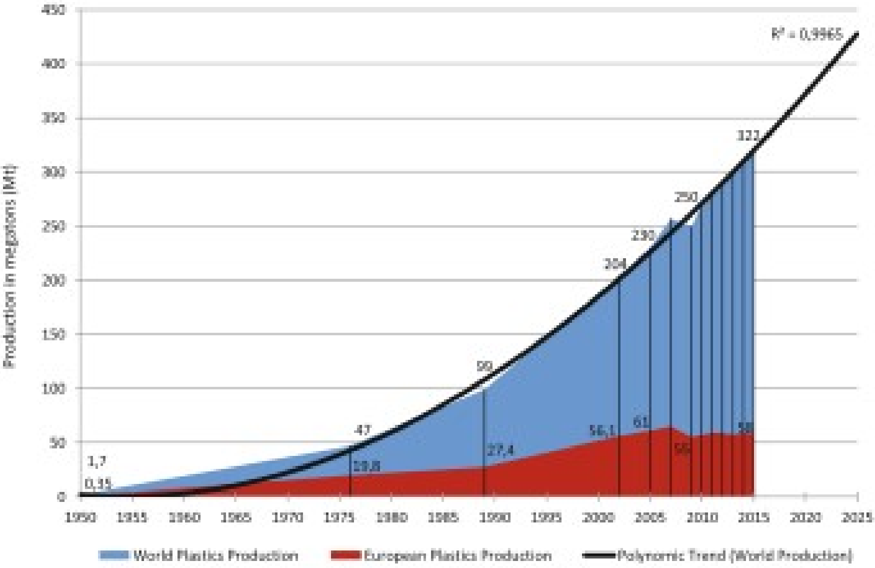

Fig. 3.1 World Plastics Production from 1950 to 2015, adapted with kind permission from PlasticsEurope (2012, p. 6, 2016, p. 12), modified by the author. R^2 is the coefficient of determination, calculated by the author. (Color figure online)

manufacturing plastics in primary forms with 1,356,000 persons employed, 56,000 enterprises manufacturing plastics products with 12,900,000 persons employed (Eurostat 2015).

During the research on these statistics from sources other than Eurostat, I discovered discrepancies concerning the numbers provided by PlasticsEurope. For example, the turnover of the producing industry indicated was 104 billion in 2010, according to (PlasticsEurope 2011b, p. 5), but in the report from 2012 (PlasticsEurope 2012, p. 5), the turnover in 2010 is state as 89 billion. It could not be determined whether this fault is related to PlasticsEurope, or PlasticsEurope's source, Eurostat, as PlasticsEurope does not provide information on the definition of 'plastics converters' and 'plastics producers', and which respective statistics are used from Eurostat for the calculation in combination with the statistics calculated by PlasticsEurope. A personal correspondence with PlasticsEurope revealed that their data is aggregated from the country-based indices by Eurostat and extrapolated, but the exact data could not be made accessible.

In 1950, the plastics production on the globe accounted for 1.7 Mt (megatons or million tonnes) (PlasticsEurope 2012, p. 6). Since then, 8.4% CAGR (compound annual growth rate) caused the production to rise to 322 Mt in 2015 (PlasticsEurope 2016, p. 12). The EU-28 including Norway and Switzerland produced 58 Mt in 2015, which is 18% of the global plastics production. However, it is to be highlighted, that PET-, PA- and Polyacrylic-Fibers are not included in this dataset. With this knowledge, it should be mentioned that the (European Commission DG ENV et al.

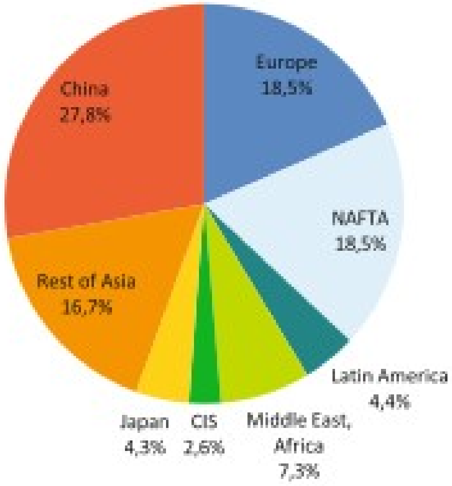

Fig. 3.2 World Plastics Production in 2015—geographic analysis, adapted with kind permission from PlasticsEurope (2016, p. 13)

2011, p. 12) states that the European plastics industry accounts for 25% of the world plastics production, likely referring to 2010, while (PlasticsEurope 2016, p. 12) states 21% in 2011. In 2020, global plastics production is likely to reach approximately 380 Mt, based on polynomial trend calculations.

Undertaking a geographic analysis of the development of the global plastics production, the shift of production towards Asia is apparent. China, Japan and the rest of Asia managed to increase the global production share from 36.5% in 2005 to 48.8% or even 51.4% including the CIS[8] countries in 2012[9] (see Fig. 3.2). In fact, the production is shifting towards Asia, because of low production costs (PlasticsEurope 2013b, p. 5), possibly due to less strict regulatory frameworks. In Europe, Germany accounts for 24.6%, and together with Italy, France, Spain, the UK and Poland, the percentage increases to 70% (PlasticsEurope 2016, p. 16).

Taking the world plastics demand per capita (PlasticsEurope 2009, p. 6) into consideration, the statistics reveal that developing countries, such as found in Asia and Africa, have a high potential for growth of plastics usage per capita in the near future (see Fig. 3.3) which might cause increased competition due to possible raw

[8]The Commonwealth of Independent States (CIS) includes Armenia, Azerbaijan, Belarus, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan and Uzbekistan.

[9]The data from 2005 refers to the EU-25 whereas the data from 2015 refers to the EU-28 now including Bulgaria, Romania and Croatia. However, their impact on the global plastic market is not significant. Furthermore, it is to be noted that the these numbers might be slightly inaccurate due to differing references to groups of countries and a lack of accurate definition of country clustering (e.g. 'Asia') by PlasticsEurope. Queries for clarification were not answered.

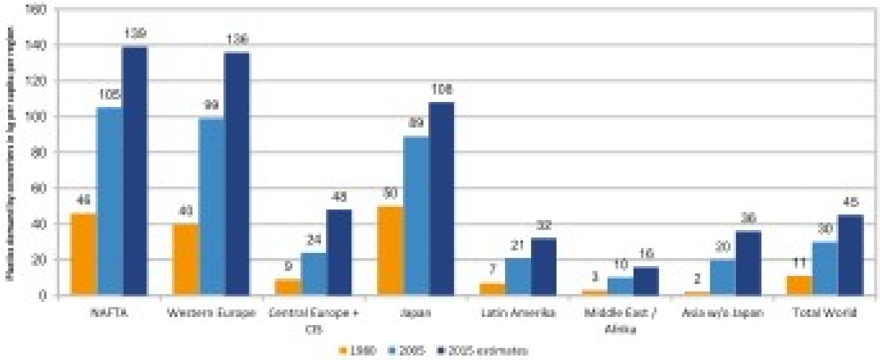

Fig. 3.3 World Plastics Demand per Region per Capita, adapted with kind permission from PlasticsEurope (2009, p. 6)

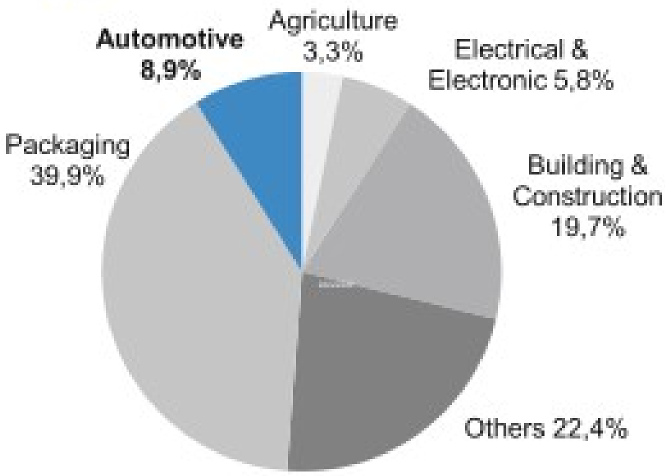

Fig. 3.4 Plastics Demand by Segment in the EU-28+N/CH in 2015 (total of 49 Mt, 'others' include consumer and household appliances, furniture, sport, health and safety,…), adapted with kind permission from PlasticsEurope (PlasticsEurope 2016, p. 17)

material shortages in resource poor regions such as the EU. In general, there will be a significant increase of global plastics production.

When examining the European plastics demand, it is to be understood that this is about the plastic converter demand, which is not to be confused with the plastics production. First, plastic is being produced and then converted into the product. Now, when analysing the European plastics demand by segment in the year 2011 in Fig. 3.4, it becomes clear that the packaging sector is dominating largely by 39.4%, directly followed by the building and construction sector with 20.3%. The continuously growing demand by the automotive sector manifests with 8.2% of the plastics converter demand, which accounts for 3.8 Mt of plastics in Europe in 2011 (Weill

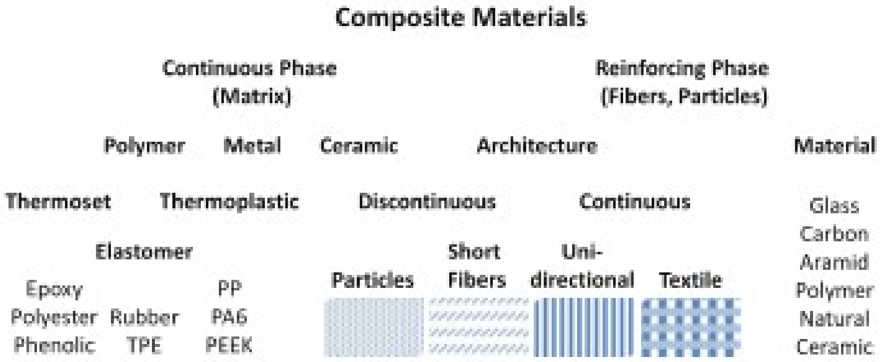

Fig. 3.5 The build-up of composite materials, adapted with kind permission from Friedrich and Almajid (2013)p. 108

et al. 2012, p. 7). Please note the difference between the demand (57 Mt) and the converter demand (45.9 Mt) of plastics in Europe due to import and export trading.

This plastics demand is largely focussing on certain types of plastics. In fact, the most prominent plastic types with regard to market share in the EU-28+N/CH in 2015 are according to PlasticsEurope (PlasticsEurope 2016, p. 19):

- polyethylene

– low density PE (PE-LD) and linear low density PE (PE-LLD) [17.3%]
– high (PE-HD) and medium density PE (PE-MD) [12.1%]

- polypropylene (PP) [19.1%]
- polyvinyl chloride (PVC) [10.1%]
- polystyrene solid (PS), expandable (PS-E) [6.9%]
- polyurethane (PUR) [7.5%]
- polyethylene terephthalate (PET) [7.1%]
- others [19.9%]

These types of plastics[10] represent the European plastics demand with the three most produced types of resin being polyethylene (29.4%), polypropylene (19.1%), and polyvinyl chloride (10.1%) (PlasticsEurope 2016, p. 19).

Reinforced Plastics and Composites

In addition to conventional plastics, there are also composites with plastics being used in automotive manufacturing. Such plastic composites incorporate a polymer matrix such as epoxy in combination with for example carbon resulting in carbon fibre reinforced plastic (CFRP or simply 'carbon'), glass (glass reinforced plastics, GRP, GFRP (glass-fiber reinforced plastics), fiberglass), aramid in order to reinforce the structure (Murphy 2013), or natural fibers (see Fig. 3.5). These materials can be engineered to achieve high stiffness and strength while remaining very light through

[10]For further information on plastic types please see Chap. 8, http://www.bpf.co.uk/Plastipedia/Polymers/Default.aspx or http://www.plasticseurope.org.

a lower density, which is critical in means of transport. Aircraft, cars and trucks are designed to be light-weight to achieve sustainability in the life-phase through lower fuel consumption. The key benefit of composite materials is that different materials with different properties are combined to achieve synergies in the resulting material: "By dispersing fibers or particles of one substance in a matrix, or binder, of another, the designer of a composite can arrive at properties neither material shows on its own." (Friedrich and Almajid 2013, p. 107). Prominent fields of application include industries such as aerospace, automotive, wind energy, marine, construction, military and sports equipment. In the automotive sector, CFRP is the dominant plastic composite material. Concerning the global demand of CFRP, the numbers nearly doubled between 2010 (51,000 t) and 2015 (91,000 t). Furthermore, 2020 estimations point to 155,000 t (CCeV and AVK 2016, p. 10) (see Fig. 3.6). Consequently, CFRP grew at 12.3% (2010–2015) which is estimated to remain constant in the following years.

Bioplastics

Bioplastics or biopolymers are not (yet) of major importance, as they grew to 1.7 Mt in 2014 (Institute for Bioplastics and Biocomposites 2015, p. 42), less than 1% of the global plastics production (322 Mt). However, bioplastic production could increase to approximately 8 Mt by 2019 (Institute for Bioplastics and Biocomposites 2015). Bioplastics are made from renewable raw materials thus reducing the use of fossil resources and achieving lower carbon footprints. They can be either biodegradable (PLA, PHAs,…accounting for 39.1%), or durable (Bio-PET, Bio-PE,…accounting for 60.9%). The main types of bioplastics are (Institute for Bioplastics and Biocomposites 2015, p. 5) (CC BY-ND 4.0; format modified by the author):

- New Economy [bioplastics developed in the last 30 years]

– chemical novel [chemical structure not comparable to standard plastics]
  PLA (polylactic acid)

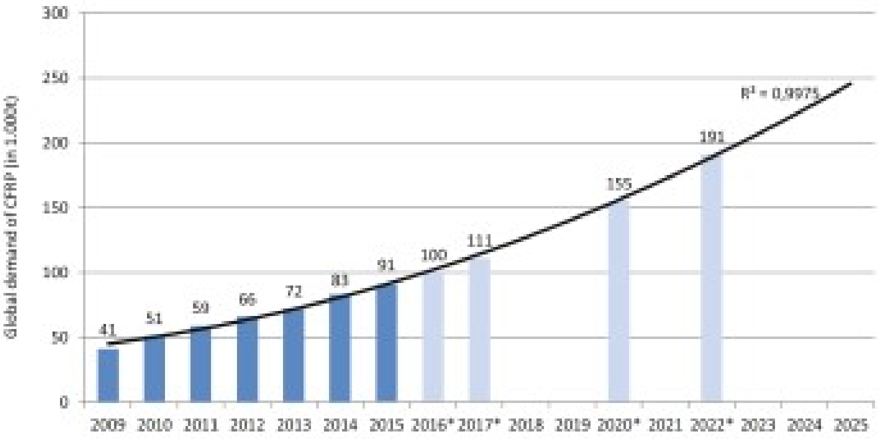

Fig. 3.6 Global demand of CFRP (*estimates), adapted with kind permission from CCeV and AVK (2016, p. 10), modified by adding a polynomial trendline

PHA (polyhydroxyalkanoates)
PEF (polyethylene furanoate)
starch blends
etc.

– drop-ins [chemical structure similar to standard plastics but bio-based]
  Bio-PA
  Bio-PE
  Bio-PET
  Bio-PP
  etc.

- Old Economy [earlier developed bioplastics]

– Rubber
– Regenerated cellulose
– Cellulose acetates
– Linoleum
– etc.

Bioplastics are currently used predominantly in the packaging sector (67%) followed by textiles (10%), consumer goods (7%), agriculture and horticulture (6%), automotive and transports (5%), and others (5%) (Institute for Bioplastics and Biocomposites 2015, p. 45). Due to the current insignificance of bioplastics, these materials are not of intensive concern in this book. However, the bioplastics industry is growing fast and could have potential so should be watched closely.

3.1.2 The Life-Cycle of Plastics

In order to understand the life-cycle of plastics, we have to investigate the production phase, the life phase and the end-of-life phase. On the report of Jean-Charles et al. (2010, p. 33), and illustrated in Fig. 3.7, the production of plastics requires crude oil (as a source of hydrocarbon monomers), various forms of energy, and additives for the polymerisation process. This production process underlies several legal directives in the European Union such as the "Registration, Evaluation, Authorisation and Restriction of Chemicals" 'REACH' (European Commission DG Enterprise and Industry 2014b) and "RoHS', the "Restriction of Hazardous Substances Directive" (European Union 2003) to ban such hazardous substances (see Sect. 3.2.3). Afterwards, the plastic material can be shaped into the desired form, to create the final plastic product.

After the usage phase, the plastic product becomes post-consumer waste, which can be collected for further waste treatment. The first possibility is 'incineration', which recovers the energy contained in the plastic. The second one is 'landfill', which describes storing the plastic waste, with the drawback of resulting emissions. The

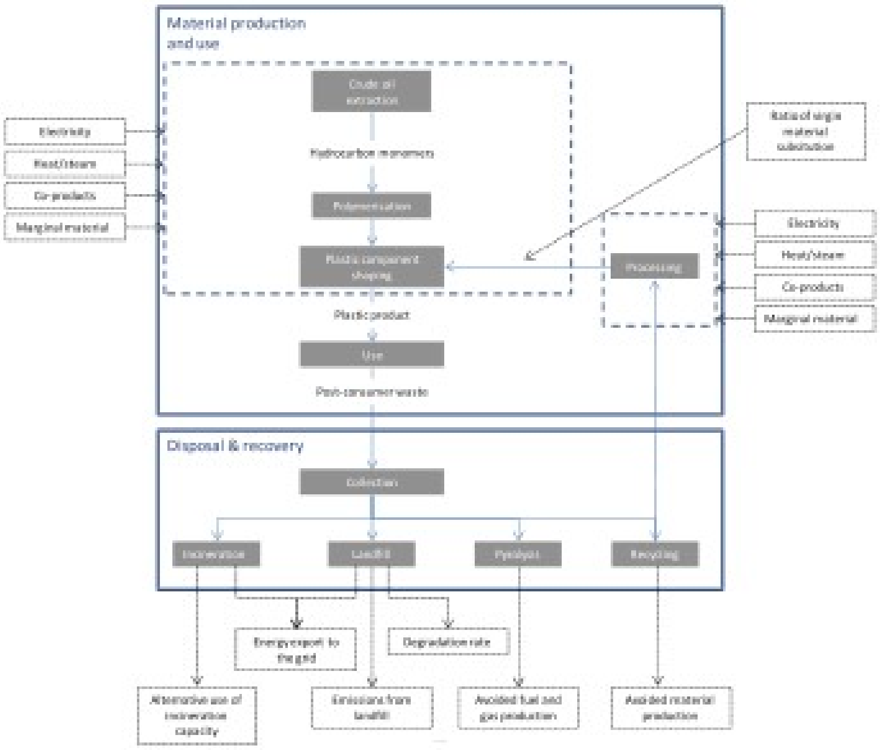

Fig. 3.7 The plastics system key parameters, used with kind permission from Jean-Charles et al. (2010, p. 33)

third is 'pyrolysis', which produces naphta, paraffin, fuel, and gas through decomposing the plastics material (Jean-Charles et al. 2010, p. 50). The fourth possibility is 'recycling', which reproduces plastic materials ready for the production of plastic products. Additionally, incineration processes and landfilling can produce energy, through, for example, harvesting gas emissions. Furthermore, these four final disposal and recovery possibilities have (dis)advantages with the most relevant being mentioned in the lower end of Fig. 3.7. For more details on the environmental impact, please refer to the Sect. 3.1.3, and for an advanced outline of recycling technologies, please consider Sect. 3.1.4 as well as Sect. 3.2.3.

Plastics Value Chain

The above-mentioned life-cycle of plastics is subject to economic activities. In fact, the life-cycle of plastics from production to waste treatment in Europe (EU-27+N/CH) in 2012 (Fig. 3.8) regarding the demand and also its development is significantly influenced by the overall economic development including the global economic crisis especially significant for the European plastics industry in the years 2008 and 2009: The demand steadily increased from the baseline of 2005 with

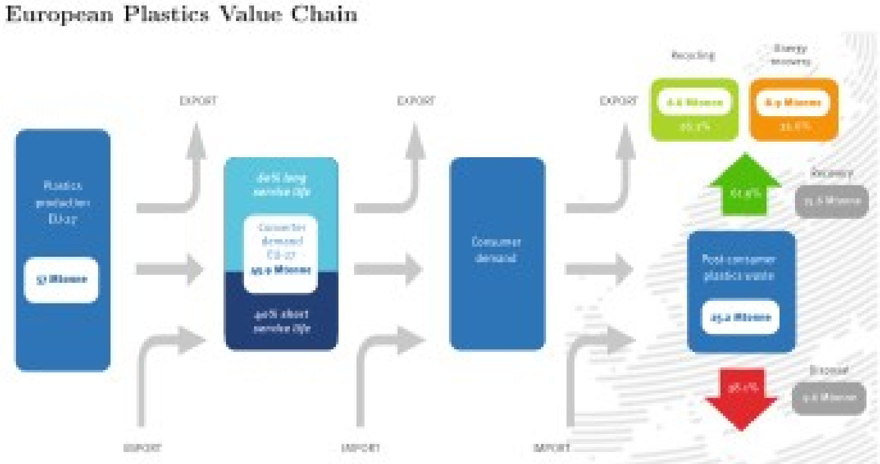

Fig. 3.8 European Plastics Value Chain in 2012, used with kind permission from PlasticsEurope (2013b). All rights reserved

47.5–52.5 Mt (+10.5%) in 2007, followed by a decrease to 48.5 Mt (−8.2%) in 2008 and to 45 Mt (−7.8%) in 2009, although Bulgaria and Romania joined the EU in 2007. In 2010 and 2011, the demand for plastics in Europe recovered and increased to 45.4 Mt (+3%) and 47 Mt (+1.3%) respectively. In 2012, the market decreased to 45.9 Mt (−2.3%). Analysing the development on the end-of-life of plastics in the EU-27+N/CH, overall post-consumer plastic waste increased by 14% from 2005 (22 Mt) to 2012 (25.2 Mt). However, in the same period, the rates on recovery increased from 47 to 61.0%, consequently resulting in a respective decrease of the disposal rate from 53 to 38.1%. Unfortunately, detailed data on import and export of plastics waste was not accessible.

European Plastics Value Chain

When investigating the plastics trade in the EU-27 in 2012, it is to be highlighted that 73.4% of the primary and 76.8% of the converted plastics are being traded within the EU (Fig. 3.9). Furthermore, the major demand for primary plastics comes from Asian countries such as China, Turkey, Hong Kong and Russia whereas the demand for converted plastics is not dominated by a particular region. However, the major importers of European plastics are located in the northern hemisphere.

Plastics Waste

After analysing the production within the life-cycle of plastics, the focus now is on the end-of-life phase as waste. In the European Union, there are four options to handle plastic waste. As claimed by PlasticsEurope (2013b) (see again Fig. 3.8), 38.1% of plastics are disposed in a landfill, 35.6% of the plastics are used in energy recovery plants, and 26.3% are recycled. The mechanical recycling rate began at 21.3% in 2008 and is expected to reach 22.8% in 2015, with respective total numbers of 5.3 and 7.0 Mt of plastics waste in the European waste business (Plastic Zero

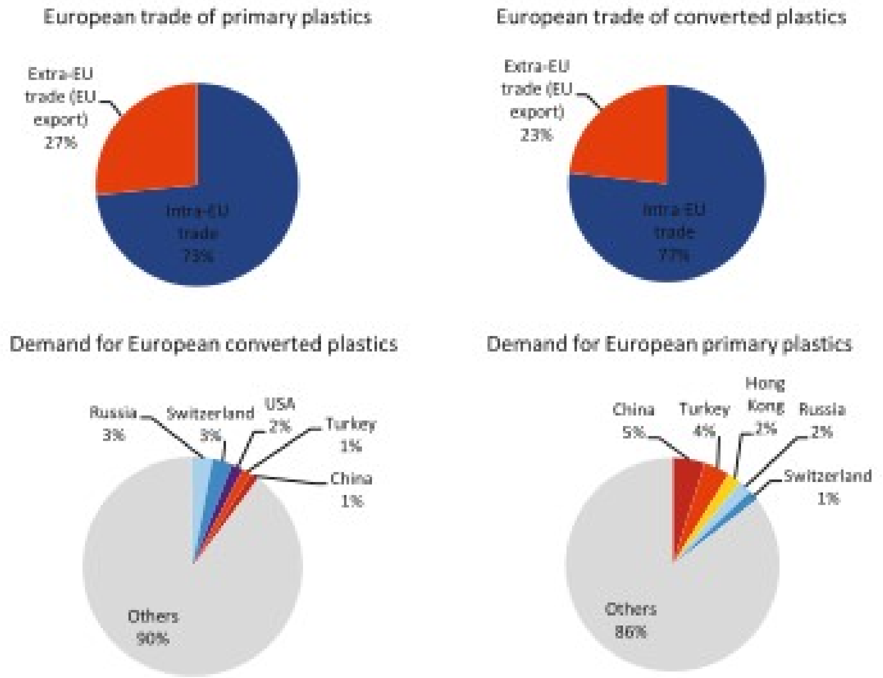

Fig. 3.9 Trade of primary and converted plastics in the EU-27 in 2012, adapted with kind permission from PlasticsEurope (2013b, p. 19)

2013). However, there is another way to dispose of post-consumer plastics: simply by exporting the waste. According to Bernhard Merkx, president of the European Plastics Recyclers 'EuPR', "Today, more than two-thirds of the total plastics waste is exported outside of the EU" in 2010 (RecyclingToday (9 November) 2010). When breaking down the plastics waste in 2008 (most recent data accessible), the hierarchy is dominated especially by the packaging sector with 62%, followed by 'building & construction' with 6% and the automotive sector with 5% (European Commission DG ENV et al. 2011, p. 66) cited after (PlasticsEurope 2009) (Fig. 3.10).[11] Consequently, automotive plastics waste accounted for 1.25 Mt of 24.9 Mt total plastics waste in 2008 (PlasticsEurope 2009).

Taking a global view, the amount of plastic waste can be estimated to exceed the European levels by a factor of 10 reaching approximately 250 Mt per year. This is estimated through the global production of 265 Mt of plastics on the globe in 2010 (PlasticsEurope 2011b, p. 5). With this estimated number, and considering a higher average age of ELVs on the globe compared to Europe which results in less plastics

[11] Remark: The data could not be found in the report by PlasticsEurope. It is assumed, that the DG ENV acquired more detailed data from PlasticsEurope.

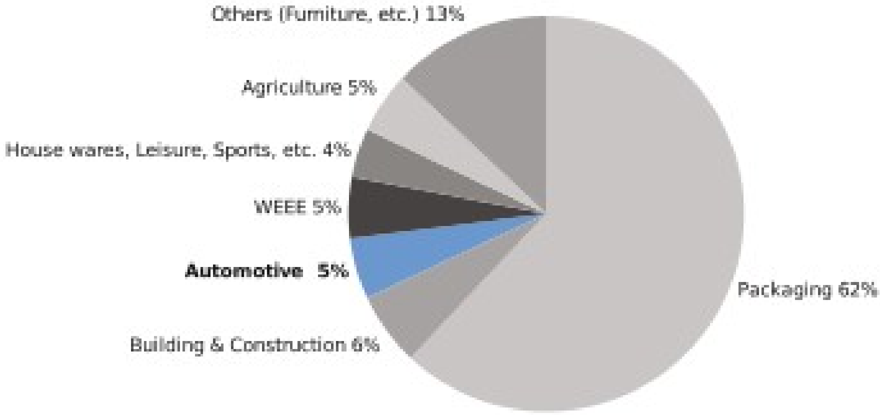

Fig. 3.10 Proportions of Plastics Waste in the EU-27+N/CH in 2008, adapted with kind permission from European Commission DG ENV et al. (2011, p. 66) cited after PlasticsEurope (2009)

per car, automotive plastics account for approximately 10 Mt every year.[12] These amounts of plastics waste on the globe can affect the environment and society, as outlined in the next section.

3.1.3 Environmental and Social Impact of Plastics

Following the life-cycle of plastics in Sect. 3.1.2, the environmental impact will be investigated, starting with the production of plastics, followed by the impact during the life phase and finally the end-of-life phase.

Environmental Impact During the Production of Plastics

Plastics are very energy efficient and can reduce greenhouse gas emissions (measured in CO_2e) in the production phase compared to other materials, as stated by Pilz et al. (2010, p. 21). Furthermore, the versatility of plastics enables energy efficient design which would not be possible without plastics. However, analysing the production of plastics reveals that the current production of plastics and mainly the required raw materials such as crude oil, gas, and coal can have negative impacts on the atmosphere, water (including drinking water and oceans), soil, flora, fauna, and humankind [for details see (Brydson 1999; Thompson et al. 2009a)]. Additionally, during the production various chemicals and metals serve as additives which can be harmful to the environment and the health, as outlined in Sect. 3.1.3. Life-cycle assessments (LCAs) offer valuable solutions to determine the environmental impact of plastics in detail. In Table 3.1, the inputs and outputs caused by the production of

[12] Approximate calculation: 265 Mt times 4% (instead of 5% in Europe due to a higher average age of global ELVs).

Table 3.1 LCA of the production of polyethylene PE (1 kg of each type), adapted with kind permission from PlasticsEurope (2014)

Indicator	Unit	HDPE	LDPE	LLDPE
Input Parameters				
Non-renewable energy resources[a]				
Fuel energy	MJ	31.5	33.7	30.5
Feedstock energy	MJ	47.8	47.8	47.8
Renewable energy resources (biomass)[a]				
Fuel energy	MJ	0.8	1.4	0.9
Feedstock energy	MJ	0.0	0.0	0.0
Abiotic depletion potential (ADP)				
Elements	kg Sb eq.	4.4E−08	5.2E−08	6.5E−08
Fossil fuels	MJ	72.0	72.8	71.3
Water use (only for polyolefin production)				
for processes	kg	7.03E−01	1.22E+00	3.62E−01
for cooling	kg	2.30E+01	4.13E+01	8.87E+01
Output Parameters				
Global warming potential (GWP)	kg CO_2 eq.	1.80	1.87	1.79
Ozone depletion potential (ODP)	g CFC-11 eq.	6.4E−04	8.2E−04	5.7E−04
Acidification potential (AP)	g SO_2 eq.	4.28	4.36	4.33
Photochemical ozone creation potential (POCP)	g Ethene eq.	6.3E−01	1.3E+00	4.7E−01
Eutrophication potential (EP)	g PO_4 eq.	1.20	1.25	1.15
Dust/particulate matter (< 10 m)[b]	g PM10	3.97	4.09	4.01
Total particulate matter[b]	g	4.31	4.45	4.31
Waste (only from polyolefin production, before treatment)				
Non-hazardous	kg	1.28E−03	2.38E−03	8.35E−04
Hazardous	kg	9.30E−04	3.06E−03	5.61E−04

[a] Calculated as upper heating value (UHV) (the gross calorific value)
[b] Including secondary PM10 (precursors to PM formation including NO_x, SO_x, NH_3 and NMVOC)

the most prominent plastic type polyethylene (PE) in the sub-forms of high-density (HDPE, whose LCA is comparable to polyethylene PP), low-density (LDPE), and linear low-density polyethylene (LLDPE) are outlined. For details on the calculation please consider the explanations[13] and the glossary in Chap. 8. In the case of PE, the dominant environmental impacts during the production are caused by "the monomer production, i.e. crude oil and natural gas extraction and transport, and the refinery."

[13] "GWP: greenhouse gas contributions in kg carbon dioxide (CO_2) equivalents (time horizon 100 years)"; "AP: acidifying contributions in g sulphur dioxide (SO_2) equivalents"; "EP: nutrifying contributions (aquatic and terrestrial eutrophication) in g phosphate ($PO_4{}^{3}$) equivalents"; "OP: ozone depleting contributions in g CFC-11 equivalents"; "POCP: summer smog contributions in g ethene (ethylene) equivalents"; "Dust and particulate matter in g" (PlasticsEurope 2011a).

followed by electricity demand, whereas "the results for ADP elements are driven by the use of pigments and catalysts, POCP scores are dominated by venting of ethene directly to atmosphere." (PlasticsEurope 2014, p. 42).

As oil is the main raw material for plastics, its impacts in the production process is of special concern. As stated by Borthwick et al. (1997), the production of oil causes for example:

- Negative atmospheric impacts [Air] (caused for example by flaring, oil and gas losses and spills, usage of diesel engines for the production and the transport, byproducts in the chemical production process)
- Negative aquatic impacts [Water] (caused for example by drilling including oil losses and spills, as well as potentially toxic drilling fluids)
- Negative terrestrial impacts [Soil] (caused for example by spills, and toxic drilling fluids)

Furthermore, the environmental impact of fossil fuels depends on the form of extraction. Oil extracted from sand (also known as tar sand) in particular poses an increased threat in terms of environmental damages through land degradation and especially greenhouse gas (GHG) emissions (measured in CO_2e). According to Woynillowicz and Severson-Baker (2009), the emissions of one barrel conventional crude oil (159 L) are 28.6 kg of CO_2e, whereas one barrel oil from oil sand accounts for 85.5 kg of CO_2e (approximately three times more). Furthermore, this form of extraction increases due to economic benefits, possibly linked to crude oil shortages and high prices. This new oil source is likely to further increase the CO_2 emissions during the plastics production. Statistical estimates provided by Hopewell et al. (2009, p. 2115), EuPC (2007, p. 3), and PlasticsEurope (2012), show that the annual consumption of fossil fuels for the production of plastics is currently accounting for 7–9% of the global oil production. 4–5% are used for the plastic material itself and additionally 3–4% are used for the production process. The world produces 95.78 million barrels (=159 liters) per day, 8% of which is used in the production of plastics—resulting in approximately 445,000,000 liters of oil used for the global plastics production in 2015[14] (U.S. Energy Information Administration 2016). Generally, the life-cycle of the primary raw material for plastics, which is oil, causes a variety of environmental impacts on eco-systems, on flora and fauna and as well as health impacts on humankind. Additionally, political and military conflicts in oil exporting countries are a threat. Consequently, oil is one of the most controversial goods of our time.

Non-standard plastics such as reinforced plastics and composites tend to have a bigger negative environmental impact in the production phase, mainly through energy demand and CO_2 emissions (Mayyas et al. 2013, p. 187). CFRP for example has a GWP between 30–40 kg CO_2 eq./kg component weight (AUDI AG 2011, p. 15) which seems reasonable compared to GWP numbers ranging from 12 to 63 as reported by

[14]Please keep in mind, that 'oil' is not exactly defined in the analysed literature, which might include or exclude other fossil liquids and by-products. As a result, please consider this calculation as a rounded approximation.

Witik et al. (2011, p. 1706). In comparison, standard plastics such as PP (polypropylene) score a GWP of around 1.8, with the side note that this number does not refer to a final component but the material exclusively.

Turning to bioplastics, one significant aspect is the inherent reduction of dependence upon fossil fuels. In terms of a life-cycle assessment of bioplastics, it is to be highlighted that the GWP of PLA for example is currently comparable to fossil fuel based plastic products. In fact, there is currently no scientific evidence that bioplastics cause less environmental degradation compared to standard plastics when considering all ecological aspects (Yates and Barlow 2013, p. 58, 65). However, the source of electricity used during the production of bioplastics might have a considerable impact (Yates and Barlow 2013, p. 64) thus increasing the significance of which country the material is produced in.

Environmental Impact During the Life-Phase

Plastics can reduce greenhouse gas emissions in the life-phase compared to other materials mainly due to their versatility to enable energy efficient design, as stated by Pilz et al. (2010, p. 21). In fact, substituting plastics would require 3.7 times more mass for the same functional units, use 57% more energy (1500–3300 million GJ/a), and generate 61% more GHG emissions (78–170 Mt) (Pilz et al. 2010, p. 11) (see Fig. 3.11). Consequently, plastics contribute significantly to reducing the environmental impact in the production and usage phase of plastic products. The ecological benefits during the usage phase are especially important in the aerospace and automotive sector with the long usage-phase of planes and cars including intensive fossil fuel demand which results in a need for lightweight design using standard and reinforced plastics, such as CFRP.

However, the life- or usage-phase as well as the end-of-life phase of plastics have the potential to release chemical additives that may be harmful, as plastics are often enhanced with so-called additives. These chemicals are used to customise the plastic material, for example to change the colour, enhance or reduce rigidity, and improve resistance against environmental degradation caused by radiance and temperature.

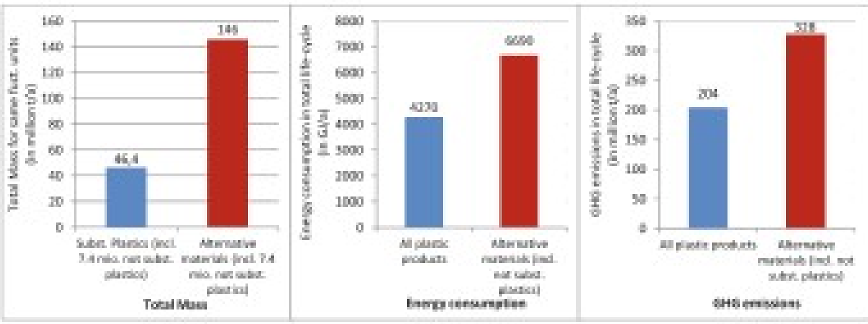

Fig. 3.11 Consequences of substituting plastics with alternative materials, adapted with kind permission from Pilz et al. (2010, p. 11)

Concerning metal contaminations in plastics, Morf et al. (2007) discovered heavy metals such as copper (Cu), antimony (Sb), tin (Sn), zinc (Zn), lead (Pb), and nickel (Ni) in concentrations above 1000 mg per kg in the plastics of electronic goods. The issue is that these additives are possibly toxic to living organisms, particularly concerning heavy metals, phthalates or bisphenol A (BPA). Despite controversy on this topic, there is still the possibility that plastics in general and especially additives which are currently considered non-toxic due to insufficient measurement might be toxic in reality. For these reasons, legal directives such as REACH (European Commission DG Enterprise and Industry 2014b) and RoHS (European Union 2003) were introduced to ban such hazardous substances (see Sect. 3.2.3).

Environmental Impact During the End-of-Life Phase

Plastics have a considerable environmental impact after their life-phase due to their material properties and primarily due to wrong treatment by society. Based on LCAs and LCA reviews by Lazarevic et al. (2010), Laurent et al. (2014), European Commission DG ENV et al. (2011), EuPC (2007), European Union (2013), Jean-Charles et al. (2010), PlasticsEurope (2014), Lithner (2011), the concerns about the end-of-life of plastics are abundant, as they cause:

- Greenhouse gas emissions (CO_2e) due to

– Energy recovery of plastics waste
– Landfilling of plastics waste

- Land degradation and waste of space through landfilling including social aspects such as a decrease of health and quality of life
- Environmental pollution through hardly degradable plastics waste (plastic particles in the environment such as on land, in fresh water, and the deep sea)
- Ingestion of plastic waste particles possibly including toxic substances by animals and thus humankind
- Leaching chemicals from landfilled plastics waste
- Externalisation of environmental costs due to plastics waste export from developed to less developed countries with less strict regulations

However, it is to be noted, that the CO_2 emissions from landfilling are insignificant over a 100-year period due to the fact that fossil fuels degrade very slowly: Only 3% of the stored CO_2 is released in 100 years, which renders landfilling a more favourable option than energy recovery (Jean-Charles et al. 2010, p. 49), when considering the CO_2 emissions over a 100-year period only, disregarding contamination of the plastics and ignoring other issues of landfilling. As a consequence, the hierarchy in this special scenario is 'recycling >incineration >landfill' when not thinking in a time span limit. But when limiting the time period to 100 years, the hierarchy can be 'recycling >landfill >incineration', as outlined in the various LCAs on numerous plastic materials by Finnveden, Johansson et al. (2000). Thus, the time span is crucial when calculating LCAs and especially the global warming potential GWP, which should be considered in at least two time spans, the GWPinfinite and the GWP100, based on Finnveden (2005), Finnveden et al. (2009). However, incineration is sometimes the only method to dispose of hazardous, toxic and contaminated waste and remove them from the system (LaGrega et al. 2010), for example hazardous medical substances (Chartier et al. 2014). The environmental impact of reinforced plastics waste varies strongly depending on the material type. CFRP for example, poses a significant challenge for waste treatment in terms of ecology and economy, because recycling can provoke high energy demand for pyrolysis, or even cause severe problems during the incineration process Sect. 3.1.4). Recycling of CFRP is currently not sufficient and only low qualitative down-cycling is possibly due to the degradation of the materials.

Regarding bioplastics, the environmental impact during the end-of-life phase is still unclear and heavily dependent on plastic type and treatment technology (Yates and Barlow 2013). Incineration can cause severe hazardous emissions if done incorrectly (Hopewell et al. 2009) and bioplastics littering can cause a similar level of environmental pollution as fossil fuel based plastics, because biopolymers are not necessarily biodegradable (see Sect. 3.1.4).

Social Impact of Plastics

The life-cycle of plastics has negative and positive impacts on the environment, but on society as well. The positive impacts on society mainly arise from the life-phase of plastics, such as enabling a variety of designs, benefits in the medical sector such as sterile products, and saving weight and thus greenhouse gas emissions (CO_2e) when being transported. But as outlined in the Sect. 3.1.3, plastics can be toxic during the usage to living organisms thus negatively affecting the life of people. However, the environmental impacts of plastics during production and the end-of-life as mentioned in Sect. 3.1.3 also influence society directly or indirectly. Especially impacts on health and especially epidemics when thinking of waste treatment in third countries such as India (Gill 2009), "and the social perceptions around the continued use and increasing levels of plastic consumption and waste production." are of concern, as stated by European Commission DG ENV et al. (European Commission DG ENV et al. (2011), p. 12). Moreover, present and future generations will be burdened by mortgages caused by non-treated plastics waste through continuous negative effects in the seas and on the surface of the globe (Ropohl 2009, p. 16). Thus, current plastic issues are very likely to negatively affect us and our descendants.

3.1.4 Waste Treatment Technologies for (Automotive) Plastics

When plastics reach their end-of-life, these materials are treated to limit negative environmental impacts and to utilise the remaining value. The treatment of plastics including plastics from end-of-live vehicles (ELVs) is divided into four options: reuse, material recovery, energy recovery, and landfilling (Ferrão, Nazareth, and Amaral 2006). Landfilling is a form of disposing plastics waste under regulated conditions on a landfill, or even under unregulated conditions. However, there are

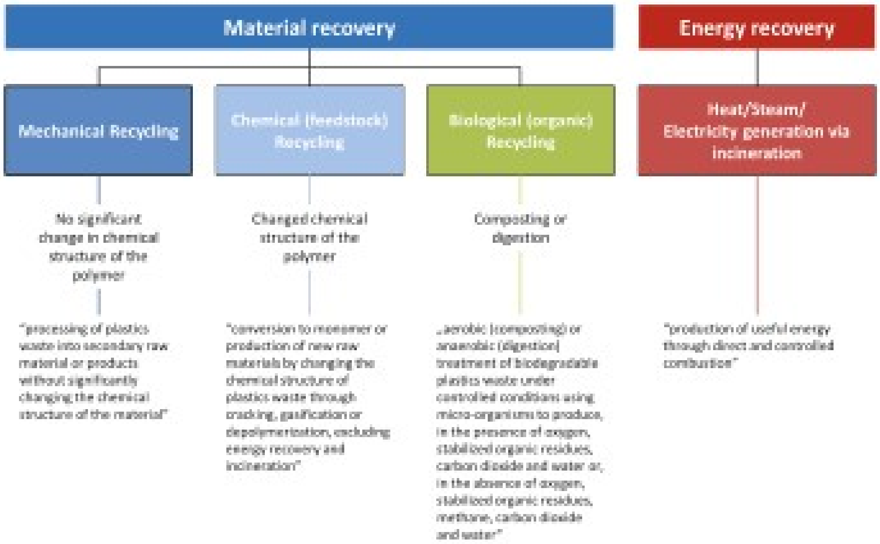

Fig. 3.12 Plastics recovery technology, adapted with kind permission from ISO (2008)

two main types of plastics waste treatment besides reuse and landfilling, according to ISO (2008): Firstly, material recovery which includes "mechanical recycling, chemical or feedstock recycling, and biological or organic recycling", and secondly, energy recovery "in the form of heat, steam, or electricity generation using plastics waste as substitutes for primary fossil fuel resources" (see Fig. 3.12). The main difference between the material recovery technologies is the change of the chemical structure of the material. Mechanical recycling does not change the structure, whereas chemical and biological recycling do change the structure, producing, depending on the technology, for example, the raw materials, elements and/or energy.

Due to the fact that the recycling process and the technical aspect are crucial in the topic of automotive plastics recycling, the available technology is fundamental to the recycling feasibility, with high regard to the economic aspect. To understand the most prevalent and promising recycling technology for plastics including automotive plastics, which is mechanical recycling (see Sect. 3.1.5), the process of this treatment type is described on the basis of a simplified illustration by Jenni (2005, p. 3), cited after Burgdorf et al. (1997), which was not available any longer (see Fig. 3.13): The mechanical recycling process starts with (A) the 'logistics', through transporting, collecting, disassembling, sorting, and shredding, for example the ELV parts, followed by controlling the quality, as in all steps. The next step is (B) 'reclamation', which refers to the grinding, washing, separation, and classification of the shredded material. The specified regrind is now moved to the next step (C) 'homogenising', where the regrind is stored, mixed, conveyed, and pelletised. Now the produced 'base recyclable' is now sent to the step (D) 'compounding', where the material is blended, reinforced, filled, modified, and stabilised accordingly to the requirements of the

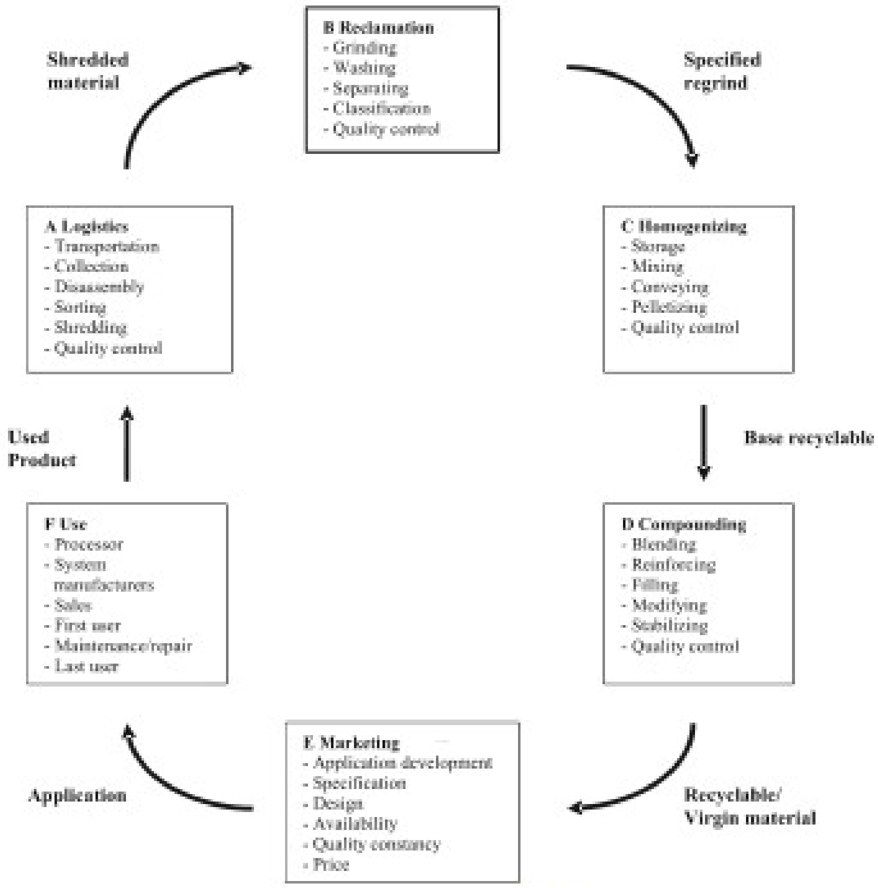

Fig. 3.13 Stages of mechanical recycling of plastics (Jenni 2005, p. 3), cited after Burgdorf et al. (1997), which was not available any longer

customer. The final recyclable or compound together with virgin materials is now (E) marketed through application development, specification, design, availability, quality constancy, and the price. The final step is (F) the 'use' through processors, system manufacturers, sales, first user, maintenance/repair, and the last user, who might return the used product to the recycling process again.

Moreover, there are several technologies for mechanical recycling, as briefly outlined in Table 3.2. An example for plastics in a mechanical recycling process is depicted in Fig. 3.14.

Apart from mechanical recycling, chemical or feedstock recycling technologies in particular offer various solutions to treat plastics waste, such as 'dissolution[15]', 'solvolysis', 'method for feeding into processes of petroleum production',

[15] Translated and paraphrased original German passage: 'Inlósungnahme'.

Table 3.2 Mechanical recycling technologies for plastics waste, adapted with kind permission from Woidasky and Wolf (2008)

Polymer system	Mechanical recycling possibilities
Thermoplastics and thermoplastical elastomeres	1.Regranulation (exclusive use of recyclates) 2. Compounding (Recyclates mixed with virgin material)
Glassfiber reinforced thermiplastics	1. Regranulation (exclusive use of recyclates) 2. Compounding (recyclates mixed with virgin material) 3. Only with glass mat reinforced thermoplastics (GMT) impact extrusion (remodeling of the component)
Duroplasts	Particle: recycling 1. Usage of the grinded mass as a filler 2. Usage of the glass fibers of reinforced masses (SMC/BMC) in virgin material
Thermoplastics or duroplastics polyurethanes[a]	1. Processing similar to thermoplastics 2. Impact extrusion (remodeling of the component) 3. Grinding and usage as PUR-filler 4. Particle composite (crush PUR and compress with binder; for soft foam as foam flake composites; for hard foam with adhesive press)
Elastomeres	Processing of scrap tires into pieces, granules or flour by grinding processes. Products for substructure boards, sound insulation boards, insulation, flour for tires, conveyor belts, mats, soles

[a]The separate account goes back to the common in the automotive industry classification

'pyrolysis', 'gasification', 'use in the cement rotary klin' and 'blast furnace' in metallurgical processes, while energy recovery from plastics waste can be operated in power stations or in waste incineration plants (Woidasky and Wolf 2008). Please note that the ecological sustainability of various material recovery technologies is determined by the input material. For example, blast furnaces which can use heterogeneous waste plastics, as found in the residue from shredded cars as a reducing agent might be more suitable than mechanical recycling. In fact, concluded that plastics waste can be used as an auxiliary reducing agent through injection in the blast furnace process. Currently, this form of recycling is done at an international steel producing company in Austria with up to 110,000 t of plastics per year as a reducing agent with substantially positive results in terms of resource efficiency (Bürgler and Kieberger 2012).

Fig. 3.14 Example of plastics before, during and after mechanical recycling, used with kind permission from MBA Polymers Austria GmbH. All rights reserved

The Recycling of Bioplastics

Bioplastics waste is still a controversial topic, due to significant discrepancies in scientific research as observed by Yates and Barlow (Yates and Barlow (2013), p. 62). Furthermore, the quantity of waste bioplastics is currently marginal but on the rise, time-shifted to the increase of the bioplastics production. According to Lorber et al. (2015), current treatment processes for bioplastic waste include:

1. Recycling (mechanical or feedstock)
2. Composting (home or industrial; "compared to anaerobic digestion, where biogas is produced, composting is an aerobic process without energy utilization but connected with uncontrolled CO_2 emissions")
3. Fermentation in Biogas Plants ("anaerobic treatment to generate biogas which can be used as an energy source")
4. Energy Recovery in waste-to-energy (WtE)-plants ("which is a CO_2 neutral method for producing heat and electricity")
5. Landfilling

Industrial composting and incineration (waste to energy) are options, but incineration in particular can cause hazardous emissions if done incorrectly (Hopewell et al. 2009). Recycling of bioplastic is considered the most favourable treatment method, especially mechanical and chemical recycling (Jean-Charles et al. 2010), whereas landfill currently seems to be the least favourable option (Yates and Barlow 2013, pp. 60–65). On the contrary, Lorber et al. (2015) deem energy recovery worthy due to the small amounts of bioplastics waste. However, it should be highlighted that biopolymers are not necessarily biodegradable thus causing similar environmental pollution as fossil fuel based plastics through litter. Additionally, biodegradability can vary to certain extents, possibly causing problems when bioplastics are mixed with conventional biowaste in terms of time required for composting or anaerobic digestion. Jean-Charles et al. (2010) point out that treatment in biogas plants is in terms of ecology preferable to conventional composting due to the usage of biogas. When recycling bioplastics, this material can also cause clogging to various degrees, if, for example, mixed with conventional plastics. Consequently, the treatment of bioplastics should be considered already at the product design phase, and especially in terms of combined treatment with conventional plastics, at least concerning packaging. For more details on bioplastics recycling technologies, consider Hopewell et al. (2009) Jean-Charles et al. (2010), Lorber et al. (2015), Yates and Barlow (2013).

The Recycling of Composite Plastic Materials

By nature, composites are hard to separate and therefore very hard to recycle. Reinforced plastics waste, such as GFRP (glass fiber) and CFRP (carbon fiber) can pose even more challenges. In-house recycling is already possible, through producing carbon-fiber mats from cutting scrap, as done at BMW for example (Bakewell 2016). These mats have different properties compared to regular CFRP which are suitable at different fields of application. Another option is to use fibers for injection moulding. However, post-consumer composites, especially CFRP, can pose threats to waste treatment facilities, such as thermal energy recovery plants. Because the carbon fibers are electro-conductive, they can cause short-circuits in the electric filter of the waste-to-energy plants, and provoke clogging. This can cause complete shutdowns of the entire plant, require technical revisions up to several days resulting in significant costs and reduced treatment of regular waste. Consequently, composites such as CFRP are required to be treated separately. One option for post-consumer CFRP waste is pyrolysis to separate matrix and fibers, but with intensive usage of energy in the form of heat. The fibers can then be recycled similar to the industrial in-house treatment methods. Another issue is that waste is being shredded when entering the treatment plant. Consequently, shredded carbon fibers in household waste cause airborne respirable particles thus exposing employees to health risks. As a result, recycling of CFRP that is ecologically and economically worthwhile is still a challenge, that requires new recycling technologies, such as solvolysis, to possibly increase the recycling rate (Witik et al. 2011, p. 1706). Currently, it is assumed that there are virtually no fiber reinforced plastics from ELVs due to the fact that the share of CFRP has risen in the last years. ELVs in Austria, for example, are 17 years old on average when they are being shredded.

For a more detailed insight into various plastic and composite recycling technology and processes, please consult Froelich (2007), Hamad et al. (2013), Maio et al. (2010), Martens (2011), Mastellone (1999), Al-Salem et al. (2009, 2010), Santini et al. (2012), Schmeisser and Clause (2011), Vermeulen et al. (2011), Williams and Williams (1997), Witik et al. (2011), Woidasky and Wolf (2008), Yang et al. (2012), Zorpas and Inglezakis (2012).

The Legal Restrictions of Plastics Recycling

Recycling is not an easy task and despite positive development of the technology there are still weaknesses. Duval and MacLean (2007) states that "limited market applications for recycled plastics, low value of recycled resin and efficacy concerns" are the main issues of recycled plastics. Definitely one of the most significant challenges is the recycling of mixed plastics waste. Currently, the abundance of plastic types in combination with contaminations (other materials) in the input material poses technical restrictions, especially in terms of sorting the materials. This calls for improved design for recycling. Moreover, certain plastic types are comparably hard to recycle, such as with flexible and film types, PVC, PS, and LDPE (Hopewell et al. 2009, pp. 2121–2123), causing sorting technology improvements to offer higher quantities with a higher efficiency. Another possible restriction for recycling are legal directives such as the 'RoHS-Directive' (Wäger et al. 2011, p. 1753), which regulates hazardous substances in electronic products (European Union 2003). RoHS can lead to an increase of costs due to the required extraction of the specified substances coming from the waste plastic used in the recycling process to ensure RoHS compliant recycled plastics.

However, the magazine (Waste Management World 2015) states, that recycling technology has achieved 99.9% purity from pieces with just 1 mm with advanced automated machinery to sort and recycle materials previously considered hard to recycle, such as those mentioned above including black plastics which was hard to detect. Concerning the economic aspects of the recycling industry, another current weakness is the quantity and quality of the input material and a low market for recycled material, related to the price of virgin plastics in relation to recycled material caused by a low oil price. Especially a stable and well-timed supply of input material with acceptable quality is a challenge, in combination with high costs for collection and sorting (Plastic Zero 2013).

3.1.5 *Environmentally Sound Solution: Circular Life-Cycle of Plastics*

With the previous analysis of the impacts of plastics and the treatment options, it is to be questioned how to solve these current issues regarding the plastics life-cycle. As Jean-Charles et al. (2010) concluded when reviewing 8 LCAs including 22 cases, the optimal solution is a circular plastics life-cycle, as a step towards an entire circular economy, as outlined by Ellen MacArthur Foundation (2012). And this is primarily manageable through recycling, which generally decreases the depletion of natural resources, decreases the energy required for the virgin material production process and reduces the plastics waste that is being incinerated or landfilled (Lazarevic et al. 2010).

For the sake of analysing the options for a circular economy and consequently the treatment options for plastics waste in terms of environmental impact, numerous LCAs need to be considered. For this reason, Lazarevic et al. (2010, p. 258) carried out a review of ten LCAs on post-consumer plastics waste treatment including the most important plastic types as mentioned above, concluding that "…for the majority of scenarios previously investigated by LCA, mechanical recycling is generally the environmentally preferred treatment option" which is confirmed by Hamad et al. (2013). "This is relevant for environmental impact categories related to energy use, [EN]including global warming potential, [GWP] acidification potential, [AP] eutrophication potential [EP], abiotic resource depletion potential [ADP] and residual solid waste production" [SW] (Lazarevic et al. 2010, p. 258) (see Chap. 8). Additionally, Lazarevic et al. (2010, p. 258) state that "the virgin material substitution ratio and amount of organic contamination could lead to recycling showing lower environmental benefits than other treatment options such as incineration with energy recovery …[additionally,] uncertainty exists as to what ratio recycled plastic is substituting virgin plastic …" This highlights the assumption that organic contamination and unclear substitution effects are crucial aspects of LCA results. A different result is given by Laurent et al. (2014, p. 580), whose comparison of 222 LCAs revealed that a final conclusion whether recycling or thermal treatment is the ecologically better solution is difficult due to differing LCA results, but highlighted that "a relatively large proportion of studies tend to favour recycling over landfilling and thermal processes for plastics and paper." (Laurent et al. 2014, p. 579).

> …mechanical recycling is the most preferred and used recycling method comparing with the chemical recycling method in which the waste are subject to complicated chemical treatments. (Hamad et al. 2013, p. 2810)

To aggregate the possible benefits of using mechanically recycled plastics instead of virgin plastics depending on the plastic type, a review was conducted relying on the data primarily provided by Borthwick et al. (1997), Jean-Charles et al. (2010), Lazarevic et al. (2010), O'Rourke and Connolly (2003), Raj et al. (2013), Al-Salem et al. (2009), Woynillowicz and Severson-Baker (2009):

- Reduction of energy consumption (from 50% (Duval and MacLean 2007); (Jenseit et al. 2003, p. 49) up to 88% with HDPE (Franklin Associates 2011)
- Reduction of greenhouse gas and especially CO_2 emissions (from 50% (Duval and MacLean 2007); (Jenseit et al. 2003, p. 48) up to 75% with HDPE (Franklin Associates 2011) as well as NO_x (Jenseit et al. 2003, p. 49) and SO_2 (Al-Salem et al. 2009, p. 2627) through decreasing the

– demand for fossil fuels (such as crude oil, gas, coal) for the production of virgin plastics including
  fossil fuels for the retrieval of fossil fuels
  fossil fuels for the transport of fossil fuels
  the release of greenhouse gas emissions (CO_2e) in the chemical production process through byproducts

– energy recovery of plastics waste

– landfilling of plastics waste (savings of CO_2 emissions ranging from 0% (PVC) up to 1080%[16] (PE) when being recycled compared to landfilled (Jean-Charles et al. 2010, p. 53), and additional savings of CH_4 emissions (methane) from plastics contaminated with organic material (Lazarevic et al. 2010)

- Reduction of land degradation and waste of space through landfilling including social aspects such as a decrease of health and quality of life
- Decrease of resource depletion and dependency through

– Decreased demand for fossil fuels for the plastic material itself
– Decreased demand for resources (especially fossil fuels) for the plastic production process

- Decreased environmental pollution through hardly degradable plastics waste (plastic debris and particles in the environment such as on land, in fresh water and the deep sea)
- Decreased ingestion of plastic waste particles possibly including toxic substances by animals and thus humankind
- Decreased leaching chemicals such as toxic additives from landfilled plastics waste
- Decreased externalisation of environmental costs due to plastics waste export from developed to less developed countries with less strict regulations

Of course, the energy demand for recycling has to be calculated cautiously to weigh up the benefits of recycling of the respective plastic type. According to information provided by Biddle (2012), "…there are usually enormous energy and CO_2 emission savings in recycling plastics compared to making plastics from petrochemicals. These savings depend on the type of virgin material being compared and the specific plastics recovery process being used by the recycler, but the range of savings are usually between about 80 and 90%!". In addition, the recyclability of the final plastic product has to be considered as well in this calculation. It might not be environmentally sound if recycled plastic is integrated into a complex composite material which is not recyclable. The mentioned emission saving potential of recycled plastics was further analysed by Prognos and Ifeu (2008) with focus on the EU Kyoto targets for greenhouse gas emissions. They claim that fully exploring the potential of recycling and recovery in flexible ratios of the entire landfilled waste could save 7% of the EU Kyoto targets.

> The results from the LCA studies reviewed have indicated that, from a life-cycle perspective, mechanical recycling of plastic waste is generally preferred to (1) feedstock recycling and (2) MSW [municipal solid waste] incineration, provided that (a) recycled plastic originates from clean plastic waste fractions with little organic contamination and (b) recycled plastic substitutes virgin plastics at a ratio of close to 1:1. (Lazarevic et al. 2010, p. 258)

Accordingly, the focus of this book is on material recovery, with the focus on mechanical and chemical recycling of ELV plastics, despite the implementation of

[16]"In this study, the authors have chosen a hypothetical infinite time period when inventorying emissions which implies that complete degradation of landfilled material is assumed." (Jean-Charles et al. 2010, p. 35).

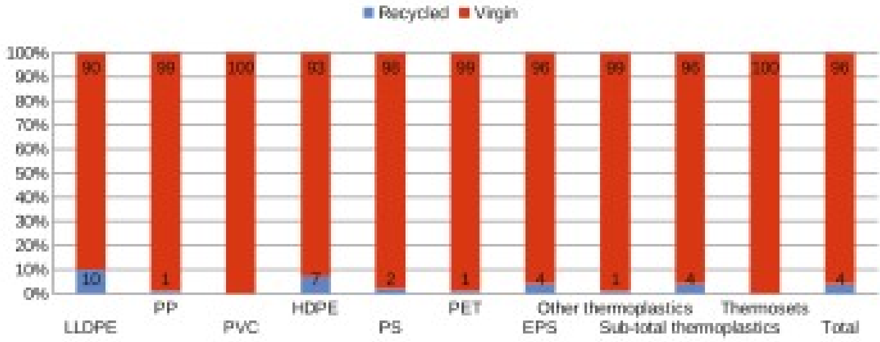

Fig. 3.15 Ratio of recycled versus virgin plastics in Western Europe, 2000, based on Hannequart (2004, p. 25), cited after APME (2002)

recycled plastics in the production process. Recycling of production waste, called in-house recycling, is considered as well, but only peripherally, because ELV recycling is an exceedingly more challenging issue compared to the recycling of clean production waste, which might not even be called waste. However, in-house recycling is another opportunity to improve the overall ecological sustainability of the car in the production phase.

Usage of Virgin and Recycled Plastics

Since recycled plastics are principally more favourable than virgin plastics in ecological terms as examined above, the actual usage of these two plastics types is to be analysed. According to Hannequart (2004, p. 25), the ratio of recycled to virgin polymer use in 'Western Europe' (not defined) in 2000 was insignificant, as illustrated in Fig. 3.15. More recent data was not accessible.

3.1.6 Plastics Are a Blessing and a Curse —A Summary

Reflecting upon the gathered information in the preceding sections leads to four factors of (most) plastics which render them suitable for countless applications resulting in the long-lasting and immense success of these materials: Plastics are affordable, lightweight, versatile, and durable.

However, the problem or the challenge lies within the operator handling the material. Especially the production phase and the end-of-life phase are exceedingly critical to date due to substantial environmental pollution and risks for society. But there is a suitable solution available: material recovery, and especially mechanical recycling. Through increased recycling and usage of recycled plastics, a circular plastics economy can be established, in order to reduce environmental pollution, societal risks and economic as well as political dependencies on fossil fuels.

Reflecting on the information and knowledge gathered in the Chap. 2, it becomes obvious that most of the theoretical solutions are not currently implemented in the plastics industry. Corporate sustainability and CSR is being discussed, but groundbreaking solutions to achieve resource and impact decoupling are not translated into practice. In fact, the prevailing mindset is focusing on obsolete values such as economic growth and fast money without considering long-term impacts on multiple levels. As a next step, we will narrow down the analysis on automotive plastics.

3.2 Automotive Plastics

Plastics in the automotive sector have become a vital material, but there are pressing issues attached to these polymers. To understand the automotive plastics life-cycle, the development and the trends on a global and mainly European scale will be analysed, followed by investigating Sects. 3.2.2, 3.2.3, and 3.3. Again, this section follows the Funnel-logic-distillation-approach.

3.2.1 Automotive and Automotive Plastic Trends

Demographic Development

The global automotive trends are first of all linked to global demographic development and the resulting increase of cars per capita. The fact that global population numbers will continue growing from 6.8 billion people to approximately 9.1 billion in 2050 (Worldbank 2014) will influence the automotive industry significantly. Especially South Asia and Sub-Saharan Africa are projected to grow the most, and for the automotive industry even more relevant is the projection that the population with middle income will rise by approximately 1.4 billion by 2050 (Worldbank 2014). Furthermore, if we additionally consider the current global geographic distribution of passenger cars, which depicts that the number of cars per 1000 people in developed countries is significantly higher (e.g., Austria: 529, Germany: 517 cars per capita) than in (yet) less developed ones (e.g., China: 44), we can assume a rise of the global car population (Worldbank 2013). In 2010, 1.015 billion vehicles were in operation, including 707 million cars and 307 million commercial vehicles (Sousanis 2011). Based on these numbers, Sperling and Gordon (2009) calculated that by 2020, there will be 1 billion cars worldwide in use, and in total more than 2 billion vehicles worldwide. Based on the even higher numbers provided by OICA (2016a), the number of cars in 2021 could already reach 1.2 billion (see Fig. 3.16), based on own calculations.

Turning to the production, Marketsandmarkets (2013) states that in 2012, 63.1 million passenger cars were produced, which aligns with the numbers from OICA (2014). In 2015 the number of passenger cars produced reached 68.5 million OICA

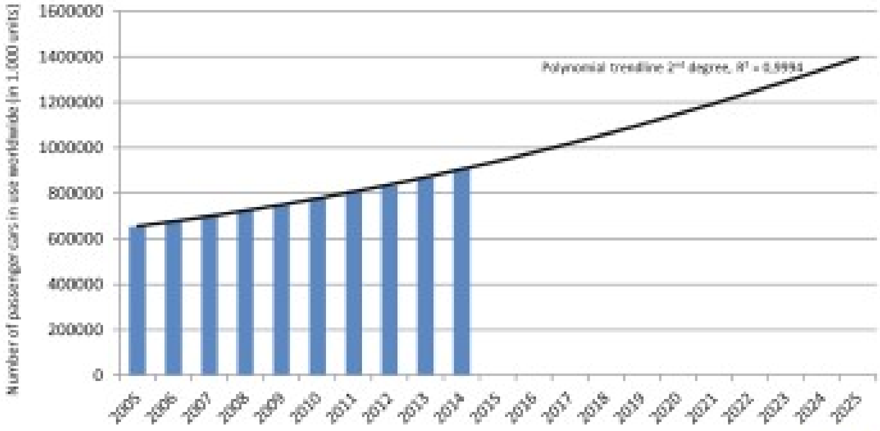

Fig. 3.16 Passenger cars in use worldwide, adapted with kind permission from OICA (2016a), modified by adding a polynomial trendline

(2016b), or even 73.5 million according to ACEA (2016) (based on non-accessible data from IHS). In 2020, the number is expected to rise to 102.5 million cars, with a CAGR (compound annual growth rate) of 7.2% from 2015, and the Asia-Pacific region will show a high growth rate (CAGR of 8.4%) (Marketsandmarkets 2015) due to the expected increase of disposable income.

Automotive Profit and Revenue

According to McKinsey (2013, p. 8), €25 billion in additional profits will be probable by 2020 and that emerging markets, especially China, will account for more than 66% of the global profit in the automotive sector with 13 billion in total and 9 billion in the premium segment alone. The rest of the profit will be made in other emerging markets (6 billion), in established markets (4 billion), but primarily in North America (2 billion).

Automotive Plastics

The above-mentioned increasing number of cars will contain progressively more plastic materials. The reason for this is that plastics represent a solution to the automotive industry for decreasing the environmental pollution during the life phase of a car by enabling lightweight construction (Kremlicka 2012; Mayyas et al. 2012, 2013; Weill et al. 2012). The need for plastics in the automotive sector rises as this material contributes to the essential weight reduction of automobiles by replacing heavy conventional materials, especially relevant for electric cars with heavy batteries. According to PlasticsEurope (2013a), new technological advancements are constantly expanding the application range of plastics in new cars thus increasing the demand for plastics.

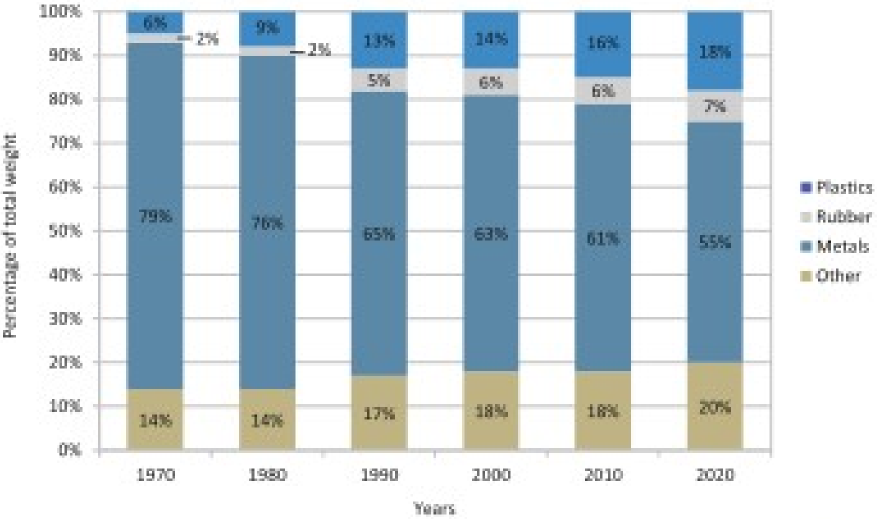

Fig. 3.17 Automotive materials development, adapted with kind permission from Weill et al. (2012, p. 2), modified by the author. (Color figure online)

> Continual innovation is a key feature in the use of plastics in cars. Plastics will continue in the next decade to help designers to innovate and take car performance further. (EuPC 2013)

In 2010, the share of plastics in new cars was 16%, which is believed to rise to more than 18–20% in the future (Weill et al. 2012). In the same year, 224 kg plastics were found in new cars, but in the future, it is possible that this number might stall or decline to 198 kg due to a decrease of the overall weight from 1400 kg in 2010 to 1100 kg in 2020 as depicted in Fig. 3.17, according to Weill et al. (2012) and as illustrated in Fig. 3.18, by PlasticsEurope (2013b).

Calculating the numbers of the global automobile car and plastics production, Marketsandmarkets (2013) reports that in 2012, 7.1 Mt of automotive plastic were consumed for passenger cars which is expected to rise to 14.37 Mt in 2020 with a CAGR of 8.3% from 2015 to 2020 (Marketsandmarkets 2015). In short, all numbers point to a distinct growth of automotive plastics. The international share for automotive plastics consumption for passenger cars in 2015 is dominated by Asia-Pacific (57.3%), Europe (25.1%), North America (10.8%), ROW (6.8%) [rest of the world] (Marketsandmarkets 2015). The generated revenue from the production of automotive plastics was $21.3 billion 2014, which is likely to increase to $40.1 billion in 2020, as provided with kind permission by Marketsandmarkets (2015).

Concerning the geographical or spatial distribution of automotive plastics, Marketsandmarkets (2013) states that the Asian-Pacific region consumes 50.5%, followed by Europe (28%), North America (11.3%), and the remaining regions (10.1%). Concerning the types of plastics, the distribution of the consumption of plastics used in newly produced cars on a global scale is primarily PP, PUR, and PA according to PlasticsEurope (2013a) as depicted in Table 3.3, including a calculation of the

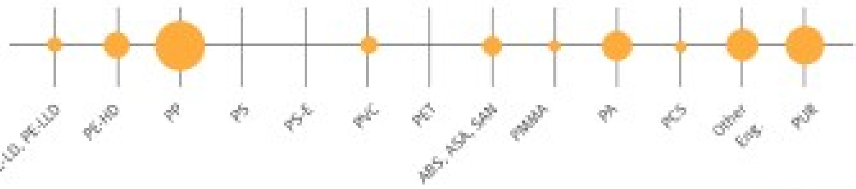

Fig. 3.18 Automotive plastic types, used with kind permission from PlasticsEurope (2013b). All rights reserved

Table 3.3 Most prominent plastics and their estimated percentages in terms of weight used in a typical car, based on PlasticsEurope (2013a) and Weill et al. (2012)

Plastic type	**Acronym**	**% by weight**	**kg (224 kg total per car)**
Polypropylene	PP	28.6	64
Polyurethanes	PUR/PU	17.4	39
Polyamides	PA	11.9	27
Polyethylene	PE-HD/MD/LD/LLD	9.7	22
Styrenic copolymers	ABS, ASA, SAN	5.3	12
Polyvinyl chloride	PVC	3.8	9
Others		23.3	51

absolute masses based on the data from Weill et al. (2012) which states that 224 kg of plastics were found in new cars in 2010. In addition to conventional plastics, there are also composites with plastics being used in automotive manufacturing. Such plastic composites incorporate for example carbon resulting in carbon fibre reinforced plastic (CFRP or simply 'carbon'), glass (glass reinforced plastics, GRP, GFRP (glass-fiber reinforced plastics), fiberglass), or aramid in order to reinforce the structure (Murphy 2013) (see Sect. 3.1.1). The demand for reinforced plastics in car production reached 25,500 t in 2015 with an estimated growth to 76,700 t automotive CFRP in 2022 (CCeV and AVK 2016, pp. 17;21). Bioplastics are still completely insignificant in the automotive sector as only 94,000 t were used in 2014 (5% of the global bioplastics production) (Institute for Bioplastics and Biocomposites 2015, p. 45) (see Sect. 3.1.1). Consequently, these materials are not the main focus of this book as conventional plastics are the most prominent polymers in the automotive sector.

Due to several also non-scientific sources concerning the share of plastic types in cars, a different insight is offered in Fig. 3.18. Please note that in this illustration, the labelling and the underlying data was not available, but it is used to show that the share of PA (polyamid) is claimed to be significantly higher than in the dataset from Marketsandmarkets (2013). In fact, there is a need for superior and publicly available data.

3.2.2 Environmental Impact of Automotive Plastics and Cars in General

The ecological factor of a highly globalised economic branch such as the automotive sector is subsequently relevant and operative on a global scale. Currently, this industrial branch is handling the ecological factor despite fuel consumption with a comparably low level of attention, regardless of its high level of relevance if one focuses on the production and end-of-life (EOL) phase of a car. The main focus of interest regarding the ecological factor is the life-phase of a car as the companies are primarily taking the greenhouse gas emissions (CO_2e) into consideration, discounting the production and end-of-life phase. In fact, this conduct or behaviour is driven by a policy of restraint limiting and penalising high greenhouse gas emissions from cars. In this context, it should be mentioned that there is also a conflict of aims between designing lightweight cars on the one hand and implementing recyclability on the other hand, while reaching these two aims is a challenge. As the life-phase of a car is thoroughly linked to the manufacturer, or in other words, as the company is being held responsible for the ecological effects caused during the life-phase, it is logical that the automotive industry is pushing to decrease the exhaust fumes detrimental to the environment. As this development is to be considered positive without exception, the industry ought to more strongly include the production and end-of-life-phase of a car to complete the scope of treatment concerning the negative ecological repercussions, beyond the implementation of legal directives such as REACH, RoHS, the ELV-directive, and producer responsibility (see Sect. 3.2.3.2) regulating hazardous substances, and promoting recycling. However, automotive businesses are still externalising the ecological costs of handling remaining negative impacts of cars predominantly to future generations regarding the production and end-of-life-phase. This is due to the fact that companies do not feel responsible enough for the negative effects of the production phase and the EOL phase. In short, they are evading the payment for the caused ecological effects, as is outlined in the following.

> The products of this industry touch our daily lives not only by providing personal mobility for millions, but also by bringing a wide array of challenges. The deterioration of local air quality in urban areas, along with global issues such as global warming, and the treatment of scrapped vehicles are just a few examples of such challenges. (Orsato and Wells 2007, p. 989)

In fact, the life of a car results in numerous ecological repercussions, based on Monterey California (2014) [17]:

- water pollution (runoff of oil, dirt, brake dust, exhaust fumes, road particles, automotive fluids, chemicals from roadways and parking lots)
- solid waste (scrapped material, tires)
- energy use (fuel)

[17] The text was partly paraphrased, summarised and complemented by the author.

- noise pollution
- air pollution
- land use (road surfaces, parking lots)
- road building (degradation of ecosystems when building roads and resource extraction for the roads from large-scale rock quarrying and gravel extraction in possibly sensitive habitats)

For a very detailed account of the automotive environmental impact concerning greenhouse gas emissions and CO_2e, please consider Patterson et al. (2011), and for a detailed outline of the complex system required for a holistic LCA of automobiles please see Mayyas et al. (2012, p. 1847). As a next step, we will investigate the application of these plastic in cars providing an overview of the structure of an automobile.

Automotive Engineering, Technical Requirements and Plastic Components

Automotive plastics have to fulfil very high technical requirements and standards in terms of performance because of the automotive industry's focus on safety, comfort, and design. For this reason, the material selection for car parts is highly dependent on the overall performance of the material. Consequently, the material selection in the automotive industry depends for example on the following properties which can compete or concur (based on Belingardi and Obradovic (Belingardi and Obradovic (2012), p. 21)):

- "Chemical composition
- Structural and mechanical characteristics
- Innovative manufacturing technologies
- Surface paintability and protection
- Innovative joining technologies
- Design of innovative structures
- Component and subassembly tests
- Maintainability and dismantling[18]
- Recycling at the end-of-life".

When plastics have passed such a material selection process, which is likely to differ slightly depending on the respective company, for passenger cars, plastics are used for the following components (EuPC 2013) (please note that this table is from 2000, as no earlier data was available and that the numbers do not add up, as the sum of the masses is 96 kg and not 105 kg as given, therefore consider Table 3.4 as an approximation):

However, this is likely to have changed over the years due to rapid plastics development, new regulations and requirements of the automotive industry.

[18]Originally, this line said "Manutenability and dismounting", but after technical and linguistic research, it was concluded and suggested that 'Maintainability and dismantling' was most probably the correct version.

Table 3.4 Plastics used in a typical car, used with kind permission from EuPC (2013)

Component	Main types of plastics	Weight in av. car (kg)
Interior trim	PP, ABS, PET, POM, PVC	20
Seating	PUR, PP, PVC, ABS, PA	13
Bumpers	PP, ABS, PC/PBT	10
Under-bonnet components	PA, PP, PBT	9
Upholstery	PVC, PUR, PP, PE	8
Dashboard	PP, ABS, SMA, PPE, PC	7
Electrical components	PP, PE, PBT, PA, PVC	7
Fuel Systems	HDPE, POM, PA, PP, PBT	6
Body (incl. panels)	PP, PPE, UP	6
Lighting	PC, PBT, ABS, PMMA, UP	5
Exterior trim	ABS, PA, PBT, POM, ASA, PP	4
Liquid reservoirs	PP, PE, PA	1
Total		105

3.2.3 The Car Life-Cycle, ELV Management, and Recycling

> Changes in automotive materials and systems are anticipated as government and industry work together to increase fuel efficiency. These changes will certainly require the development of new and advanced technologies for sustainable automotive materials recycling. (Daniels et al. 2004, p. 32)

The car life-cycle in the EU is a special case—statistics show, that a large proportion of end-of-life vehicles (ELVs) is going missing every year. According to Oeko-Institut e.V. et al. (2016),[19] more than 3.6 million ELVs were missing in 2013 (see Fig. 3.19). These missing cars represent a significant loss of resources which are not kept within the EU for recycling.

Analysing the car life-cycle with the focus on the treatment of end-of-life vehicles, several process stages are required until all the different materials are recycled, recovered, or landfilled. The current process is depicted in a simplified version in Fig. 3.20. For a more detailed outline of the complex life-cycle system required for a holistic LCA of automobiles please see Mayyas et al. (2012, p. 1847). However, as stated in the exemplary quote above, insufficient attention has been given to recycling in the automobile life-cycle.

First of all, there are two main geographical regions of interest, namely the European Union and other countries and regions, labeled 'Extra-EU'. In fact, there are two systems in parallel: First, the automobile life-cycle, which is regulated, struc-

[19]Data sources according to Oeko-Institut e.V. et al. (2016): POLK; European Automobile Manufacturers Association (ACEA); Eurostat; Eurostat Foreign Trade Statistics (FTS). The calculation methods can be found in this report as well.

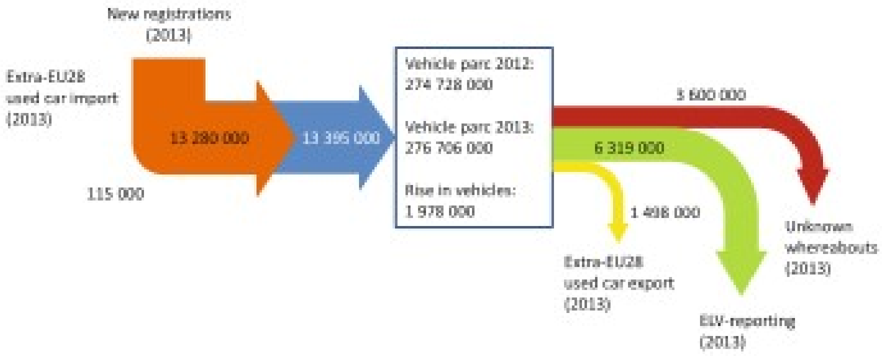

Fig. 3.19 Automobile streams in the EU-28 in 2013 (M1+N1 vehicles), reproduced from Oeko-Institut e.V. et al. (2016) (CC BY-SA)

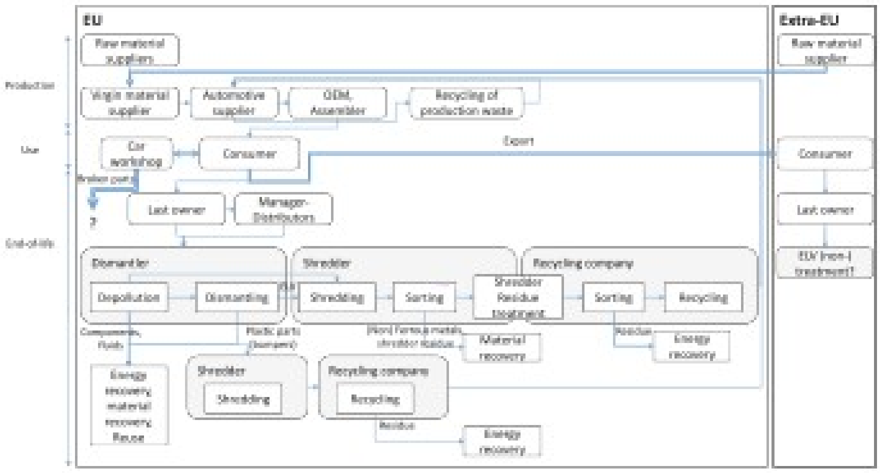

Fig. 3.20 The car life-cycle in the EU with the focus on ELV treatment, adapted with kind permission from Kanari et al. (2003), Maudet et al. (2012)

tured, and deemed sustainable in the European Union. However, there is a second system, which is primarily unofficial and running in the background. This is the system connecting the automobile life-cycle in the EU with the ‘Extra-EU’, that is, adding the import of raw materials and the export of ELVs. Turning to the life-cycle of a car in the EU, the production phase (on the very left in the illustration) starts with the raw material suppliers, which are mainly from Extra-EU countries due to the scarcity of raw materials within the EU. The raw materials are transported to the virgin material suppliers, such as virgin plastic material suppliers, which then supply the virgin material to the automotive suppliers, such as plastic parts moulders. Possibly, recycled material is delivered to the automotive suppliers as well. Additionally, waste plastics from the production are recycled due to their high purity.

This is possibly done right on the production site, which is called in-house recycling. Then, the parts or modules are transported to the car assembler (usually the OEM) that assembles the parts and modules to produce the car, which is then delivered to the customer. Now in the usage phase of the car, the customer usually has the car maintained at car workshops, where broken parts are disposed of. The reuse of ELV plastics is very low, if done at all, due to damage from the dismantling process; used bumpers are available for sale (Martens 2011, pp. 258–260). When the car is no longer deemed satisfying, substantial volumes of still working used cars are either exported legally or illegally, for example to extra-EU countries or regions such as Africa and the Middle East (Parliament 2010, pp. 10, 42), or considered an end-of-life vehicle (ELV) by the last owner or a manager of the distributors and sent to the waste management industry. This refers back to the "problem-shifting from one part of the life-cycle to another, from one geographical area to another" (Finnveden et al. 2009, p. 17) (see Sect. 2.4.3).

In the end-of-life of the car in the EU, the dismantler is de-polluting and dismantling the car, where fluid components and plastic parts which are easy to dismantle, such as bumpers, are used for energy and material recovery, being reused or recycled directly. Subsequent to the dismantler, the shredder receives the ELV and shreds into smaller parts which are then sorted. After the sorting, the ferrous, non-ferrous metals and a share of the residue after shredding is sent to the respective material recovery facility. The remaining fluff is called automotive shredder residue (ASR), which is a material mixture with mainly plastics (35–55%) followed by rubber (10–20%), metals (6–13%), textiles (7–15%), and other fine materials such as glass, sand, paint and more (10–20%), according to Ciacci et al. (2010) citing Boughton and Horvath (2006), Filippi et al. (2003), Laraia et al. (2007), Morselli et al. (2010), Nourreddine (2007). However, these numbers differ widely according to Ferrão, Nazareth, and Amaral (2006), Vermeulen et al. (2011). This ASR is then transported to the recycling company, which then further sorts the ASR to gather plastics for recycling (please see Sect. 3.1.4). The recycled plastics are partly sent to the automotive industry in a closed loop. The remaining residue is treated through energy recovery. For more details on ASR recycling consult Buekens and Zhou (2014). However, when turning to the extra-EU usage and end-of-life phase of cars (on the very right in the illustration), the ELV treatment is still to be questioned.

Concerning the waste treatment quality, Martens (2011, p. 258–260) describes another valuable aspect of ELV recycling, that the dismantling and the waste purity is of high importance for mechanical recycling. For example, most bumpers are coated and thus the paint has to be removed for recycling. As blast cleaning causes particles to be encased into the bumper, the latter have to be first shredded and then sent to the paint removal. As a result, but still depending on the plastic type, mechanical recycling might not be the best option. Nevertheless, this part is amongst the easiest to recycle due to material purity, size, and the easy dismantling (Akovali et al. 2013, p. 87).

Moreover, Vermeulen et al. (2011, p. 21), Nourreddine (2007), Kim et al. (2002), and Bodenan et al. (2012) underline that quality and quantity are still a challenge, the automotive shredder residue (ASR) material has to fulfil certain physical and chemical requirements, and that gasification[20] of the plastics waste and blast furnace might be a valuable option for ASR recycling.

3.2.3.1 Automotive Plastics Waste

Moving to the end-of-life of cars, especially the ELV plastics treatment is still highly insufficient, as the energy recovery (incineration), recycling (mechanical and feedstock/chemical), and disposal rates in the EU-27 including Norway and Switzerland in 2008 illustrate (Fig. 3.21). In fact, landfilling is the prevailing waste treatment method for automotive plastics in Europe in 2008. More than 1.247 Mt of automotive plastics originated from ELVs, but only 9% were recycled and 11% were used for energy recovery whereas most of the plastics were disposed (80%), according to European Commission DG ENV et al. (2011, p. 86), presumably likewise on a global scale. In total, the ELV waste generated in 2012 is estimated at 6.23 Mt in the EU-27 (Eurostat 2014).

According to the cited report for the European Union provided by (European Commission DG ENV et al. 2011, p. 86), there was a very low recycling rate of plastics from end-of-life vehicles (ELVs) within the EU due to the fact that most of the member states except Denmark have no legal obligation for ELV dismantlers to remove automotive plastics for recycling (GHK and Service 2006, p. 65). Additionally, the revenue from ELV plastics is zero per ton (Ferrão and Amaral 2006).

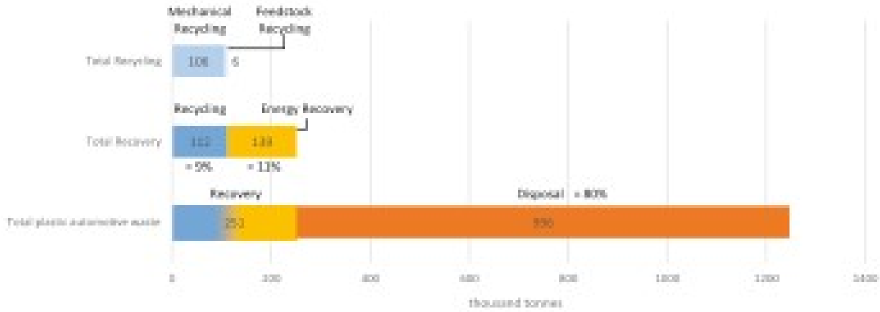

Fig. 3.21 Treatment of total automotive plastics waste in EU-27+N/CH in 2008, adapted with kind permission from European Commission DG ENV et al. (2011, p. 86)

[20]Definition of new registrations according to European Union (2001): M1 (orange in the illustration) = "Vehicles designed and constructed for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat." and N1 (blue in the illustration) "Vehicles designed and constructed for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes.".

Table 3.5 Plastics content in a 2015 ELV, estimation (European Commission DG ENV et al. 2011, p. 125)

	%	kg
PP	42	44.63
PU	11	11.69
PA/PC	8	8.50
ABS	7	7.44
PVC	7	7.44
Other	12	13.81
Total	100	106.26

As a consequence, the recycling rate of automotive plastics was at 0% in most of the member states in 2006 (GHK and Service 2006, p. 65).[21] Even in 2011, "the proportion of plastics from ELVs being recycled is extremely low" (European Commission DG ENV et al. 2011, p. 70). However, the low rates imply that treatments other than recycling are predominant in the end-of-life process of automotive plastics. Unfortunately, there was no recent complete dataset on ELV plastics treatment available from the European Commission and Eurostat, even after personal requests were made.

Upon investigation of the estimated plastics contained in ELVs from the year 2015, European Commission DG ENV et al. (2011, p.125) estimates that in 2015, 106 kg of plastics are theoretically available for recycling. In Table 3.5, the composition of plastics from ELVs in the year 2015 is depicted and shows that polypropylene is by far the most dominant plastics type with 42%, followed by polyurethane (11%), polyamides and polycarbonates (8%), acrylonitrile butadiene styrenes (7%), polyvinyl chloride (7%) and others (12%).

Reinforced plastics and composites waste such as CFRP (carbon fibre reinforced plastics) from ELVs is currently not significant in quantity, but could be in the future. However, in the production process of CFRP around 33% is waste, and the treatment of CFRP waste is a huge challenge (see Sect. 3.1.4). Other composites are also by nature difficult to recycle due to the physical and chemical combination of inherently different materials. Bioplastics waste from ELVs is also not yet of major concern, but might be in the years to come. Therefore, treatment of ELV bioplastics waste should be of political and industrial concern as facilities and the waste treatment framework could require adaptation (Stagner et al. 2012, p. 1050). Returning to standard plastics, it is to be said that the quantity of plastics from ELVs available for recycling is remarkably significant, yet the recycling process itself is still a challenge. However, in order to potentially close this automotive plastic loop, the application of recycled (automotive) plastics is crucial.

[21] Please note that in this report the terms 'recovery' and 'recycling' are sometimes mixed up, as on page 86.

Table 3.6 Usage of recycled plastics in car fleets in Europe (BMW Group 2015; Daimler AG 2015; PSA Groupe 2015; Fiat Chrysler Automobiles Group [FCA] 2015, p. 64; Volkswagen AG 2015; Nissan Motor Corporation 2016, p. 138; Renault Group 2015, p. 16; General Motors 2015; Ford Motor Company 2016)

OEM	Proportion of recycled plastics
FCA Group (Fiat/Chrysler)	34.9% (avg. 2015)
BMW Group	No clear indication (up to 20% in 2014)
Nissan Motor Corporation	No clear indication (13% in the best performing model)
PSA Group (Peugeot/Citroen)	No clear indication
Renault SA	No clear indication
Ford Motor Company	No clear indication
General Motors Company	No clear indication
Volkswagen Group	No clear indication
Daimler AG	No clear indication

Usage of Recycled Plastics in Cars

Car manufacturers are currently not particularly interested in using recycled plastics in cars, according to Maudet et al. (2012), pp. 4, 5). Moreover, it is stated that the reasons against using recycled plastics in cars are mostly the poor quality image of recycled plastics, that recycled plastics are displacing virgin plastics on the market, that "quality, volume and price" and "performance and consistency of performance" are not satisfactory to the automotive industry (Maudet et al. 2012, pp. 4, 5). However, OEMs implement recycled plastics, but most do not declare the real content publicly. According to the sustainability reports of major OEMs in Europe, only Fiat/Chrysler states their usage of recycled plastics or polymers in their car fleet accounting for 34.9%. No other OEM provided clear information about their usage of recycled plastics as depicted in Table 3.6. Some OEMs only provided data on only one car model which was probably the best one concerning recycled plastics, or stating up to percentages, which could refer to zero usage as well. However, after discussions with OEMs and suppliers, many companies seem not to know the exact share of recycled plastics in their products, due to complex supply chains and sometimes even non-communicated usage of recycled plastics by suppliers for cost reduction. Generally, cross-fleet data is still insufficient and needs to be published.

According to Toldy et al. (2009, p. 971), "…the ratio of the applied secondary plastics in the production of the primary products varies between 5 and 25%. The ratio of recycled plastics, which can be added to the product, depends from the technology, currently it can be up to 50%. Recycled plastic materials can be used as secondary raw material mainly in non-visible, non-coloured, non load-bearing parts, when no further processing is done, in non-prestige brands." This highlights that recycled materials are currently applied cautiously and concealed, which is supported by Maudet et al. (2012, pp. 4, 5) describing the reasons for this issue: First of all, recycled plastics are still considered inferior to virgin plastics. Secondly, the recycled plastics displace virgin material, whereas the production of virgin plastics is a perfectly closed process guaranteeing high quality. Thirdly, recycling companies do not meet the quality and quantity requirements of OEMs and suppliers, yet.

However, there are also studies from the industry concerning the usage of recycled plastics in cars proving interest about this topic. For example, CARE Group and BPF (2003) did a "Plastics Reprocessing Validation Exercise—PRoVE" which shows that for example compounds using 25% recycled PP and ABS plastic from ELVs and 75% virgin plastics have suitable material properties. However, only low-tech products were made, such as air filter housings and radiator grilles, despite the fact that the input material was handpicked, thus ensuring material purity. Still, they acknowledge, that research has to be done on a larger scale. Furthermore, it is necessary to research the material properties of blended products incorporating virgin and recycled plastics. According to Raj et al. (2013, p. 202), the optimal material properties without any drawbacks are achieved with 10–40% recycled plastics, depending on the focus (tensile, flexural, or impact strength). However, this study has to be extended significantly to various types of recycled plastics as there are considerable differences between various recyclate suppliers. Furthermore, Maudet et al. (2012, p. 7) elaborate that such compounds can increase the quality of recycled material, but this is not preferred by the automotive industry. In practical tests using recycled plastics from production waste, Covestro Deutschland AG (2015) advises that 10–20% recycled material (reclaim) can be added to virgin plastics, and "up to 100% for parts where properties are of secondary importance …. Additionally, Maudet et al. (2012, p. 7) claim that only locally recycled material is preferable to virgin material, highlighting the impact of transportation. However, in order to advance recycling in the car life-cycle, politics is another highly relevant factor, as discussed next.

3.2.3.2 Politics and the Legal Framework in the EU

National politics and especially the European Union are strongly influencing recycling in the life-cycle of automobiles. Since resource scarcity is a central element in the politics and the legal framework in the EU, the regulation of the whole life-cycle of automobiles, several directives and their effects on the system have to be taken into consideration. Beginning with the production phase of a car, the EU established the REACH-Directive, which is concerned with the "Registration, Evaluation, Authorisation and Restriction of Chemicals" (European Commission DG Enterprise and Industry 2014b). "The main aims of REACH are to ensure a high level of protection of human health and the environment from the risks that can be posed by chemicals, the promotion of alternative test methods, the free circulation of substances on the internal market and enhancing competitiveness and innovation. REACH makes industry responsible for assessing and managing the risks posed by chemicals and providing appropriate safety information to their users. In parallel, the European Union can take additional measures on highly dangerous substances, where there is

Table 3.7 ELV-Directive (European Union 2000, p. 38)

	As of Jan 1, 2006	As of Jan 1, 2015
Reuse and recycling (%)	80	85
Reuse and recovery (%)	85	95

a need for complementing action at EU level." (European Commission DG Enterprise and Industry 2014b). As a consequence for plastics recycling and recycled plastics in the automotive sector, REACH influences the production and the usage of recycled plastics in cars through the legal obligation of registering, evaluating, authorising, and restricting the content in plastic materials concerning their impacts on the environment and human health. Another legal measure influencing recycling is the "Restriction of Hazardous Substances Directive" (RoHS), which regulates hazardous substances in electronic products (European Union 2003), thus leading to an increase of costs due to a required extraction of the specified substances coming from the waste plastic used in the recycling process to ensure RoHS compliant recycled plastics (Wäger et al. 2011, p. 1753).

Turning to the end-of-life of vehicles, the European Union implemented the ELV-Directive to regulate the treatment of cars after the usage phase. This directive stipulates that by 2015 95% of the ELV by weight has to be reused, recovered, and recycled, whereas a maximum of 10% might be treated with energy recovery (Table 3.7) (European Union 2000, p. 38).

Product stewardship and the (extended) producer responsibility 'EPR' laws are additional drivers for corporate sustainability, furthermore can companies develop better products if they incorporate the end-of-life phase of their products, for example by take-back policies (Kralj and Markic 2008; Rossem et al. 2006).

Currently, the European Union is working and implementing the "CARS 2020 Action Plan", which endorses the suggestions provided in the final report of the previous process, called 'CARS 21', a "Competitive Automotive Regulatory System for the 21st century". The recent CARS 2020 Action Plan is now "promoting the innovation and advanced technologies, improving market conditions, global competitiveness and anticipation of change." (European Commission DG Enterprise and Industry 2014a). Moreover, the CARS 21 final report (European Commission DG Enterprise and Industry 2012, p. 54) states the importance of R&D among other things in the fields of suitable materials (including substitutes) and 'ecological and efficient manufacturing, including recycling' within the research and innovation plan 'Horizon 2020'.

Within the Horizon 2020 programme, the "European Green Vehicles Initiative" (EGVI) (EGVI 2014) was established, which is "delivering green vehicles and mobility system solutions which contribute to the development of a competitive and sustainable transport system in Europe". Moreover, alternative and lightweight materials and vehicle recycling is within the scope of the EGVI. In addition to automotive specific aims, the EU is pursuing advancement of the circular economy and resource efficiency in general, such as in "Towards a circular economy: A zero waste programme for Europe" (European Commission 2014c) and the "European Resource Efficiency Platform" (European Commission 2014a). Furthermore, the European Commission put forward a proposal to ban landfilling of recyclable materials including plastics by 2025 (European Commission 2014b, p. 25): "Member States shall not accept the following waste in landfills for non hazardous waste by 1 January 2025, recyclable waste including plastics, metals, glass, paper and cardboard, and other biodegradable waste."

In summary, the European Union is actively addressing challenges concerning alternative materials, recycling and waste treatment in directives and research and development programmes. However, the usage of recycled plastics in the automotive sector is of no explicit concern to date.

3.3 Summary: Holistic Controversy of Automotive Plastics

The industry reality concerning automotive plastics is bipolar in terms of theory and reality: On the one hand, plastics reduce the environmental impact during the usage phase; on the other hand, plastics have a negative environmental impact in the production and end-of-life-phase of a car. Now to summarise the outlined controversial system of automotive plastics, the following facts recap the global challenges and automotive trends with regard to the environmental impact of automotive plastics:

1. Exponential population growth
2. New markets, new consumers
3. Increase of affluence/wealth = more cars per capita
4. Increase of plastics share in cars = Increase of plastics demand

= Increase of demand for fossil fuels
! No circular economy
! Extraction and emission of greenhouse gases caused by automotive plastics

Now following the lead of the "I = P × A × T" calculation by Commoner (1972), Ehrlich et al. (1971), which states that the human impact (I) on the environment is equal to the product of the population (P), the affluence (A), and the technology (T) and its criticism by Alcott (2010), who claims that the variables (P, A, T) are actually dependent of each other and therefore the equation should reconsidered by calculating I = f(P, A, T), the following calculation was developed subsequently to the previously mentioned global challenges and automotive trends concerning plastics. Replacing 'affluence' with 'cars per capita', and 'technology' with 'plastics share' as well as 'recycling rate', the 'environmental impact of automotive plastics' can be calculated together with the 'population':

I = f[P, C, S, R] Environmental impact of automotive plastics [I] =

f [Population (P), Cars per capita (C), Plastics share (S), Recycling rate (R)]

Changing the perspective from automotive plastics to the car in general, an expansion of the focus only on the life phase of a car is apparent. In particular, the rise of fuel efficient and especially electric cars increases the importance of the production and end-of-life-phase in the environmental impact throughout the life-cycle of cars due to reduced emissions in the life phase (Hawkins et al. 2013, p. 1). Patterson et al. (2011) point out that a mid-size gasoline-powered car emits 23% of the life-cycle CO_2, and a mid-size electric vehicle more than 57% in the production phase, when assuming 310g CO_2/kWh. Of course, this depends on the respective generation of electricity. A similar effect concerning the focus on the production phase is created by an increased usage of high tech plastics and composites. This consideration of the whole life-cycle of cars amplifies the necessity for practical solutions in order to decrease the negative effect of plastics in the production and end-of-life-phase by strengthening the circular plastics economy and sustainable recovery.

Generally, research on the industrial reality revealed that at present, there is sustainable thinking in the industry and in politics, but the attitude toward holistic sustainable acting still leaves something to be desired. It seems, and this is only an estimation, that the automotive industry is paying attention primarily to the life-phase of cars, to decrease the fuel consumption due to regulations and marketing benefits, while tending to disregard the production- and end-of-life-phase because of few incentives and legal directives to do so, which causes "problem-shifting from one part of the life-cycle to another, from one geographical area to another" (Finnveden et al., 2009), p. 17) (see Sect. 2.4.3). However, there is also a conflict of aims between designing lightweight cars and recyclability. As a result, recycled plastics are not as important as they should be, although their potential to decrease negative environmental impacts is known. The secondary raw materials business or waste management industry is challenged to recover valuable plastics from end-of-life cars to render the import of crude oil for producing virgin plastics obsolete. As a result, the economy is primarily linear so that the automotive plastics production and recycling system is causing negative impacts on the environment.

The environmentally sound solution is a circular economy where automotive plastics materials are recovered through various technologies, depending on the waste plastics. When considering the potential, now from plastics in general, the numbers are convincing: "By eliminating the landfilling of plastic waste by 2020 it is estimated that 80 Mt of plastic waste would be prevented from going to landfill, an amount representing about 1 billion barrels of oil or €70 billion (if 1 barrel = $100 and $1 =€0.70)" (PlasticsEurope 2013c, p. 4). A consequential positive effect of such a circular economy is the creation of green jobs and sustainable value. The estimated potential when increasing the recycling rate of plastics to 70% by 2020 is to create 162,018 jobs in the EU (Friends of the Earth 2010, p. 31). Calculating the numbers for the automotive industry based on the figures from PlasticsEurope (2013c, p. 86), European Commission DG ENV et al. (2011), the potential when recycling the 996,000 t of landfilled automotive plastics in 2008 is worth €871.500 million. When including the currently energy recovered automotive plastics (139,000 t in 2008), leading to 1,135,000 t, the potential value rises to €993,125 million, which could create 10,555 new jobs in 2020, when calculating 9.3 new jobs per 1000 t recycled material in the EU-27 in 2020 provided to (Friends of the Earth 2010, p. 22).

But currently this potential is not yet harvested. Therefore, we need holistic and future-oriented thinking to transform our economy for the better and to harvest its potential. We need a change in mind.

> …recycling appears to be the one mid-term challenge to be confronted worldwide. This implies not only developing recyclable materials with sufficient performance but also introducing recyclable automotive parts. (Weill et al. 2012, p. 6)

The outcome of the presented theoretical analyses highlights that further investigation on this topic is vital, especially on the ecological sustainability of plastics in the automotive sector, the reasons for the low usage of recycled plastics and the automotive plastics recycling rate, and the ecological sustainability challenges and trends of the automotive plastics production and recycling system at that time. Accordingly, the research questions of this book have been designed to answer this call (see Chap. 1). These questions are dealt with in the following empirical part of this book.

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Chapter 4
What Do the Experts Say? The Survey Results About Automotive Plastics and Recycling

Abstract Cash-hungry managers versus real-world sustainability. Is this the case in the automotive plastics and recycling industry? To find out, a survey was conducted throughout Europe covering all the key players, ranging from virgin plastics producers, automotive industries including OEMs and suppliers, shredders, and recyclers as well as research institutions. In this chapter, the survey results are outlined and cross-checked with the results of the experts workshop. By doing so, quantitative data from the survey is merged with qualitative data from the workshops increasing the real-world representation. This approach enables the investigation of the reasons for the insufficient implementation of recycling in the car life-cycle as outlined in the previous chapters, and to ultimately provide solutions to advance the circular economy of automotive plastics.

What Do European Experts Say About Automotive Plastics Recycling?

To investigate the reasons for the insufficient implementation of recycling in the car life-cycle as outlined in the Chap. 3, and to ultimately provide solutions to advance the circular economy of automotive plastics, the following survey was conducted in 2014 within Europe covering all the key players in the automotive plastics production and recycling system, ranging from virgin plastics producers, automotive industries including OEMs and suppliers, shredders, and recyclers as well as research institutions. For more detailed information on the methods, please refer to Chap. 8. In the following, the survey results are described and supported by the results of the experts workshop, which was conducted to validate and discuss the survey results. By doing so, quantitative data from the survey is merged with qualitative data from the workshops increasing the real-world generalisability. Now focussing on the survey results, it should be mentioned that the original groups from the survey were clustered into the following group clusters[1], for the sake of reducing complexity (Table 4.1):

[1] The original survey group 'association' is 'association, cluster, interest group, research institute automotive/recycling/plastic'.

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Table 4.1 Clustering of survey groups

Clustered group	Original groups in the survey
Automotive industry	= OEM + Supplier + Association
Recycling industry	= Recycler + Association recycling
Virgin plastics industry	= Virgin plastics producer + Association plastic
Academia, science, research	= Academia, science, research
Politics	Excluded due to low number of participants

Unfortunately, several participants selected 'other' when deciding on the groups and wrote, for example, 'distributor' or 'technical consultant', and could therefore not be used at all. The survey statistics were calculated on the basis of Fisher (1970) and Zimmermann-Janschitz (2013) with a renowned and popular statistics program and visualised with a popular tabular software. In this survey, most questions are closed with given response options to enable quantification and statistical calculations. Most importantly, the results are genuine without any attempt to perform p-hacking, thus distorting the outcome and design flaws are described to ensure maximum transparency. The results were checked for correlation and significant differences with the 'Pearson Chi Square test' between answers from the survey groups, and complete and incomplete questionnaires. There was no relevant correlation calculated, and only one relevant significance found (OEMs and suppliers on the question: 'Did you or your company investigate possible applications of recycled plastics in your products?') which revealed considerable, and to be honest unexpected agreement between the groups, especially between the virgin plastics producers and the recyclers, which is outlined in the survey.

4.1 Validation of Survey Data Through Expert Workshop

Because this survey's statistical representativeness is not to be determined in this research due to limited resources (see Chap. 8), the data gathered was validated and discussed within an expert workshop. Hosted at the Department of Geography and Regional Science, at the Karl-Franzens-University Graz in Austria, representatives of the automotive, plastics and recycling industry took part. These experts have exceptional expertise as they are representatives from large interest groups, associations, and clusters from each of the relevant industry branches. Additionally, experts from the ecological industry sector and from the academic field regarding geography and regional science, and systems sciences, innovation, and sustainability research opted in. As a result, the survey data was rigorously validated and discussed by a highly knowledgeable, heterogeneous, and critical group in a three-hour session. The qualitative comments of the experts on the quantitative research results are embedded in the descriptions of the survey results. However, the questionnaire results are now outlined in the following.

4.2 Demographic Data and Details About the Survey Participants

Demographic Information

The demographic questions revealed that 81% (120 people) of 149 participants are male, and 19% (29 people) are female (see Fig. 4.1). Regarding the age, the majority of participants is between 25 to 45 (53%), followed by 46 to 65 (43%), <25 (3%), and >65 (1%) (see Fig. 4.2). For easy differentiation, the demographic and personal data was not framed in contrast to the main questions.

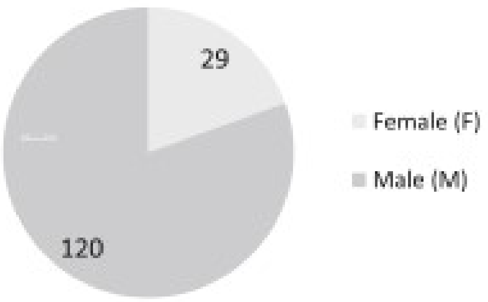


Fig. 4.1 Gender of the survey participants (n = 149)

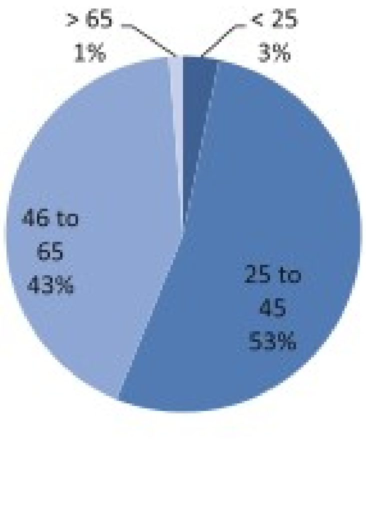


Fig. 4.2 Age of the survey participants (n = 155)

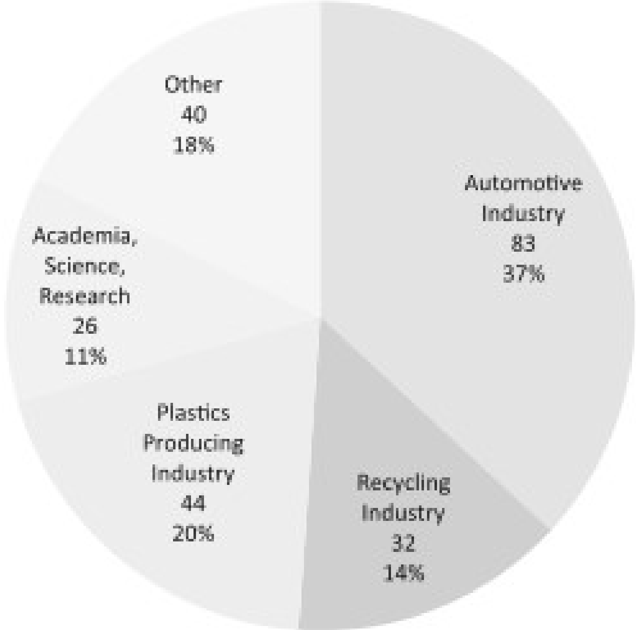


Fig. 4.3 The clusters of survey participants (n = 225), with the total number and the percentage below

Professional Information

The participating groups of the survey are primarily subject to the level of interest for participating in the survey and hugely different numbers of employees (see Chap. 8), which caused a non homogeneous distribution (see Fig. 4.3). The automotive industry is represented by 83 participants and is the largest group. The plastics producing industry accounted for 44 participants, the recycling industry for 32, and 26 experts participated from the scientific community. Unfortunately, 40 participants did not choose from the given possibilities regarding their type of employer or institution but chose 'others'. These could not be taken into account, due to lack of clarity. For example, several participants declared to be a 'consultant', or 'service provider'. As a result, the 'others' were excluded in the statistical calculations.

The above-mentioned groups or clusters were developed to draw clear and comprehensible conclusions by clustering the related branches. The automotive cluster, for example, is primarily consisting of members from automotive suppliers and automotive plastics converters (48 participants), and automotive assemblers/OEMs (30 participants). In addition, 5 people from an automotive focussed association, cluster, interest group or research institute took part, as depicted in Fig. 4.4.

The plastics group is composed of 32 virgin plastics producers and 12 from plastics focussed associations, clusters, interest groups, and research institutes (see Fig. 4.5). The high share of the latter is in strong contrast with the automotive and recycler

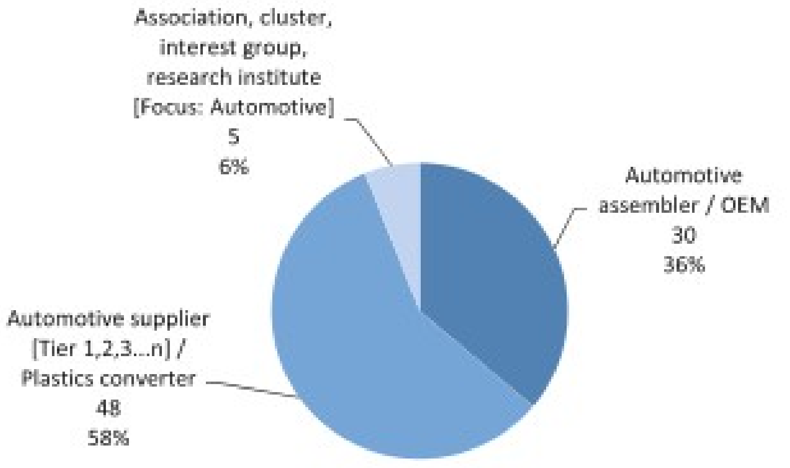


Fig. 4.4 The automotive groups of the survey (n = 83), with the total number and the percentage below

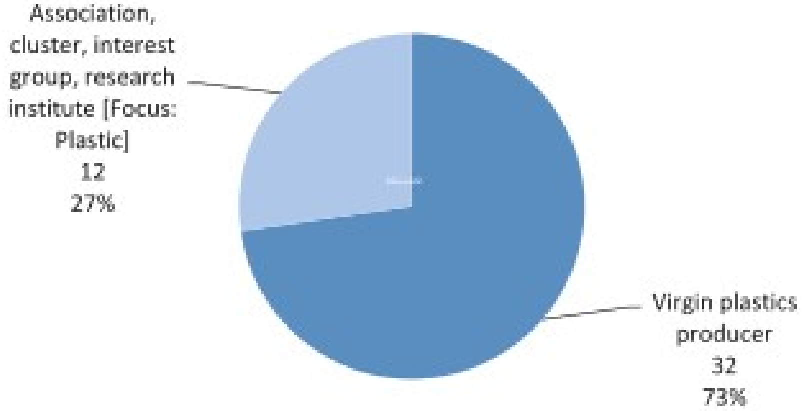


Fig. 4.5 The plastics groups of the survey (n = 44), with the total number and the percentage below

groups, and suggests a higher focus on research, networking, and cooperation in the plastics branch. However, due to that number of participants, this is only a presumption which was supported by the findings and experience during this book.

The recycling group is composed of 31 recyclers and shredders of plastics including other materials and goods as well. Just 1 participant is from a recycling focussed association, cluster, interest group, or research institute (see Fig. 4.6).

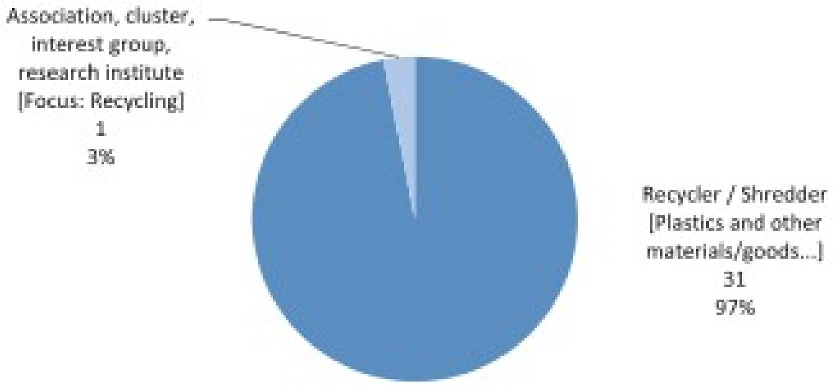


Fig. 4.6 The recycling groups of the survey (n = 32), with the total number and the percentage below

4.3 Automotive Plastics Recycling and Recycled Plastics

General Questions to all Survey Participants

This set of questions is composed of the opinions and the knowledge of the automotive, the plastics, the recycling, and the scientific groups together and represents the overall status quo and the trend of the plastics production and recycling system in the automotive sector. However, statistically significant differences between the four groups are presented as well, but the groups are in accord on most questions, which was very surprising to the author.

The first question concerns the trend of automotive plastics usage in the year 2020, which revealed that the share of plastics in cars is very likely to rise significantly in the future (Fig. 4.7), as the majority (65%) claims that in the year 2020, the average share of plastics by weight in new cars in Europe will rise to a minimum of 21%. Furthermore, more than 26% of the survey participants say that the share will rise to exceed 30%. In 2010, this share was 16%, according to Weill et al. (2012) (see Fig. 3.17). The experts from the workshop mentioned that not just plastics will increase, but plastics in a mixture of materials for lightweight construction and low costs. Furthermore, high strength steel was considered a considerable competitor with plastics. Additionally, the experts asked how 'plastics' were defined and how CFRP is classified. These are legitimate questions, however due to limited space and time in the survey, certain definitions such as 'sustainable materials' or 'plastics' were not given. In addition, CFRP—carbon fibre reinforced plastics can be included within 'plastics' or labeled as 'composites'. This aspect could be improved for further research, but then many more participants would have exited the survey prematurely due to an increased length and mental demand. In this case, CFRP was and is considered a plastic material. However, a suitable definition is provided in Sect. 3.1:

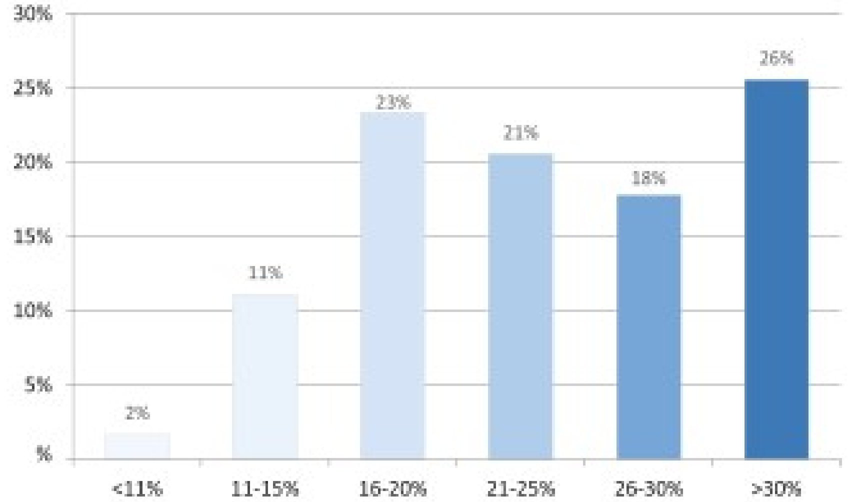


Fig. 4.7 The average share of plastics (including thermosets, without rubber) by weight in new cars in Europe will be in 2020 at…(n = 180)

> A plastic substance; specifically: any of numerous organic synthetic or processed materials that are mostly thermoplastic or thermosetting polymers of high molecular weight and that can be made into objects, films, or filaments (Merriam-Webster's Collegiate® Dictionary 2017)[2]

Interpretation: The share of plastics (including thermosets, without rubber) by weight in new cars will further rise till 2020.

In regards to asking about ecological sustainability and materials in general (see Fig. 4.8), 81% of those questioned consider sustainable materials a competitive advantage. The sustainability could be achieved for example through generally ecofriendly and CO_2 reduced production. This result reveals that sustainability is an economic competitive advantage factor in selecting materials.

Interpretation: 81% consider sustainable materials (CO_2 reduced production, generally eco friendly,…) a competitive advantage.

The next question was designed to elaborate on the attractiveness of sustainable materials in the future. According to 67%, consumers will demand more sustainable materials in cars in the year 2020 (see Fig. 4.9). The experts from the workshop criticised that 'sustainable materials' were not defined in detail. However, they concluded that the common definition in this survey at that time was that sustainable materials in this context are recycled and renewable virgin materials, which are holistically and generally deemed sustainable. In addition, the experts mentioned that not the consumer, but the law was the driving force as well as whether the actual consumer

[2]By permission. From Merriam-Webster's Collegiate® Dictionary, 11th Edition ©2017 by Merriam-Webster, Inc. (www.Merriam-Webster.com).

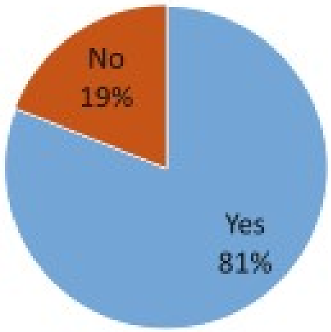


Fig. 4.8 Do you consider sustainable materials (CO_2 reduced production, generally eco friendly…) a competitive advantage? (n = 195)

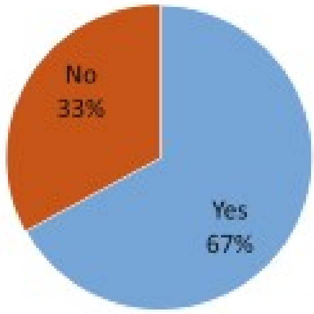


Fig. 4.9 Do you think the consumer will demand more sustainable materials in cars in the year 2020? (n = 167)

demand and the statements of the survey participants do match. This would require another book. The experts said that awareness raising is needed for the consumers before they can demand more sustainable materials. But the question is: Who does it? One solution would be holistic eco-labeling (similar to the energy labeling of refrigerators) and that the car sellers should offer such data for the consumer. However, there has to be made a difference between the various consumer types, because a typical SUV driver is not concerned with this issue, but in contrary, the 'early adopters' such as Tesla, BMW i and Toyota Prius drivers are concerned.

Interpretation: The consumer will demand more sustainable materials in cars in the year 2020.

Consequently, 74% say that marketing with recycled plastics will be beneficial in the year 2020 (see Fig. 4.10).

Interpretation: Marketing with recycled plastics will be beneficial in 2020.

Focussing on the attractiveness of recycled plastics, 93% of those questioned stated that increasing the share of recycled plastics in new cars is positive (see Fig. 4.11). The experts from the workshop mentioned that when carsharing increases, the argument 'our fleet is sustainable and is made from sustainable materials' could be more important than right now, where other factors are more important for the individual.

Now to focus on recycled plastics within the notion of sustainable materials, 87% of 184 survey participants state that recycled plastics can compete with virgin plastics

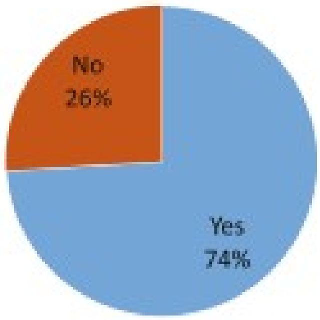


Fig. 4.10 Do you think that marketing with recycled plastics (e.g.: 'Our product is made from 'RxPLAST'') will be benefical in 2020? (n = 162)

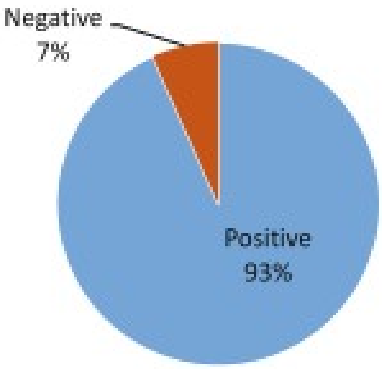


Fig. 4.11 Increasing the share of recycled plastics in new cars is…(please state your opinion) (n = 150)

(see Fig. 4.12). Still, only 7% say that recycled plastics can replace virgin material in all applications. The majority claims that recycled plastics can compete in numerous applications (33%) or in some applications (47%). Only 7% think that virgin material cannot compete, and 7% are unsure. This shows that currently, recycled plastics are not or are not regarded as providing equal performance compared to virgin plastics.

Interpretation: recycled plastics can compete with virgin plastics in various applications.

Moreover, numerous survey participants commented on this question, highlighting several facts concerning the usage of recycled plastics. The most stated notion (which was paraphrased by the author), is that only the material specification is relevant, but not the origin. Whether the plastic is virgin or recycled material is according to four survey participants of no relevance. Three of those questioned claim that the performance of recycled plastics decreases after several cycles of recycling, which ultimately leads to material downcycling, three other participants mentioned that recycled plastics are only suitable for parts with lower requirements. Another frequent comment was that in order to advance the competitiveness of recycled plastics, constant supply and constant high-performance material properties have to be achieved.

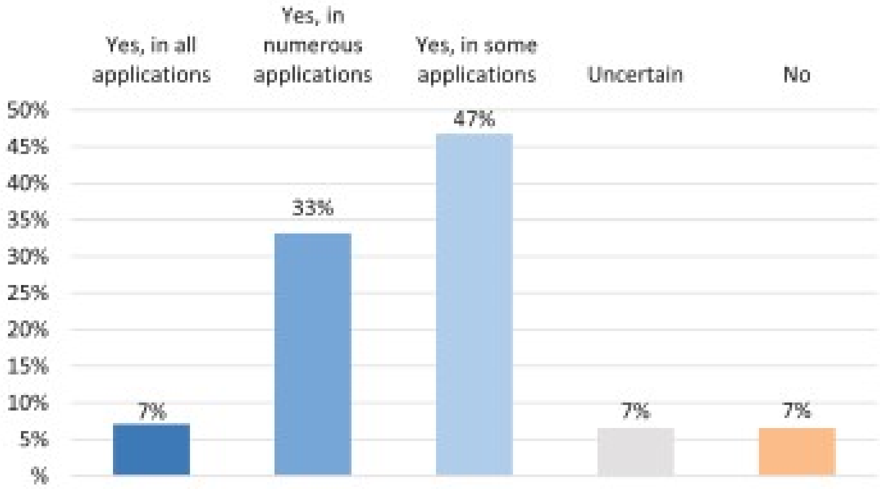


Fig. 4.12 Do you think recycled plastics can compete with virgin plastics? (n = 184)

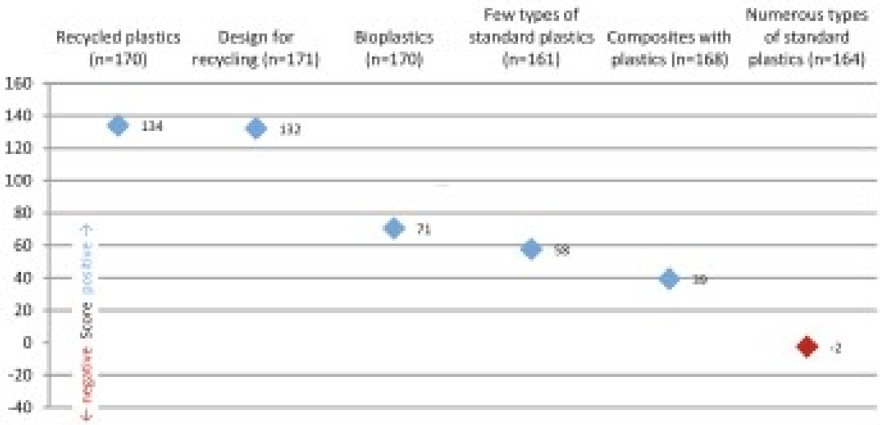


Fig. 4.13 What do you think about the following plastic materials and technologies concerning their potential to increase or decrease the sustainability over the whole life-cycle of cars? - Score

The next question was designed to reveal the opinions on ecological sustainability in the automotive sector concerning plastic materials and technologies (see Fig. 4.13). The calculated[3] score shows that recycled plastics and design for recycling have the most significant potential to increase the ecological sustainability of cars over the whole life-cycle, when focussing exclusively on materials. The single negative score is 'Numerous types of standard plastics', which means that this option is perceived as decreasing to decrease ecological sustainability.

[3]The scores were calculated using the following scoring system: 'Increase sustainability' = +2; 'Slightly increase' = +1; 'no change' = 0; 'slightly decrease' = −1; 'decrease sustainability' = −2.

Interpretation: Recycled plastics and Design for recycling have the highest potential to increase sustainability.

This score can also be regarded as a plastics sustainability hierarchy:

1. Recycled plastics
2. Design for recycling
3. Bio plastics
4. Few types of standard plastics
5. Composites with plastics
6. Numerous types of standard plastics

To discover the positive and negative aspects of recycled plastics in comparison to virgin plastics, several factors were analysed. A combined overview through a calculation of the respective scores is depicted in Fig. 4.14. The majority of the survey participants indicate that using recycled plastics instead of virgin plastics in the automotive sector decreases the performance and the homogeneity of the plastic materials, leading to a decrease up to virtually no change of the quality of products. Further, the health and quality of life of waste industry workers is unchanged. Additionally, the majority of the survey participants indicate that using recycled plastics instead of virgin plastics in the automotive sector firstly decreases the quality of the products and the plastic materials; secondly, it decreases the material costs but not the final product price for the end-consumer; thirdly, it decreases the dependency on and the depletion of fossil fuels significantly, and decreases the life-cycle CO_2 emissions of the plastics. Furthermore, the biggest positive impact of using recycled instead of virgin plastics concerning CO_2 emissions is in the production phase, followed by the end-of-life phase. Additionally, recycled plastics decrease the land degradation and the number of waste plastic particles in the environment.

In order to further understand the pro- and counter-arguments for recycled plastics, firstly, the five main reasons why industrial customers purchase recycled plastics and secondly, what five main reasons limit the use of recycled plastics was questioned in the survey. Some might argue that the formulation of these two questions was unfortunate due to a problematic comparison of ‘reasons to purchase’ and ‘reasons that limit the use’. This is acceptable as the ‘reasons to purchase’ are similar to the ‘reasons that enable the use’, and the ‘reasons that inhibit the purchase’ are similar to the ‘reasons that limit the use’. However, the reasons why industrial customers purchase recycled plastics are as follows (see Fig. 4.15). The most important of the five top reasons to purchase recycled plastics for industrial customers is the factor ‘costs’. More interestingly, the second most chosen reason is ‘marketing benefits/positive impact on CSR’, which was not foreseen by the author. The next factors in the top-five are ‘demand from the end-consumer’, ‘available quantity’ and ‘recyclability’. The experts from the workshop discussed whether ‘recycling’ refers to ‘in-house recycling’ during the production within the company or ‘post-consumer recycling’. In fact, it does not matter, because both are considered. The group stated that around 80% of recycled plastics is made from production waste due to maximum purity and unmixed sources. Further, the experts claimed that the high score of the ‘demand from

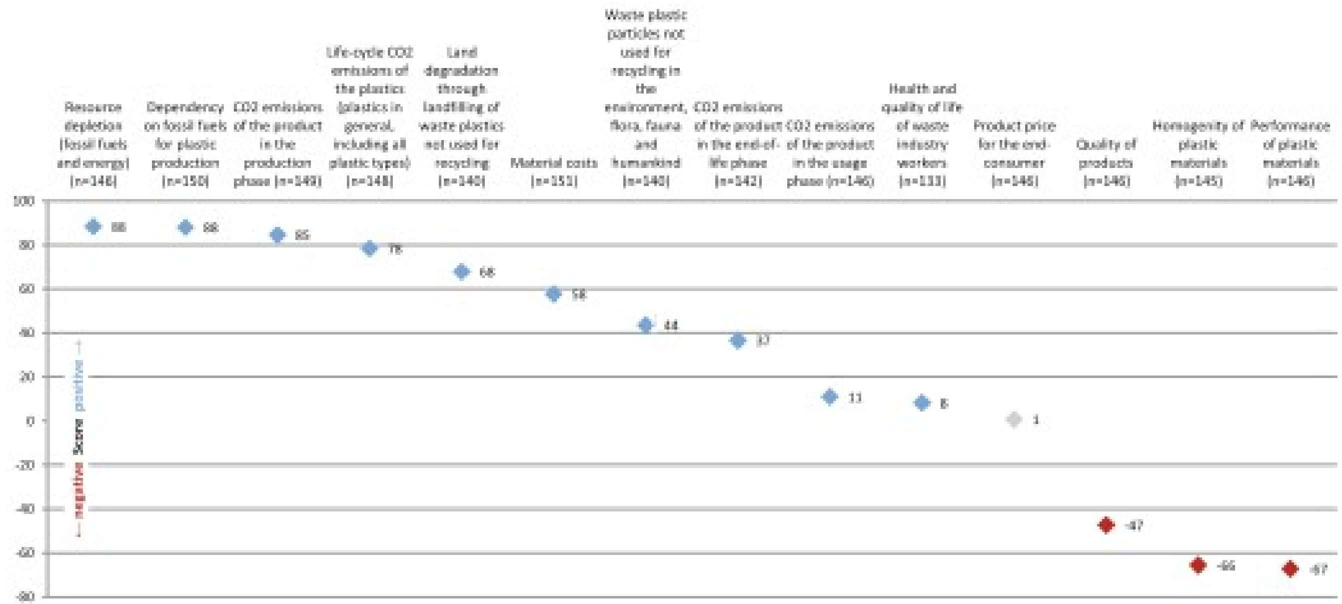


Fig. 4.14 The use of recycled plastics instead of virgin plastic in the automotive sector…- Score
Interpretation: The main positive impacts when using recycled plastics focus on reducing the CO_2 emissions and on decreasing the land degradation and the number of waste plastic particles in the environment

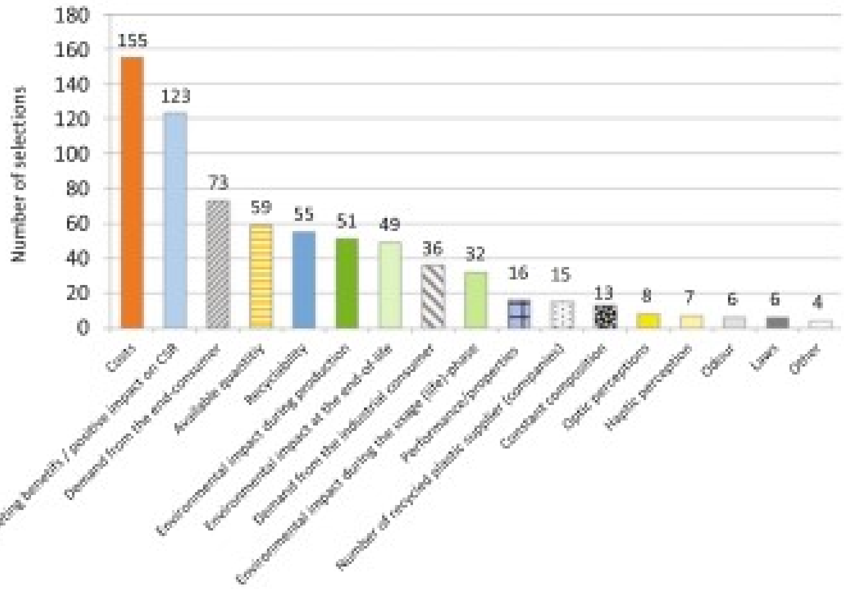


Fig. 4.15 What are the five main reasons industrial customers purchase recycled plastics? (n = 181, answers were given)

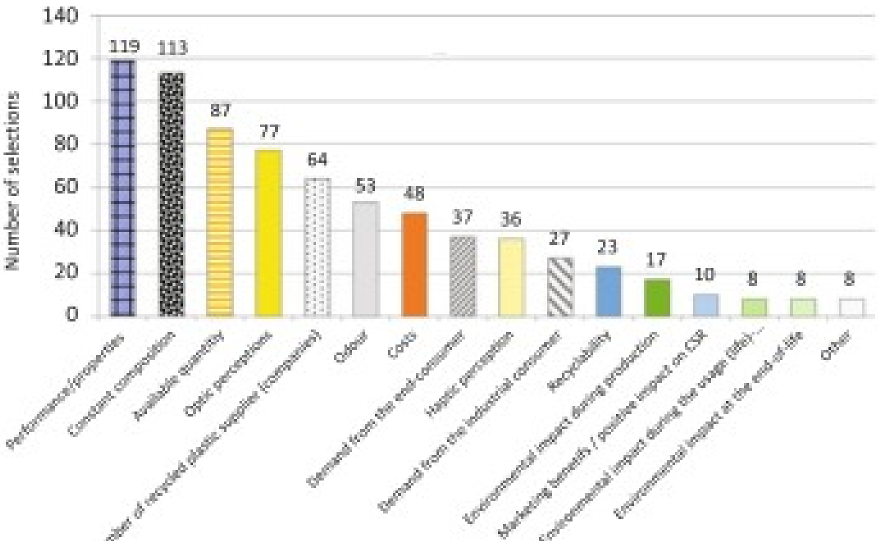


Fig. 4.16 What are the five main reasons that limit the use of recycled plastics? (n = 176)

the end-consumer' is doubtable, because BMW for example creates this demand with the i-series, as the demand for recycled plastics is just a sub-factor to date.

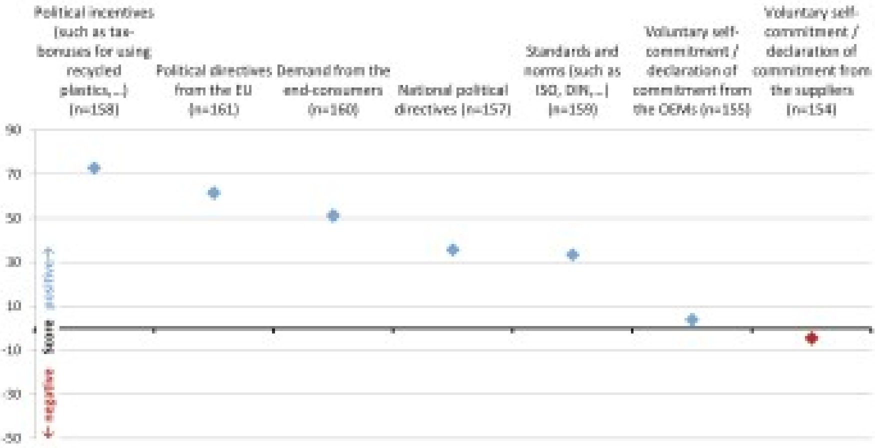


Fig. 4.17 In 2020, what do you think will be the best driver to increase the usage of recycled plastics? - Score

Interpretation: Economic aspects are the main reasons for recycled plastics.

The five main reasons that limit the use of recycled plastics (see Fig. 4.16) are headed by 'performance/properties' and 'constant composition'. The next limiting factors are 'available quantity', 'optic perception', and 'number of recycled plastic suppliers (companies)'. The most striking factor when comparing the limitations and the pro-arguments (see Fig. 4.15) for recycled plastics is that the 'available quantity' is in the top-five of both the list of limiting factors, and in the list of enabling factors. The experts from the workshop stated that the existing supplier contracts lasting for years might be an obstacle for using recycled plastics, because the OEM knows the supplier, the (constant) product performance, the costs, and so forth. But the OEM has (mostly) no experience with recycling plastics suppliers.

Interpretation: Performance and supply are the main obstacles for recycled plastics.

The most promising drivers to increase the usage of recycled plastics in 2020 (see Fig. 4.17) are 'political incentives (such as tax bonuses for using recycled plastics)' followed by 'political directives from the EU'. In third place is the 'demand from the end-consumers' followed by 'national political directives' and 'standards and norms (such as ISO, DIN,…)'. The worst drivers are 'Voluntary self-commitment/declaration of commitment from the OEMs' and 'voluntary self-commitment/declaration of commitment from the suppliers'. The expert group discussed which company will be the pioneer and brave enough to rely on recycled plastics, also because of the stability of the company. Additionally, they implied that politics should move away from the recycling and recovery quotas. Instead they should introduce quotas for the production of materials. For example, politics should prohibit hazardous substances and stipulate to use at least 20% recycled materials to companies. As a result, a new directive for prohibition of substances (harzardous and virgin) could be implemented. Additionally, the usefulness of the ELV-Directive was questioned. Possibly it is unhelpful because of the considerable export of ELVs. Moreover, the expert group concluded that politics might have no opinion, or should or even must not have an opinion. This might also be represented by the missing feedback and the rejection from politics in survey. Possibly, this issue is not yet considered important enough.

Interpretation: Politics and the end-consumer have biggest influence on increasing the share of recycled plastics.

Intermediate conclusion concerning pro and con of using recycled plastics: The five main reasons for industrial customers to purchase recycled plastics are costs, marketing benefits, demand from the end-consumer, the available quantity, and the recyclability. In short, finance driven aspects are the predominant reason for purchasing recycled plastics. On the contrary, the five main reasons that limit the usage of recycled plastics are performance, constant composition, available quantity, optic perceptions, and the number of recycled plastic suppliers. In short, technology driven aspects and the supply are the most important reasons limiting the usage of recycled plastics.

4.4 Special Information from the Survey Groups

4.4.1 The Survey-Automotive Group

The automotive group of this survey is the largest with 83 participants, which is dominated by the automotive suppliers (58%), followed by the automotive assemblers or OEMs (36%), and finally the automotive focussed associations, clusters, interest groups, and research institutes (6%) (see Fig. 4.18).

For the automotive group, a fundamental question was used to discover possible inhibitions concerning reasoning in the material decision process (see Fig. 4.19). When asked about the importance of three aspects in the decision making process for materials in the automotive branch, the majority indicated that the facts, such as cost, performance, the life-cycle assessment,…etc. are very important (69%) or important (26%). Another aspect, the formalities, such as request formst and certification processes, is rated very important by 21%, and important by 43%. Further, the experience with the material is primarilty rated as very important (39%), and important (46%). This results in a hierarchy starting with 'facts', followed by 'experience', and finally 'formalities', rendering all of these aspects central for the material decision making process. Moreover and strikingly, the importance of formalities shows that the bureaucracy is indeed an essential factor.

The experts from the workshop said that another critical aspect is whether the material suppliers are already in contract with the OEM, or the Tier 1, 2,…, n suppliers, because if so, it strongly influences the material decision making process.

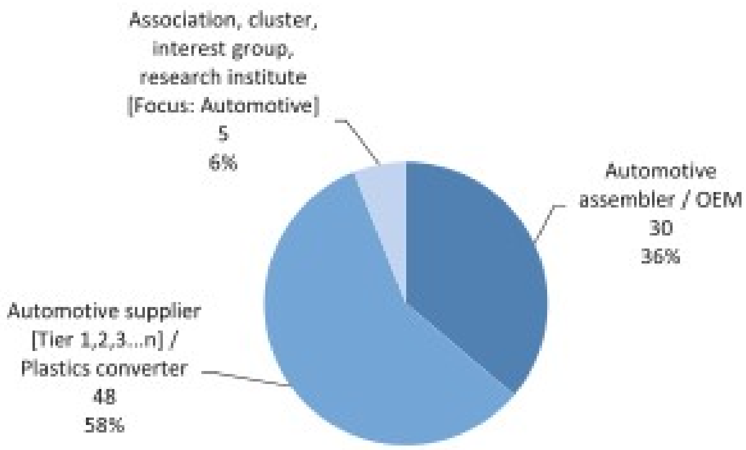


Fig. 4.18 The automotive groups of the survey (n = 83)

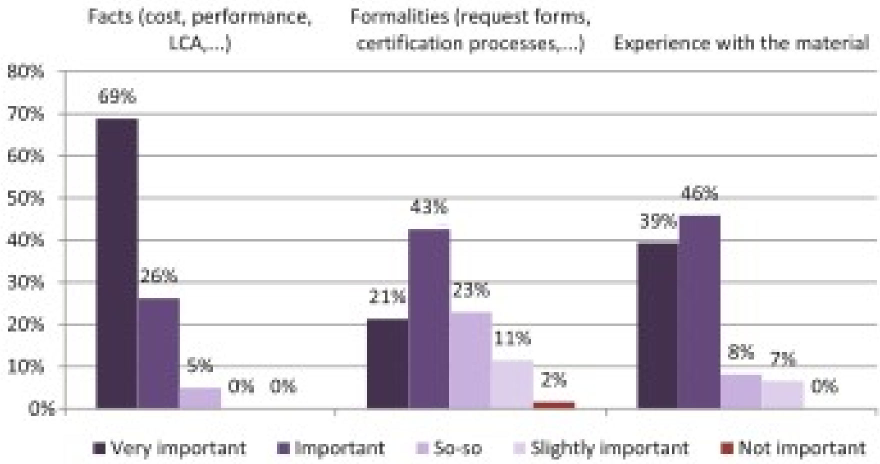


Fig. 4.19 How important are the following aspects in the decision making process for materials in the automotive branch? (n = 61)

Interpretation: Facts and experience crucial, but formalities are also important for deciding on materials.

Consequently, after elaborating on the material decision making process in the automotive sector, it is essential to understand the existence or availability of facts concerning the application of recycled plastics (see Fig. 4.20). 77% of those questioned state that they or their company did investigate possible applications of recycled plastics in their products, and 23% indicated that they did not.

Interpretation: Most have investigated possible applications of recycled plastics, OEM more than supplier.

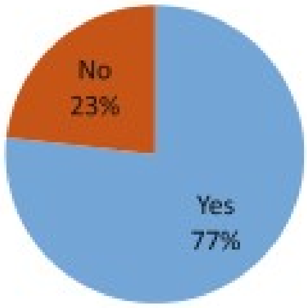


Fig. 4.20 Did you or your company investigate possible applications of recycled plastics in your products? (n = 56)

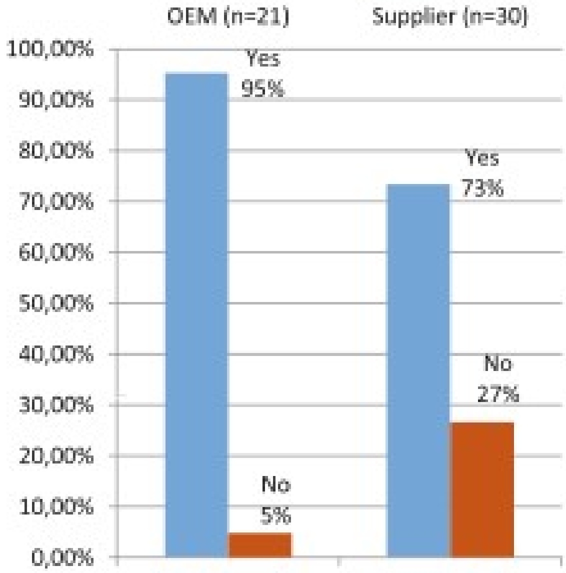


Fig. 4.21 OEM and supplier on question: Did you or your company investigate possible applications of recycled plastics in your products?

Besides the considerable lack of enquiries on recycled plastics, the difference between the OEMs and the suppliers was significant[4] (see Fig. 4.21). Whereas 95% of the questioned OEM employees or their company did investigate possible applications of recycled plastics, only 73% of the suppliers did the same. However, when concerning the number of companies and their employees, the difference between the OEMs and the suppliers gives rise to the suspicion that supplier companies with less employees might not have the resources for intensive material research as OEM companies with thousands of employees do.

Moving from the willingness to investigate recycled plastic materials, the actual usage is now of concern. 68% of those questioned or their companies use recycled plastics in the production of their products (see Fig. 4.22). In comparison to the investigation of possible applications of recycled plastics (see Fig. 4.20), the minor

[4]Statistical significance: 0.043, asymptotical significance (2-sided), Pearson Chi Square test.

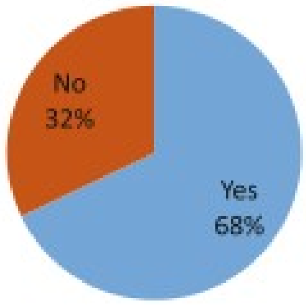


Fig. 4.22 Do you or your company use recycled plastics in the production of your products? (n = 53)

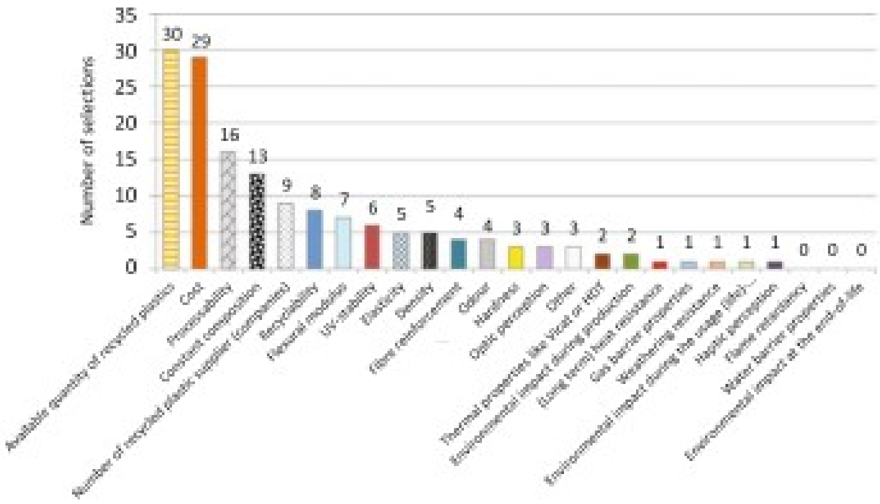


Fig. 4.23 Which 5 most important factors made the usage of recycled plastics feasible? (n = 35)

difference of 9% indicates that once recycled plastic materials were investigated, the chance to use recycled plastics is considerable.

Depending on the usage of recycled plastics, the participants were asked about the reasons for and against the recycled plastics. The five main reasons to purchase recycled plastics are 'available quantity of recycled plastics', followed by 'cost', 'processability', 'constant composition', and 'number of recycled plastic suppliers' (see Fig. 4.23). However and in strong contradiction, the five main reasons that limit the use of recycled plastics are also headed by 'available quantity of recycled plastics', followed by 'optic perception', 'constant composition', 'number of recycled plastic suppliers', and 'hardness' (see Fig. 4.24).

The experts from the workshop stated that the cost/performance relationship, the price of the raw materials and the problem of overcapacity of crude oil/virgin plastics are additional factors which could be included in the reasons for recycled plastics.

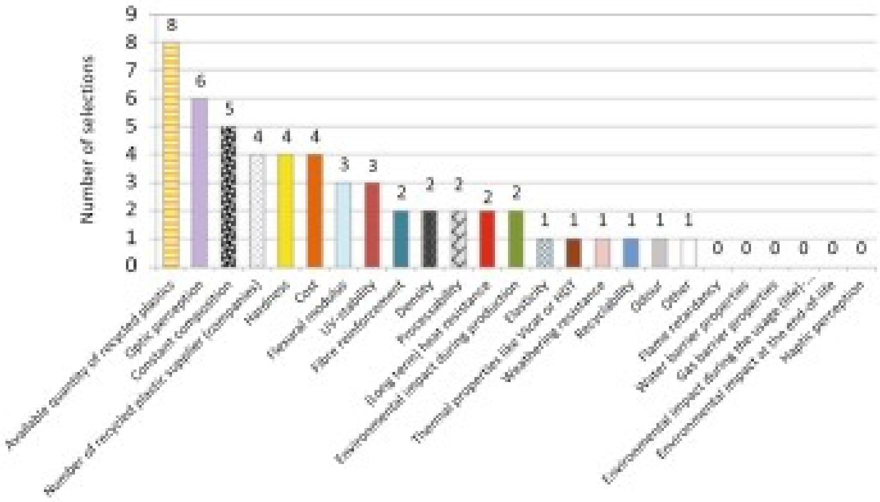


Fig. 4.24 Which five most important factors made the usage of recycled plastics not feasible? (n = 13)

Additionally, political quotas might be an important obstacle as well and included in the reasons against recycled plastics.

Interpretation: Available quantity and costs are the most important factors for using recycled plastics.

Interpretation: Quantity, and supply, as well as material properties are the most important obstacles for using recycled plastics. This contradiction with the factors in favour of recycled plastics might be dependent on the choice of supplier(s), because one company might have found and chosen suitable suppliers, whereas another company might not have.

In order to go into details concerning the usage of recycled plastics in the automotive industry, the survey participants were asked what the actual (not maximum) average percentage of recycled content is in their products (see Fig. 4.25). 37% stated that less than 5% recycled plastics are used, 26% stated that it is between 6–10, and 16% indicated 11–15%. The remaining participants said that it is ranging from 16–20% (9%), 21–25% (5%), whereas 0 chose 26–30 and 7% stated that they use more than 30% of recycled content. In fact, 63% use less than 10% of recycled content in plastics for their products.

Interpretation: 63% say "less than 10% of recycled material in automotive plastics".

To discover possible trends in the usage of recycled plastics in the automotive sector, the survey participants were asked about their future with recycled plastics (see Fig. 4.26). 88% of those questioned said that their company plans to increase the share

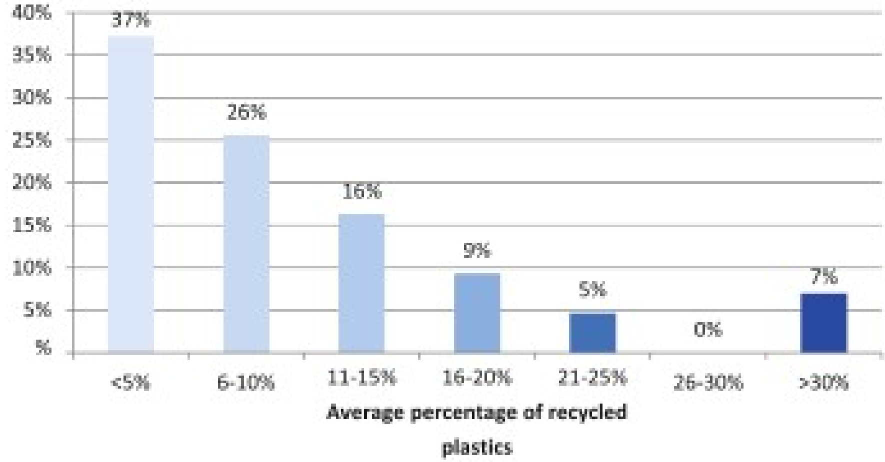
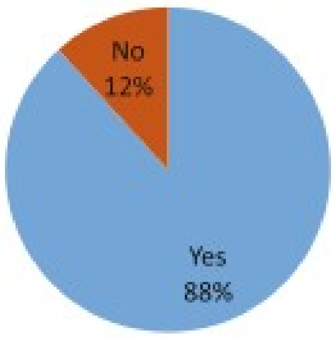


Fig. 4.25 What is the actual (not maximum) average percentage of recycled content in plastics in your products? (if the plastic material is 10% recycled plastics and 90% virgin plastics, please pick '6–10%') (n = 43)

Fig. 4.26 Does your company plan to increase the share of recycled plastics in new cars or car parts till 2020? (n = 34)



of recycled plastics in new cars or car parts until 2020. This indicates a considerable increase of the implementation of recycled plastics in the automotive sector overall.

Interpretation: 88% of the automotive companies plan to increase the share of recycled plastics.

4.4.2 The Survey-Recycling Group

The recycling group of this survey is the smallest with 32 participants, which is dominated by the recyclers and shredders (97%), followed by the recycling focussed associations, clusters, interest groups, and research institutes (3%) (see Fig. 4.27).

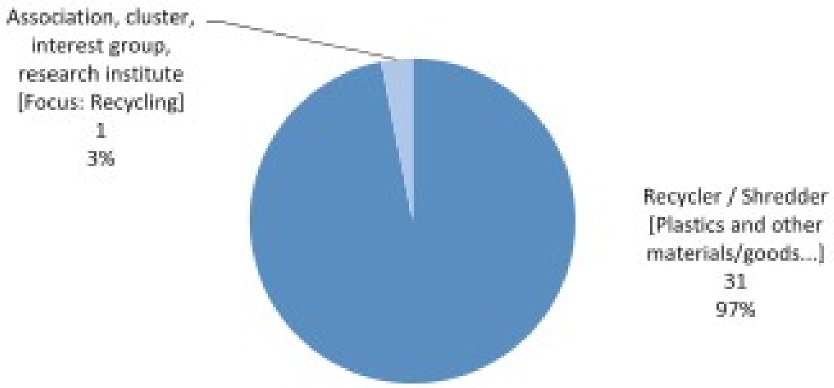


Fig. 4.27 The recycling groups of the survey (n = 32), with total number and the percentage below

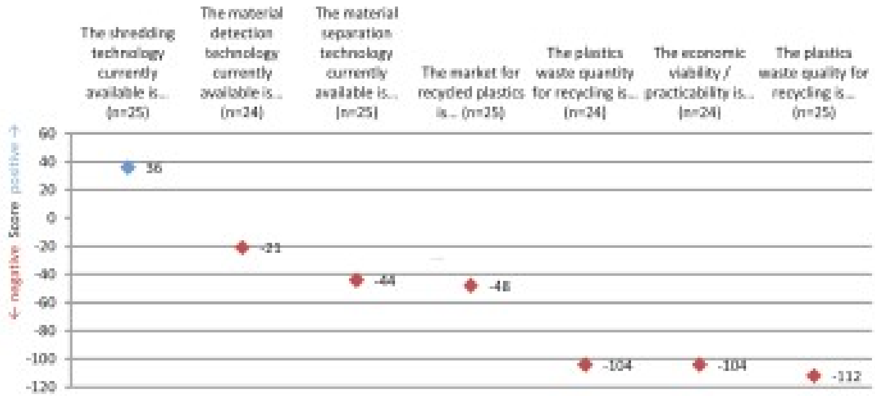


Fig. 4.28 What are the challenges of ELV plastics recycling? - Score

The following question is concerning the challenges of end-of-life vehicle plastics recycling. When calculating each score[5] for each challenge, the following ranking (see Fig. 4.28) is revealed.

The experts from the workshop explained that highly advanced technology is currently only available in the laboratory. Furthermore, the input quantities are too low for one company. The question of the industrial customer of recycled plastics is also of concern. Therefore, it is advisable to allocate the material fractions to specialised companies because one recycler for everything is not recommendable. In fact, several specialised companies are the solution. Moreover, another challenge is the cleaning (washing) of the input material, which is very demanding.

[5] The scoring system for the calculation: Very good = +2, Good = +1, Fair = −1, Poor = −2; then multiplying with the percentages.

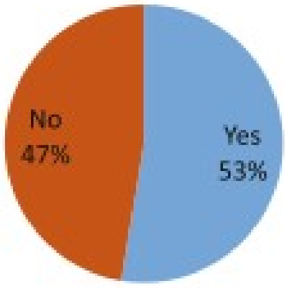


Fig. 4.29 Did you or your company investigate possible applications of recycled plastics in the automotive industry? (n = 19)

Interpretation: Only shredding technology is rated positively.

To discover possible trends in the treatment of plastics waste from ELVs, the survey participants were asked about their prognosis for the year 2020. The experts from the workshop emphasised that the target is definitely 'no landfilling' in central Europe. The ranking for the ELV plastics waste treatments according to quantity, from the most dominant treatment type to the least dominant one, can be concluded as follows, in spite of sharp divisions:

Rank 1: Mechanical recycling (40%) followed by thermal (28%)
Rank 2: Mechanical recycling (48%)
Rank 3: Thermal energy recovery (29.2%) followed by re-use (25%)
Rank 4: Chemical recycling (41.7%)
Rank 5: Landfilling (62.5%)

When only focussing on the most dominant type in each rank, the following hierarchy is plausible:

Rank 1: Mechanical recycling
Rank 2: Thermal energy recovery
Rank 3: Chemical recycling
Rank 4: Landfilling

Moving from the ELV treatment to the usage of the recycled plastics, 53% of those questioned stated that they or their company did investigate possible applications of recycled plastics in the automotive industry (see Fig. 4.29), and 45% of those questioned stated that they or their company sell recycled plastics to the automotive industry (see Fig. 4.30). The experts from the workshop stated that OEMs and the automotive industry in general are a very good customer for recycling companies on account of long production cycles of cars, which ensure long-lasting and secure contracts.

Interpretation: Almost half of the recycling companies have investigated possible applications of recycled plastics in the automotive industry.

Interpretation: Nearly half of the recycling companies actually sell recycled plastics to the automotive industry, i.e. nearly as many as did investigate this selling point.

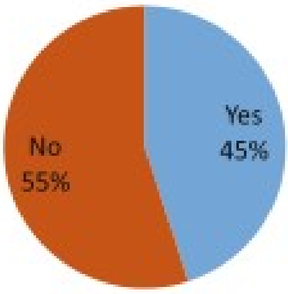


Fig. 4.30 Do you or your company sell recycled plastics to the automotive industry? (n = 20)

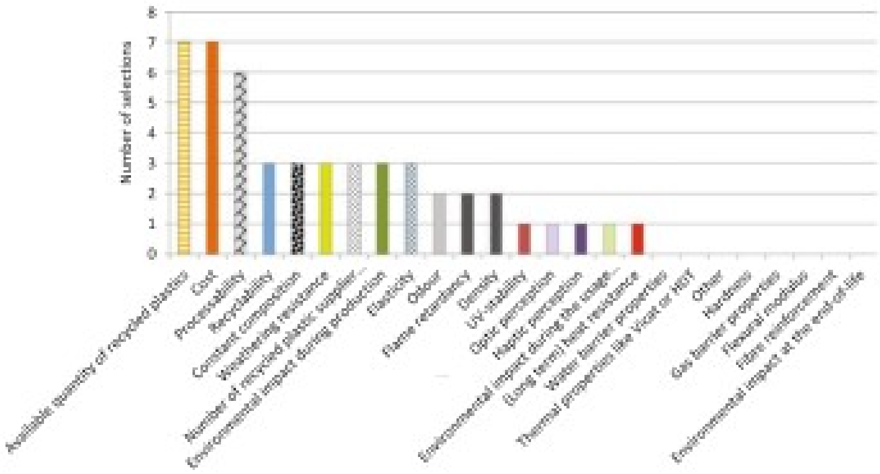


Fig. 4.31 Which factors made the selling of recycled plastics feasible? (n = 8)

Subsequent to the previous question about the selling of recycled plastics, now the reasons are of interest. As depicted in Fig. 4.31, the most selected factors which made the selling of recycled plastics feasible are 'available quantity of recycled plastics' and 'costs', followed by 'processability', 'recyclability', and 'constant composition'. When asking about the number of automotive customers for recycled plastics, 25% declared five, three, two, and one customer(s) respectively (N = 8, no diagram necessary) and when asking for the quantities in tonnes per year, 42.9% selected 2000 t per year and 14.3% each selected 200, 150, 100 and ten tonnes per year (N = 7, no diagram necessary). In contrast, or rather surprisingly similarly, the factors which made the selling of recycled plastics not feasible are 'available quantity of recycled plastics' and 'costs', followed by 'recyclability', 'constant composition', and 'weathering resistance' (see Fig. 4.32). However, the representativeness of this question is to be handled with care due to a small number of participants. The experts from the workshop mentioned that the quantity is important and bears risks, which might be caused by a lack of definition in the questionnaire.

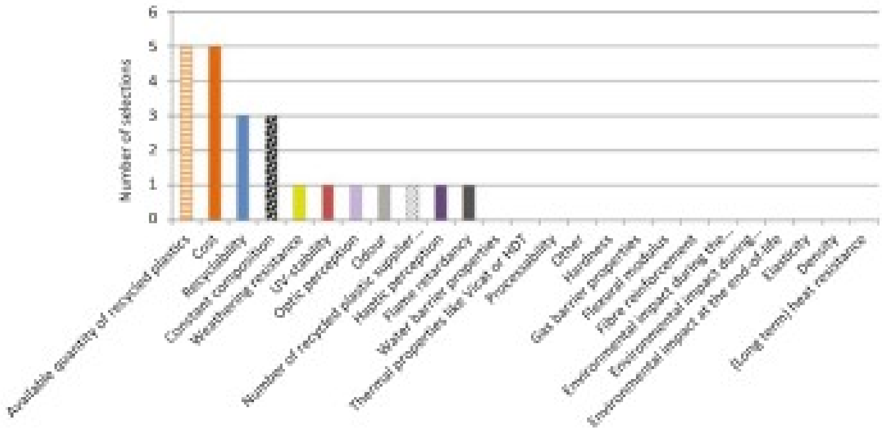


Fig. 4.32 Which factors made the selling of recycled plastics not feasible? (n = 9)

Interpretation: Quantity, cost, and processability made the selling of recycled plastics feasible.

Interpretation: Quantity and cost made the selling of recycled plastics not feasible.

4.4.3 The Survey - Plastics Group

The plastics group of this survey is the second largest with 44 participants, which is dominated by the virgin plastics producers (73%), followed by the plastics focussed associations, clusters, interest groups, and research institutes (27%) (see Fig. 4.33).

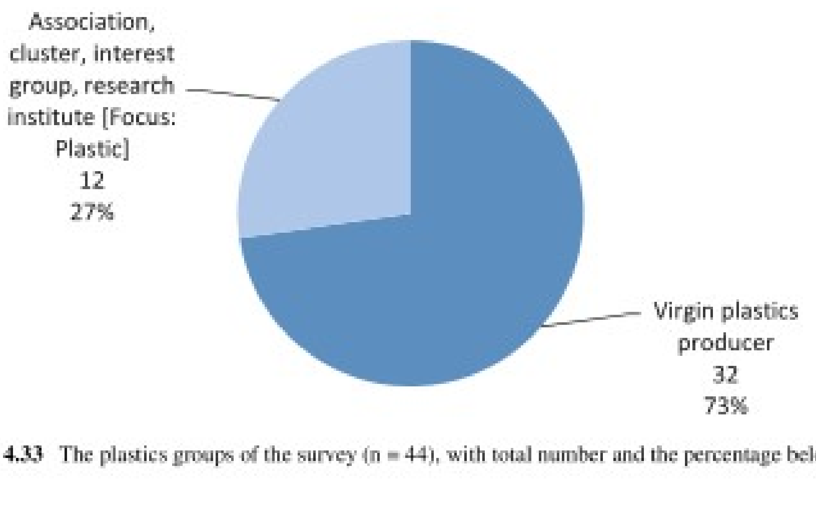


Fig. 4.33 The plastics groups of the survey (n = 44), with total number and the percentage below

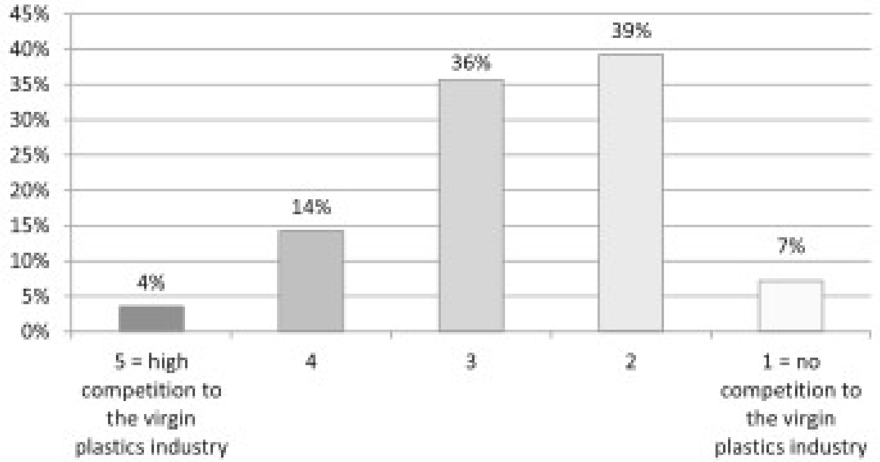
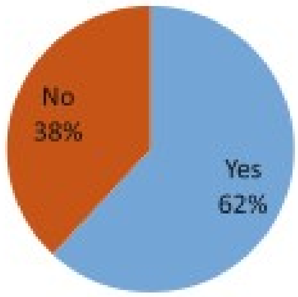


Fig. 4.34 How competitive do you think is the plastics recycling industry? [The plastics recycling industry is…] (n = 28)

Fig. 4.35 Do you think that recycling plastics is feasible/beneficial for your company? (n = 21)



Because recycling might be seen as a threat to the virgin plastics producers, a question about competitiveness was raised. The majority stated that the plastics recycling industry is in medium to minor competition with the virgin plastics industry, as 36% selected the medium option '3' and 39% the low option '2' on the 5 to 1 scale (see Fig. 4.34). The experts from the workshop summarised that virgin plastics producers do not think that the recyclers are real competition.

Interpretation: Most plastics producers state that the recycling industry is in medium to minor competition with the virgin plastics industry.

Furthermore, 62% of the plastics group say recycling plastics is feasible, or beneficial, for their company (see Fig. 4.35), which indicates a positive attitude towards recycling within the virgin plastics producing companies and institutions. The experts from the workshop said that the high percentage of yes-sayers is unusual.

As a next step, we take a closer look at the reasons why plastics recycling is practical, feasible, or useful for the company of those questioned (see Fig. 4.36). The majority (eight participants) indicate that the 'demand from customers' is key,

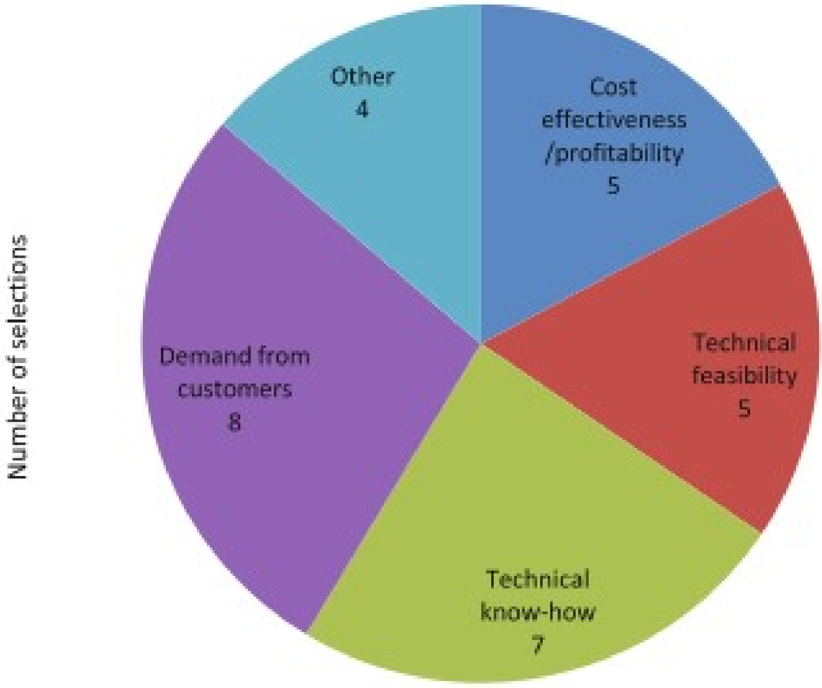


Fig. 4.36 Why is plastics recycling practical/feasible/useful for your company? (n = 10)

whereas seven state that the 'technical know-how' is the reason for the feasibility. Five each selected "technical feasibility" and 'cost effectiveness/profitability'. Within the 'other' responses, one states that "[r]ecycling of plastics should take place wherever eco-efficient and sustainable as per the waste framework directive. First prevent and plastics prevent wasting resources such as energy to make the cars lighter. Then re-use whenever possible. Then recycle when sustainable etc...)". A second one states that it is feasible "in 'non-car' industries", a third mentions "image", and another one "CSR".

The reasons why plastics recycling is not practical, feasible or useful for the companies of those questioned are the following (see Fig. 4.37). The majority (six participants) indicate that 'cost effectiveness/profitability' is the issue. Four mention the 'technical feasibility', three the 'demand from customers', and one each refer to the 'technical know how' and to 'risks, health concerns'.

Concerning the future outlook of recycling in the virgin plastics companies, the participants were asked whether their companies are considering going into or intensifying plastics recycling (see Fig. 4.38). Those questioned say 'yes' (16%) or 'rather yes' (32%). 21% are 'unsure' and 16% each state 'rather not' and 'no'. These results show that plastics recycling might be increasingly implemented within plastics producing companies.

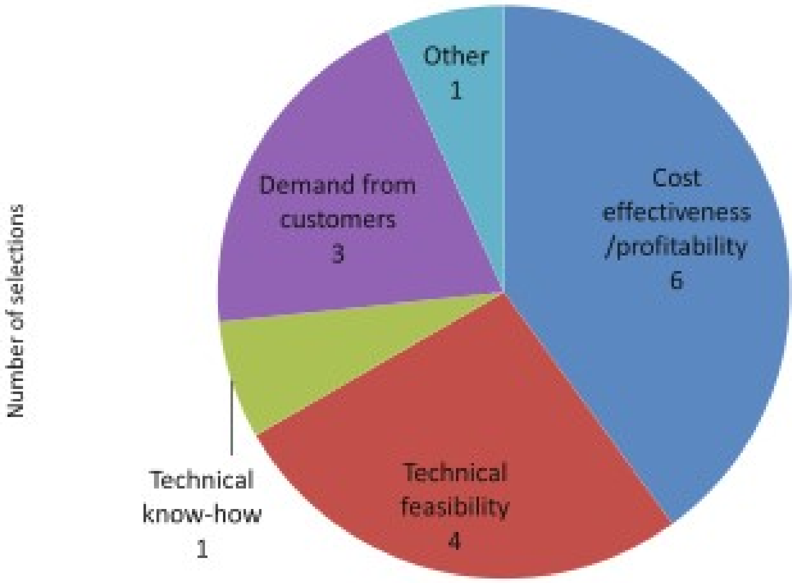


Fig. 4.37 Why is plastics recycling not practical/feasible/useful for your company? (n = 8)

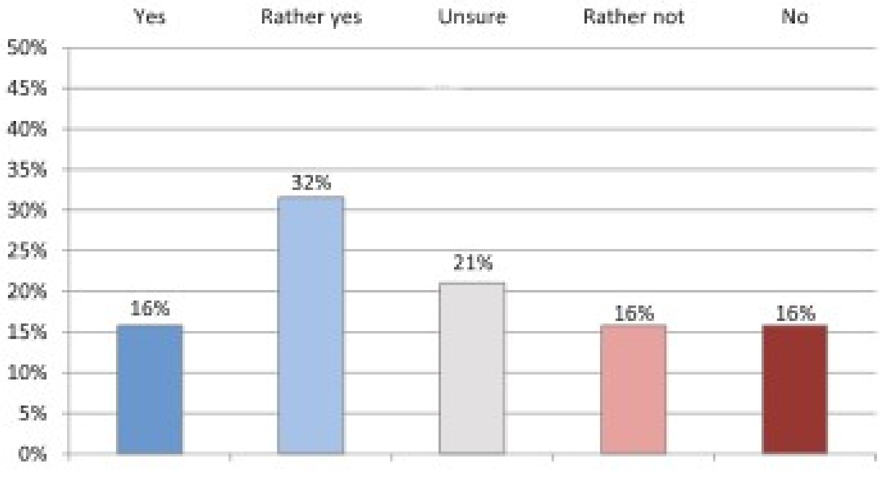


Fig. 4.38 Is your company/institution considering going into or intensifying plastics recycling? (n = 19)

Interpretation: Plastics recycling might be increasingly implemented within virgin plastics producing companies.

In contrast to the companies' policies and plans, the focus is now on the opinion of the survey participant from the plastics industry (see Fig. 4.39). On the question whether they think that going into or intensifying plastics recycling is positive, 33%

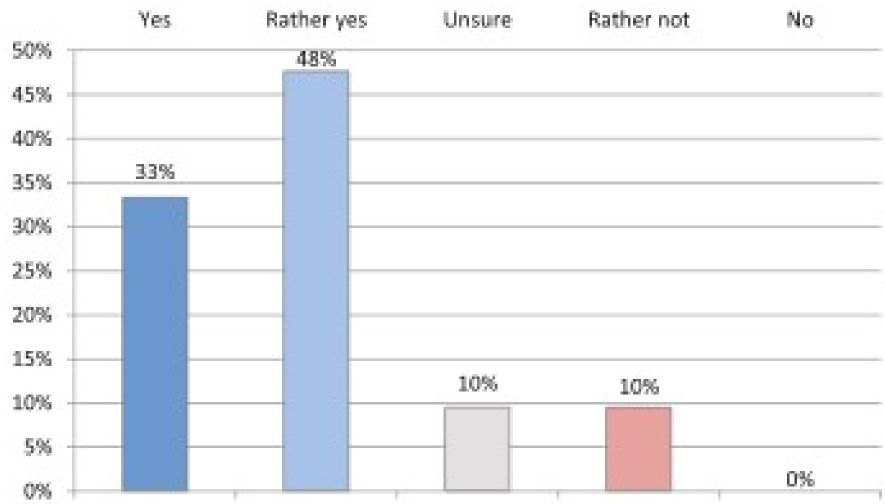


Fig. 4.39 Do you think going into or intensifying plastics recycling is positive? (n = 21)

say 'yes' and 48% 'rather yes'. Only 10% each state 'unsure' and 'rather not'. This shows that those questioned have an exceedingly positive attitude towards plastics recycling.

Interpretation: Those questioned have an exceedingly positive attitude towards plastics recycling.

To re-focus on the company, the survey participants were asked whether they think that a recycling line of business or department would be positive for their company or institution (see Fig. 4.40). 25% say 'yes' and 38% 'rather yes', 19% are 'unsure', 6% say 'rather not', and 13% 'no'. These results show that the majority of the virgin plastics industry thinks that a recycling line of business or department would be positive for their companies.

Interpretation: Most of the virgin plastics industry think that a recycling line of business or department would be positive for their companies.

Intermediate conclusion on a transition towards recycling: Concluding the opinions and plans for recycling in the plastics producing industry, there is a recycling mindset ladder: The survey participants are strongly in favour of recycling, and they believe that it would be positive for their companies. The companies do consider going into or intensifying plastics recycling, but to a lesser extent.

The following question concerns the recycling of end-of-life vehicle plastics. When calculating each score[6] (see Fig. 4.41) for each challenge, the following ranking is revealed:

[6]The scoring system for the calculation: Very good =+2, Good = +1, Fair = −1, Poor = −2; then multiplying with the percentages

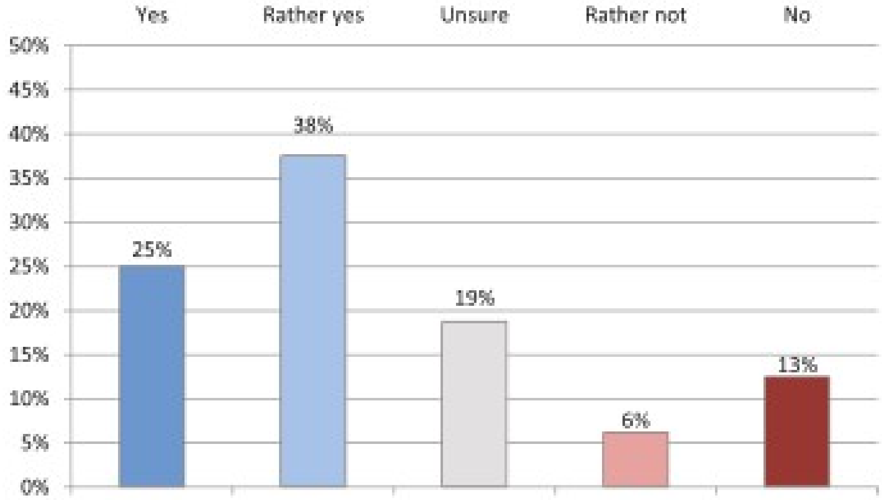


Fig. 4.40 Do you think a recycling line-of business or department would be positive for your company/institution? (n = 16)

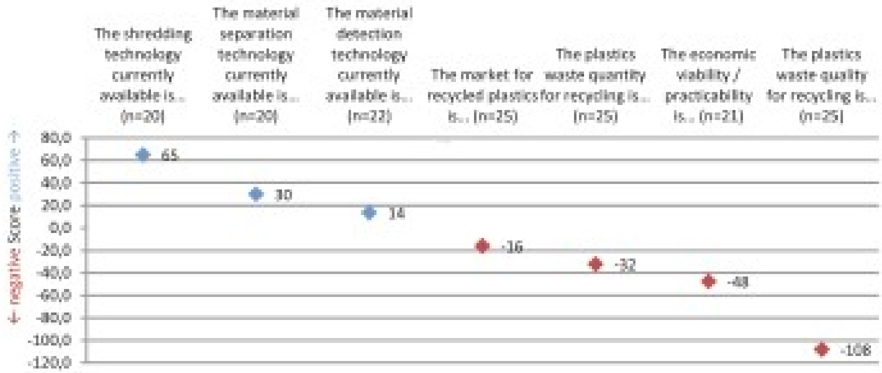


Fig. 4.41 What are the challenges of end-of-life vehicles plastics recycling? - Score

Interpretation: Technology is rated positively, but the market and waste quality is rated negatively.

To discover possible trends in the treatment of plastics waste from ELVs, the survey participants were asked about their prognosis for the year 2020. The ranking for the ELV plastics waste treatments according to quantity, from the most dominant treatment type to the least dominant one, can be concluded as follows, in spite of sharp divisions:

Rank 1: Mechanical recycling (48%) followed by thermal (28%)
Rank 2: Mechanical recycling (28%)
Rank 3: Thermal Energy recovery (29%) followed by mechanical recycling (25%)

Table 4.2 Treatment hierarchy for automotive plastics from the survey and the workshop

ELV plastics <15 years	ELV plastics >15 years
Mechanical recycling	Blast furnace
Blast furnace	Thermal energy recovery
Thermal energy recovery	Chemical recycling
Chemical recycling	Landfilling
Landfilling	

Rank 4: Chemical recycling (50%) followed by re-use (29%)
Rank 5: Landfilling (83%)

When only focussing on the most dominant type in each rank and clearing the repeating rank two, the following hierarchy is plausible:

Rank 1: Mechanical recycling
Rank 2: Thermal energy recovery
Rank 3: Chemical recycling
Rank 4: Landfilling

The expert group intensively elaborated on this topic because of the missing 'blast furnace' option. As a matter of fact, steel production uses waste plastics as a reduction material (or reducing agent) (Miller et al. 2014) substituting fossil fuel, and this process is declared 100% material recycling, while others claim it was 60% material recycling and 40% thermal recovery, depending on the country. Furthermore, blast furnace is perfectly suitable for old (negatively changed, low performance) plastics from ELVs, for example older than 15 years old (this is depending on the exposure to UV-rays for example). Moreover, it is difficult to define blast furnace treatment: whether it is material recycling, thermal recovery or something in between. Additionally, there are currently big differences between countries concerning this definition, which causes import and export of plastics waste to increase the recycling/recovery rates. A possible solution is a new ranking from best to worst with blast furnace (Table 4.2).

Nevertheless, the group argued that landfilling in Europe could possibly be excluded from this ranking, as it is mostly or at least will be prohibited. However, 'export' of waste could be included as well. Additionally, the group discussed the growing challenge of recycling composites and the potential of material recycling of tires, which requires further analysis.

4.5 The Survey Results in a Nutshell

The majority of the survey participants indicate that using recycled plastics instead of virgin plastics in the automotive sector decreases the performance and the homogeneity of the plastic materials, leading to a decrease up to virtually no change of the quality of the final products. Furthermore, the majority stated that while using recycled plastics instead of virgin plastics in the automotive sector decreases the material costs, but not the final product price for the end-consumer, it significantly decreases the dependency on and the depletion of fossil fuels, and decreases the life-cycle CO_2 emissions of the plastics. Additionally, the majority indicated that the biggest positive impact of using recycled instead of virgin plastics concerning CO_2 emissions is in the production phase, followed by the end-of-life phase. Recycled plastics also decrease land degradation and the number of waste plastic particles in the environment. The five main reasons for industrial customers to purchase recycled plastics are 'costs', 'marketing benefits', 'demand from the end-consumer', the 'available quantity', and the 'recyclability'. In short, finance-driven aspects are the predominant reason for purchasing recycled plastics. On the contrary, the five main reasons that limit the usage of recycled plastics are 'performance', 'constant composition', 'available quantity', 'optic perception', and 'number of recycled plastic suppliers'. In short, technology driven aspects and the supply are the most important reasons limiting the usage of recycled plastics. Concluding the opinions and plans for recycling in the plastics producing industry, there is a recycling mindset ladder: The vast majority of the survey participants are strongly in favour of recycling, and they believe that it would be positive for their companies. The companies actually do consider going into or intensifying plastics recycling, but to a lesser extent.

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Chapter 5
A SCOT Analysis, Future Perspectives and Scenarios on Recycling

Abstract Even people with very little time still want to benefit from comprehending automotive plastics recycling challenges and opportunities. In pursuance of a very simple and clear outline of the current usage of recycled plastics in the automotive sector, a SCOT analysis was performed. This analysis incorporates Strengths, Challenges, Opportunities, and Threats, thus providing a holistic future outlook. It is based on an iterative process including expert interviews and literature reviews, and was tested and revised together with leading experts from all the relevant industries to compile a very short, comprehensible, real-world analysis.

The strengths of using recycled plastics as depicted in the SCOT analysis (see Fig. 5.1) lie mainly in reducing the costs and the environmental impact. A considerable strength of recycled plastics is the ability to reduce the material costs for the respective company compared with using virgin plastics. However, the cost advantage is depending on the plastic type and the recycling effort, correspondingly the recycling costs, through a cost-benefit evaluation: imagine a very complex composite plastic material which can only be recycled by numerous cycles of complex recycling lines to separate the plastics, which can be cost intensive. This might lead to a higher-priced recycling material compared to virgin plastics. Still, this is an option for companies who neglect virgin material.

In addition, using recycled plastics reduces the waste plastics on landfills and the resulting emissions released from the waste plastics due to possibly several extra life-cycles in products. And if landfilling is obsolete, there are no landfilling costs and possible residual debts and liabilities now or in the future, which might even have to be paid by tax payers. However, one expert from a workshop mentioned that landfilling should be excluded generally in this analysis, because it is not significant in Europe.

Furthermore, when using recycled plastics instead of virgin material, the inherent CO_2e content of the product is reduced due to the generally lower CO_2e content of recycled plastics as it prevents the chemical treatment and particularly the extraction of new fossil fuels containing CO_2e. This is especially important when considering

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different forms of fossil fuel extraction, such as oil sands as a source (see Sects. 3.1.3, 3.1.5). Thus, recycled plastics reduce the CO_2e emissions of cars in the production phase, thus improving the greenhouse gas balance of the respective companies and increasing their corporate sustainability and CSR reputation. Not only the CO_2e emissions are reduced, but also the energy consumption compared to virgin materials (see Sects. 3.1.3, 3.1.5). Nonetheless, this again depends on the recycling effort and the plastic type. Additional strengths mentioned are independence from the oil industry and, for example, OPEC countries, which might suffer from political instabilities, and real or artificial shortages, thus increasing the price.

The challenges of using recycled plastics in the automotive sector consist of sufficient quality and quantity, doubts and objections, and general recycling technology problems. The performance of recycled plastics is, at least according to the experts and the results from the survey, still a challenge. However, there is disagreement on this issue, because representatives of several recycling companies claimed in personal discussions and during the first workshop that this is not a challenge anymore. However, the majority currently consider the performance of recycled plastics a challenge. Aside from the quality issue, the available quantity of recycled plastics is also worthy of improvement. Currently, more companies might be using recycled plastics if the delivery capacity were sufficient. Additionally, not just the quantity of the recycling material, but also the quantity of the suppliers of recycling material is of concern, because automotive companies only accept material if there are at least three largely independent suppliers available.

Now in order to produce high quality recyclates, there are still technical, and consequently primarily financial challenges to be taken on. For example, to establish a high quality closed loop with automotive plastics, upcycling has to be of concern, as automotive plastics degrade over time and are currently used in composites. In order to stimulate the recycling business, thus enabling higher quality recyclate production, the demand for recyclates has to be adequate, which is currently to be increased. This is partly caused by too high material requirements by the automotive industry as well as fears and reservations regarding recycled plastics, which is also supported by the results from Toldy et al. (2009, p. 971). Considering the recycling of automotive plastics waste, the whole recycling process including the available volume, the collection, detection, and sorting of ELV-plastics is a considerable challenge. Currently, the recycling of ELV-plastics is virtually non-existent due to a lack of sufficient and interlinked facilities, which would require investments. Moreover, one limiting reason is the intricate performance/cost relationship or trade-off. Concerning the usage of recycled plastics from ELVs in other key markets, such as the packaging sector, which is known for high hygiene standards, certain regulations might inhibit the usage of recycled plastics. However, when considering that possibly diesel could enter ELV-plastics, thus endangering the hygiene of the recyclate, again the recycling technology has do be adapted accordingly. Furthermore, the establishment of a recycling cluster or network might be inherently difficult since this sector cannot yet draw on a substantial size and lobby.

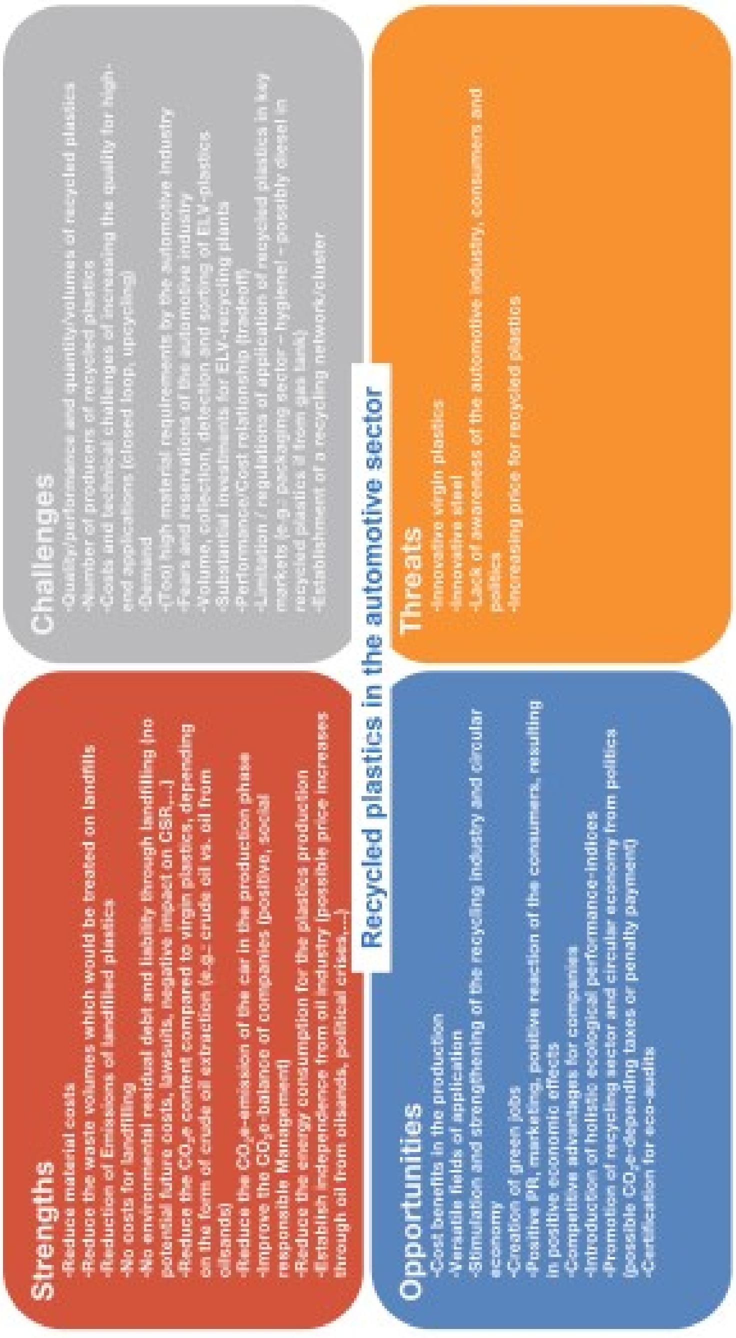

Fig. 5.1 SCOT analysis of the usage of recycled plastics in the automotive sector, developed with experts

The opportunities lie primarily in the cost benefits and improvements in terms of environmental impacts thus creating positive effects for corporate sustainability and CSR. In fact, using recycled plastics has the potential to save expenses during the production due to generally lower material costs compared to virgin plastics. And of course, depending on the quality of the recyclates, recycled plastics have a versatile field of application, equal to virgin plastics. Consequently, an intensified application of recycled plastics in the automotive sector stimulates and strengthens the recycling industry, and correspondingly the circular economy which creates more green jobs. Moreover, companies that replace large amounts of virgin plastics with recycled material have beneficial effects concerning PR and marketing, thus causing the consumer to react positively. This results in competitive advantages and subsequently in additional revenue. Now moving away from single companies to industrial associations and politics, another opportunity arises in the form of holistic ecological performance indices. By introducing such indices, companies who use recycled plastics can take further advantage of their material choice compared to companies which solely rely on virgin material, because the indices offer another channel to communicate the sustainable acting of a company. Staying in the realm of politics, another promising opportunity is the promotion of the recycling sector and the circular economy, for example by means of taxes or penalty payments depending on greenhouse gas emissions. Additionally, using recycled plastics can allow one to certify for eco-audits, which enables the company to measure and communicate the recycling material choice.

The threats are mainly the competition from the virgin plastics and metal industry, and the lack of awareness of society. In fact, the virgin plastics industry is highly innovative and is constantly improving their products. Especially inexpensive virgin plastics are in considerable competition with recycled plastics as this is one of the major arguments to favour recycled over virgin plastics. Additionally, innovative high-strength steel, magnesium, and aluminium, intelligently designed to enable significant lightweight construction are in competition with recycled plastics and plastics in general. Furthermore, the factor that the recycling of most metals is already realized satisfyingly contributes to a positive life-cycle impact. Another threat to recycled plastics in cars is the lack of awareness of the automotive industry. In fact, automotive experts still claim that using recycled plastics extensively is not possible. However, the recycling experts state that almost every plastics part could be made from recycled material and that this is just a lame argument, possibly caused by a lack of knowledge about the properties of recycled plastics, long-term relationships with the virgin industry, no motivation for change and effort, or just a lack of courage. An additional threat might be an increasing price of recycled plastics due to increased costs of the production and the material. Turning to the recycling of automotive plastics, one workshop expert highlighted that composites in general are a considerable threat for recycling and have to be stopped immediately.

SCOT Summary: Reflecting on the outcome of the SCOT analysis, it becomes clear that recycled plastics have significant benefits regarding ecological and economic aspects compared to virgin plastics, although the material quality is considered to offer room for improvement. Moreover, the ecological and economic value is acknowledged and taken advantage of by select companies, but only to a very low extent with considerable opportunities to a significant increase.

Future Perspectives and Scenarios

Abstract

Because the future cannot be foretold, only prognoses based on current trends and statements or intentions for the future can be extrapolated. Due to this high uncertainty, in this chapter have was developed relying on literature research mainly including reports from key companies, data from the survey and information gathered through expert interviews. Essentially, the prognoses are based on all the data outlined in this book up to that stage. In direct succession of the prognosis, the development of this chapter with the generated data and knowledge from the preceding research stages will complete the analysis. Based on the Level-based assessment of future perspectives concerning recycled plastics in the automotive sector (Fig. 5.2), point-of-view scenarios were developed due to the fact that multiple perspectives on the topic of automotive plastics recycling are existent and relevant for the whole automotive plastics production and recycling system (Table 5.2). Four points of view based on the findings in Chap. 2 were selected including the technical, economic, ecological and finally geographic viewpoint. Additionally, four key factor-based scenarios were developed independently, based on the two key factors for the development of the automotive plastics production and recycling system. This approach generated four scenarios, one ideal, two sub-ideal, and one worst-case scenario regarding the future of the mentioned system, as outlined in this chapter.

With the knowledge and information obtained from the previous chapters, the modelling of future perspectives is now of concern, followed by the development of scenarios while paying special attention to the automotive sector and key companies. Following the principles of Schoemaker and van der Heijden (1992); Schoemaker (1995), this research stage considers the “three classes of knowledge” (Shoemaker 1995, p. 38) regarding the future perspectives of automotive plastic materials and recycling:

- “Things we know we know”
- “Things we know we do not know” and
- “Things we don’t know we do not know”

Several strategies can be applied to achieve a glimpse into the next years. According to Vergragt and Quist (2011, p. 2) based on Börjeson et al. (2006), Dunn (1994), and Linstone (1999), there are three classes or methods for this undertaking: “what will happen (trend extrapolations; business as usual scenarios); what could happen (forecasting; foresighting; strategic scenarios) and what should happen (normative scenarios like those used in backcasting)”. In this book, the first prognosis relies

Table 5.1 Overview of future perspectives concerning recycled plastics in the automotive sector - Literature sources: Sperling and Gordon (2009); Weill et al. (2012); Heuss et al. (2012); BMW Group (2015); Daimler (2015); Fiat Chrysler Automobiles Group (FCA) (2015); Ford Motor Company (2016); General Motors (2015); Nissan Motor Corporation (2016); PSA Groupe (2015); Renault Group (2015); Volkswagen (2015); European Commission (2011, 2014a, b, c); European Union (2013); PlasticsEurope (2016)

	Source		
Prognosis	**Literature**	**Survey**	**Expert workshops and interviews**
Number of cars will increase worldwide	X (=confirmed)	0 (=not asked)	X
Car weight will decrease	X	0	X
Share of plastics in cars will increase significantly till 2020	X	X	X
Innovative metals (High strength steel, aluminium, magnesium,…) will increase	X	0	X
Holistic life-cycle thinking will increase	X	0	X
Political incentives for circular economy will increase	X	0	X
Increasing share of recycled plastics in new cars and car parts till 2020		X	X
Demand for more sustainable materials will increase till 2020		X	X
Marketing with recycled plastics will be beneficial in 2020		X	X
Hierarchy of ELV treatment in 2020: 1. Rank: Mechanical recycling 2. Rank: Thermal energy recovery 3. Rank: Chemical recycling 4. Rank: Landfilling		X	X

on trend extrapolations (see Table 5.1) to show what is likely to happen without disruptive innovations and changes. The second prognosis is a combination of trend extrapolation and normative prognosis to highlight the difference and offer respective solutions (see Fig. 5.2). Regarding the first set of scenarios (see Table 5.2), a combination of trend extrapolation and normative scenarios is also applied, but subdivided according to points of view including a technical, economic, ecological, and a geographic viewpoint, because of the fact that there are multiple perspectives on the topic of automotive plastics recycling and they are relevant for the whole automotive plastics production and recycling system, thus of relevance for future perspectives.

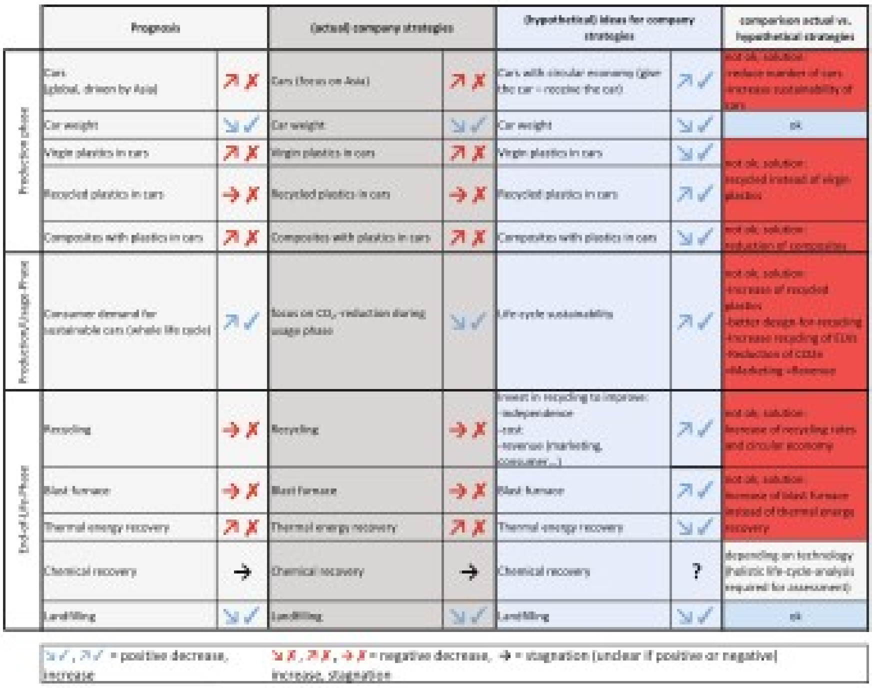

Fig. 5.2 Level-based assessment of future perspectives concerning recycled plastics in the automotive sector

The second set of scenarios is based on strategic scenarios (what could happen) and normative scenarios (what should happen) (see Fig. 5.3). This combination of methods or approaches was applied to achieve a variety of future outlooks, each with its strengths and weaknesses. The trend extrapolation or 'business-as-usual scenario' for example "is mostly for the short-term and for well-defined and rather stable systems", but rather disregards that society is "highly unsustainable and thus unstable" (Vergragt and Quist 2011, p. 748). Strategic scenarios and prognoses achieve a high level of creativity and "they try to anticipate the unforeseeable" and can change the present. Normative scenarios and prognoses such as backcasting scenarios "better recognize the systemic nature of the challenges ahead, and often assume that systemic societal transitions are necessary in order to achieve desirable futures" (Vergragt and Quist 2011, p. 749).

Now arriving at the actual future perspectives (see Table 5.1), it is of importance that they have been developed relying on literature research mainly including reports from key companies, data from the survey and information gathered through expert interviews. Basically, the prognoses are based on all the data outlined in this book up to this point. The table provides on the left side the prognoses supported by the occurrence in various sources, such as in literature or specialist conferences, the survey, expert workshops, and finally interviews. This offers an overview of the

Table 5.2 Point-of-view-based scenarios concerning automotive plastics recycling

Status quo			This will happen in the near future (2020)	This should happen	
				Optimistic	**Circular economy utopia**
Point of view	**Technical**	Low recycling rate of ELVs	Slow increase of recycled materials and ELV recycling	Higher volumes of recycled materials	Very high volumes of recycled materials
		Low quantity of recycled material		Recycled materials have near virgin quality	Recycled materials have virgin quality
		Material quality ranging from excellent to limited		Fast production	Fast production
	Economic	Increase of cars	Increase of cars	Increase of reasonably sustainable cars	Increase of highly sustainable cars
	Ecological	Increase of cars	Increase of cars	Decrease of car population	No cars with negative environmental impact
		Slow increase of sustainable cars	Slow increase of sustainable cars	Significant increase of sustainable cars	Crude oil free plastics only
					Recycled and renewable materials with low environmental impact
					Maxed out circular economy
	Geographic	No increase of spatial distribution of automotive industries	Increased spatial distribution of automotive industries and global trade	Decrease of spatial distribution of automotive industries	Local production only
		No increase of unsustainable global trade (ELVs, ASR-plastics, crude oil,…)		Decrease of unsustainable global trade	Local resources only

significance, which is also separately outlined in the very right column through a score to assess the significance depending on the number of sources the prognosis is found in. 'X' represents 'confirmed', '0' represents 'not asked' in the survey, and no indicator represents no occurrence. The literature source is offered on the bottom when following the numbers in brackets in the literature column. The prognoses are arranged like a funnel, ranging from broad prognoses on the top to narrow ones on the bottom.

The first set of prognoses (first main row labeled 'Automotive industry prognosis') in Table 5.1 discuss the automotive industry in general and show three main developments. First of all, the number of cars worldwide is increasing. Currently, Asia is regarded as the main growth market. Secondly, the average car weight is decreasing due to intense weight-reduction measures to lower the emissions during the usage phase. Thirdly, innovative metals, such as high-strength steel as well as light metals such as aluminium and possibly magnesium are on the rise in the car production. Those metals fulfil the safety and design requirements and can reduce the weight compared to traditional steel.

The second set of prognoses (second main row labeled 'Recycling related prognosis') in Table 5.1 is related to circular economy in general, and especially regarding plastics. On the side of OEMs and suppliers, holistic life-cycle thinking is increasing, but slowly. The questionable profit-orientation is still the utmost priority, which hinders the required progress of a sustainable economy. On the side of politics, an increase of political incentives for a circular economy is perceivable. However, those incentives are still in its infancy and require significant enhancement. Concerning plastics in cars, their share of plastics is further increasing from 16% in 2010 up to more than 30% in 2020. In addition, the share of recycled plastics in new cars and car parts will continue increasing up to 2020, alongside the increasing demand for more sustainable materials in general up to 2020. Moreover, in this year at the latest, marketing with recycled plastics will be beneficial for the automotive industry. Concerning the end-of-life of cars, the dominant ELV treatment will be mechanical recycling, followed by thermal energy recovery, chemical recycling and landfilling in the end. And on the side of the virgin plastics industry, it is expected that those companies will go into or intensify plastics recycling. Composite materials and bioplastics were not included in the prognoses, as they are for the foreseeable future only of minor interest in the automotive sector and not (yet) relevant for recyclers. However, a future increase of these materials is possible which would require additional research.

To achieve a more detailed prognosis, several developments were structured according to the different phases of a car, combined with actual company strategies, hypothetical ideas for company strategies, and possible solutions in case the two preceding did not agree. The method for this prognosis is a combination of trend extrapolation in the first column (what will happen), and normative prognosis in the second column (what should happen). In the third column, the two prognoses are compared to detect the difference and offer respective solutions. The basis for the table in Fig. 5.2 is the data gathered up to this point in this book and represents

Scenarios→	1	Sustainable world	2	Sub-ideal sustainability	3	Illusive sustainability	4	Nightmare
Political recycling initiative	↗ ✓	• significant increase of circular economy • increased supply of recycled plastics (new recycling companies, expansion of existing recycling companies) • more recycled	↗ ✓	• increase of of circular economy • increased supply of recycled plastics (new recycling companies, expansion of existing recycling companies) • decrease of recycled plastics in cars • increase of ELV plastics recycling	↘ ✗	• stagnation of circular economy • no increase in supply of recycled plastics • possible increase of recycled plastics in cars if amounts are available • stagnation of ELV plastics recycling	↘ ✗	• significant decrease of circular economy • decreased supply of recycled plastics (decrease of recycling companies) • less recycled plastics in cars • less recycling of ELV plastics
Costs of recycled plastics	↘ ✓		↗ ✗		↘ ✓		↗ ✗	

Fig. 5.3 Automotive plastics recycling scenarios based on the two key factors politics and costs

an overview and outlook for the future concerning the automotive industry down to automotive plastics recycling and the usage of recycled plastics.

In Fig. 5.2, the first set of prognoses (first main row) dealing with the production phase of cars are mostly negative from an environmental point of view, because the global car population, the share of virgin plastics in cars, and the share of composites in cars will be increasing while recycled plastics will be implemented only gradually. However, the average car weight will be decreasing, which is positive due to fuel savings. Currently, the actual company strategies (top middle) are alike, because these are currently determining the path. In order to advance sustainability with the primary focus on the ecological aspect in the production phase, the following ideas and solutions should be implemented: First of all, the number of cars should be decreased and the car should be regarded and treated as a circular product, not a linear one, thus ensuring the recovery of valuable materials, in this case especially plastics. Additionally, the share of recycled plastics should be increased, thus replacing virgin plastics. Furthermore, non-separable and therefore very hard to recycle composites should be avoided. Carbon fiber reinforced plastics are currently not sufficiently treatable in terms of ecology and economy, because only pyrolysis can separate the carbon fiber from the resin (mostly epoxy) which is exceedingly energy consuming. Additionally, CFRP can cause clogging and short-circuits in the electric filter of thermal energy recovery plants which provokes complete plant shut-downs for days. Shredded carbon fibers in household waste cause airborne respirable particles thus exposing employees to health risks. However, bioplastics can also cause clogging to various degrees, if, for example, mixed with conventional plastics.

The second set (second main row) of prognoses in the overlapping phase of production and usage of automotive plastics, a positive trend driven by the consumer who demands more sustainable cars over the whole life-cycle. Currently, the automotive companies are orientating their efforts on the usage-phase of the car through measures to reduce fuel usage. In order to ensure life-cycle sustainability, car producers must increase the share of recycled plastics where applicable, because safety critical parts are justifiably difficult, but non-visible parts could be suitable with a layer of virgin material on top. Further, they need to improve the design-for-recycling and the recycling rate of ELVs which combined, results in an overall reduction of greenhouse gas emissions (CO_2e) consequently enabling marketing benefits and therefore revenue.

The third set (third main row) of prognoses dealing with the end-of-life phase of automotive plastics is predominantly negative. While recycling and blast furnace will be stagnating, thermal energy recovery will be increasing. In order to encourage ecological sustainability, the recycling rates and the overall circular economy should be increased, which provides independence, will decrease car production costs, and create revenue through marketing. Furthermore, blast furnace should be pushed and thermal energy recovery should be avoided. Chemical recovery is uncertain in regards to whether the predicted stagnation is positive or negative, depending on the used technology. A positive development is the apparent and necessary decrease of land-filling of automotive plastics.

Scenarios

In direct succession to the prognosis, the development of scenarios with the generated data and knowledge from the preceding research stages will complete the analysis. Based on the Level-based assessment of future perspectives concerning recycled plastics in the automotive sector (Fig. 5.2), point-of-view scenarios have been developed because of the fact that multiple perspectives on the topic of automotive plastics recycling are existent and relevant for the whole automotive plastics production and recycling system (Table 5.2). Four points-of-view based on the findings in Chap. 2 were selected, including the technical, the economic, the ecological, and finally the geographic viewpoint. The social aspect was not considered for this analysis due to the focus on ecology in this research, but discussed in Chap. 6. The scenarios are split into optimistic and circular economy utopias, which are based on the status quo and the prognoses.

Point-of-View Based Scenarios

The technical viewpoint highlights that currently the material quality is ranging from limited to excellent, depending on the technology and the financial effort for the recycling process. Additionally, low quantities of recycled plastics are available and low rates of ELV plastics recycling are prevailing. In the future, a slow increase of recycled materials and ELV plastics recycling are predicted. However, the optimistic scenario indicates higher volumes of recycled plastics, higher or near virgin quality and fast recycling production processes. The utopian scenario indicates very high volumes, equivalent quality of recycled and virgin plastics and even faster recycling production processes.

The economic viewpoint shows that currently and in the future, an increase of cars is apparent. The optimistic scenario indicates a significant increase of the car population that is reasonably sustainable, and the utopian scenario indicates a high number of exceedingly sustainable cars to create sustainable revenue.

The ecological viewpoint highlights, similar to the economic viewpoint that currently the number of cars is increasing, but additionally that an indication of increasing sustainable life-cycle thinking that is producing more sustainable cars is perceptible. In the future, both trends will be intensified. However, the optimistic scenario indicates a decrease of the car population while the share of sustainable cars is increasing. The utopian scenario indicates no cars with a negative environmental impact, only recycled and renewable plastics instead of virgin plastics, and a maxed out circular economy concerning plastics in the automotive sector.

The geographic viewpoint shows that currently, no increase of spatial distribution of automotive industries and unsustainable global trade is apparent. In the future, these trends are increasing due to increased outsourcing. However, the optimistic scenario indicates a decrease of both trends and the utopian scenario indicates local production and local resources only.

Key Factor Based Scenarios

During the second expert workshop, the most important factors for the development of the automotive plastics production and recycling system have been discussed and distilled with the result that the costs and the political (in)action have the most significant influence. For this reason, these two factors served as a basis for developing four scenarios, one ideal, two sub-ideal, and one worst-case scenario (Fig. 5.3). The arrows represent a decrease (arrow down), or increase (arrow up), which is positive (check mark), or negative (cross) regarding sustainability thus generating the four scenarios.

Scenario 1 - Sustainable world The political recycling initiative is enhanced and the costs of recycled plastics are decreasing. As a result, a significant increase of the circular economy, including an increased supply of recycled plastics, new recycling companies, an expansion of existing recycling companies, an increase of recycled plastics in cars, and an increase of ELV plastics recycling is indicated.

Scenario 2 - Sub-ideal sustainability The political recycling initiative is declining and the costs of recycled plastics are decreasing. As a result, a stagnation of the circular economy, including no increase of the supply of recycled plastics, a possible increase of recycled plastics in cars if enough quantities are available, and a stagnation of ELV plastics recycling is indicated.

Scenario 3 - Illusive sustainability The political recycling initiative is enhanced and the costs of recycled plastics are increasing. As a result, an increase of the circular economy, including an increased supply of recycled plastics, new recycling companies, an expansion of existing recycling companies, a decrease of recycled plastics in cars, and an increase of ELV plastics recycling is indicated.

Scenario 4 - Nightmare The political recycling initiative is declining and the costs of recycled plastics are increasing. As a result, a significant decrease of the circular economy, including a decreased supply of recycled plastics, a decrease of recycling companies, less recycled plastics in cars, and less recycling of ELV plastics is indicated.

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Chapter 6
The Recycling Renaissance: Solutions and Practical Tools to Advance Automotive Recycling

Abstract So what should we do now? Many people are already aware that sustainability is the next major requirement, but how can we improve sustainability in the automotive plastics production and recycling industry? For this reason, a roadmap to circular plastics for companies was developed. It includes a selection of wide-ranging solutions based on guidelines, expert workshops, a survey, literature reviews, discussions, and expert interviews. To improve the circular usage of automotive plastics, a roadmap was developed which can be used and implemented on various sections within the automotive plastics recycling and production system. Additionally, solutions for political and independent institutions are provided. Ultimately, we need to establish an economy and society that meets objectives and rules mainly to prevent environmental degradation. This can be achieved by applying the solutions provided in this chapter.

> The question I now hear most often from managers …is not 'Why should we be sustainable?' but 'So what do we do?' (Unruh 2013, p. xi)

Now to know what to do, we need to recap that the superordinate interest of future humankind is true sustainability which establishes an economy and society that is meeting objectives and rules mainly to prevent environmental degradation as outlined in Sect. 2.4. The most relevant goals to improve primarily the ecological dimension of sustainability for the economy and especially the companies in the case of automotive plastics are:

1. Save the atmosphere (reduction of greenhouse gases (CO_2e))
2. Save resources
3. Save energy

However, the path up until now has primarily been shaped by the following negative developments, as outlined in detail in the Chap. 3:

1. Increase of human population
2. Increase of cars per capita
3. Increase of mobility

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Therefore, the overarching goals to advance ecological sustainability have to be pursued in a most determined, rigorous, and drastic way, and the guidelines and solutions provided in the following can help to reach those goals.

6.1 A Roadmap to Circular Plastics for Companies

Companies which are early adopters that act even before political incentives are applied are likely to benefit the most as the decline of the linear economy arrives. This will be the day the circular economy surpasses the linear economy which, I call 'the Circular Economy Turning point' - CET.

> Sustainable development can be a source of success, innovation, and profitability for companies. To use this source and to deal with the challenge of sustainability, corporations need a framework they can rely on in order to identify opportunities and threats and to develop, implement, control, and improve corporate sustainability strategies to be both more sustainable (for themselves and the society) and more successful in economic terms. (Baumgartner 2014, p. 258)

However, many companies and CEOs report that sustainability is regarded as a disadvantage in global competition with non-sustainable companies (Nidumolu et al. 2009). Fortunately, this is not the case since a study of 30 large companies revealed that "becoming environment-friendly lowers costs because companies end up reducing the inputs they use. In addition, the process generates additional revenues from better products or enables companies to create new businesses." (Nidumolu et al. 2009).

6.1.1 Step 1: Incorporate Sustainability and Circular Economy in the Company Strategy

> The ultimate key to corporate sustainability is the CEO's commitment.

Without the support from the company leader, no idea will flourish in the end. The CEO is the ultimate key to achieving corporate sustainability, because when the top changes, the bottom follows quickly. A suitable approach to implement sustainability in companies is the "framework for corporate sustainability management" (Baumgartner 2014, p. 269) "to support planning, implementing, reviewing, and controlling corporate sustainability activities" relying on the principles of the FSSD (see Sect. 2.4.1). Within this framework, connected and looped phases (see Fig. 6.1) are based on three management levels: The normative level incorporates the "vision and mission", the strategic level incorporates the sustainability strategy, and the operational level incorporates the implementation of the latter (Baumgartner 2014, p. 258). Starting with the initiation phase, the vision has to be chosen in the 'normative positioning' phase, then "[t]he analysis of the contextual factors gives an indication

Fig. 6.1 Phases of corporate sustainability management, used with kind permission from Baumgartner (2014, p. 269)

of the relevance of sustainable issues for the company" (Baumgartner 2014, p. 264). In this case, sustainability can either be ignored, act as a complement to an existing vision, or function as an influencing main element in the vision thus forming the corporate image (Baumgartner 2010, p. 119). In the next phase the intensity of the strategy has to be defined, whether it is passive or active (visionary), followed by deciding on long-term goals through applying backcasting, which is "a method in which the future desired conditions are envisioned and steps are then defined to attain those conditions" (Holmberg and Robèrt 2000, p. 294). Through this framework, companies can improve corporate sustainability in line with economic success (Baumgartner 2014, p. 258).

In general, companies have to give sustainability a higher priority, employ sustainability change managers or train their own managers, establish a sustainability agenda company-wide, promote ideas how to improve the ecological performance throughout the life-cycle, and manage their implementation. Basically, different groups have to work together. Consequently, senior management is in need of methods to advance corporate sustainability such as provided by (Kiron et al. 2013, p. 12):

1. "Strong CEO commitment to sustainability
2. Clear communication of responsibility of sustainability
3. Sustainability reporting
4. Company/operational KPIs [key performance indicators] [related to sustainability]
5. An executive-level steering group
6. A separate function for sustainability
7. Link between sustainability performance and financial incentives
8. Responsible person for sustainability per business unit

9. Personal KPIs related to sustainability
10. A chief sustainability officer (CSO)"

It should be noted that in many small and medium enterprises (SMEs), up to large companies, there is no specialised CSO. Usually there is one designated expert on health, safety and environment (HSE) that has to deal with sustainability alongside their other assignments. From my personal experience with HSE officers in companies, they often do not even have authority to give directives, which prohibits significant improvements regarding sustainability, especially when collaboration with the employees is essential.

Returning to sustainability guidelines, one outstanding source to achieve corporate sustainability is provided by the United Nations Global Compact (2016). This institution offers for example the "Guide to corporate sustainability", the "Roadmap for Integrated Sustainability", the "Blueprint for Corporate Sustainability Leadership within the Global Compact", and more practically, the "SDG Compass", a "guide for business action on the SDGs" [Sustainable Development Goals] on their website[1]. For example, in the "Guide to corporate sustainability", the main challenges are distilled to just five sustainability aspects for companies to work with, each featuring elaborated strategies:

1. Principled Business
2. Strengthening Society
3. Leadership Commitment
4. Reporting Progress
5. Local Action

Following for example these sustainability methods, guidelines and especially the SDG compass are perfectly suitable for getting started with corporate sustainability, and implementing it into the corporate strategy. Additionally, the proposed corporate sustainability needs to be defined through measurable targets, for example with the "Sustainability Balanced Scorecard", as outlined in a review on SBSC architectures by Hansen and Schaltegger (2016). The next step is to change the way companies deal with innovation.

6.1.2 Step 2: Implement Sustainability-Oriented Innovation (SOI)

> The current economic system has placed enormous pressure on the planet while catering to the needs of only about a quarter of the people on it, but over the next decade twice that number will become consumers and producers. Traditional approaches to business will collapse, and companies will have to develop innovative solutions. That will happen only when executives recognize a simple truth: Sustainability = Innovation.
> (Nidumolu et al. 2009, p. 64)

[1]https://www.unglobalcompact.org.

So how does sustainability become practice in companies? Most importantly by developing innovative ideas. Ideally, these ideas are based on "Sustainability-oriented innovation" (SOI) (Adams et al. 2012; Hansen and Grosse-Dunker 2013), and in case of circular plastics, primarily on the ecological level of the entire life-cycle of the product. "The traditional focus of innovation often lies on the development of technically improved or entirely new products and processes, thus on technological innovation. While these efforts are very important, they alone cannot solve some of the overarching sustainability challenges, particularly increased absolute resource consumption and waste." (Hansen and Grosse-Dunker 2013, p. 2411). Consequently, the paradigm of SOI should substitute or improve traditional innovation processes. What makes this concept special is that the three general types of innovations (process, organisational and product innovations) are expanded by the environmental dimension (Klewitz and Hansen 2014, p. 58):

1. Process innovations (for example through eco-efficiency and eco-effectiveness (see Sect. 2.4.2))
2. Organisational innovations (for example through changing the company structure, corporate processes and management (see Sect. 6.1))
3. Product innovations (for example through Ecodesign including organic or recycled materials (see Sect. 6.1.3.2))

For many companies, true sustainability is innovation. It includes changes and risks. Sometimes even disruptive change, when a company's core business is removed and replaced with a more sustainable one. For example, this can happen if a virgin plastics producer is expanding into plastics recycling, thus substituting the initial core business of producing virgin plastics by producing recycled plastics. Some would say this is a bold move - which it is - but it is a sustainable move from a virgin plastics producer dependent on crude oil to a plastics supplier including waste as a material source. However, sustainable innovation does not necessarily have to be this disruptive, but it may require new ways of thinking, to leave the old paths and break new ground. In order to implement SOI, Hansen et al. (2009) developed a generic and holistic model for decision makers called the "Sustainability Innovation Cube" (SIC) (see Fig. 6.2). With SIC, innovations can be improved in terms of sustainability by analysing 27 areas, which can reduce risks with SOIs and enables a cost-benefit analysis. Furthermore, the model is based on three dimensions including "target" (economic, environmental and social effects), "life-cycle" (production, usage and end-of-life) and "innovation type" (technological, product-service system, or business model innovation) (Hansen et al. 2009, pp. 688–694). For details on SOI and solid practices and methods to enable sustainable innovation, I can further recommend Klewitz and Hansen (2014); Adams et al. (2012); Hansen and Grosse-Dunker (2013) as well as the "Network for Business Sustainability" (http://www.nsb.net).

Walk the Talk - Putting Theory into Practice

So what is the challenge to achieve industrial sustainability? It is certainly not the theory, because "most managers believe a sustainable strategy is a competitive necessity" and companies are increasing their engagement in sustainability (Kiron et al.

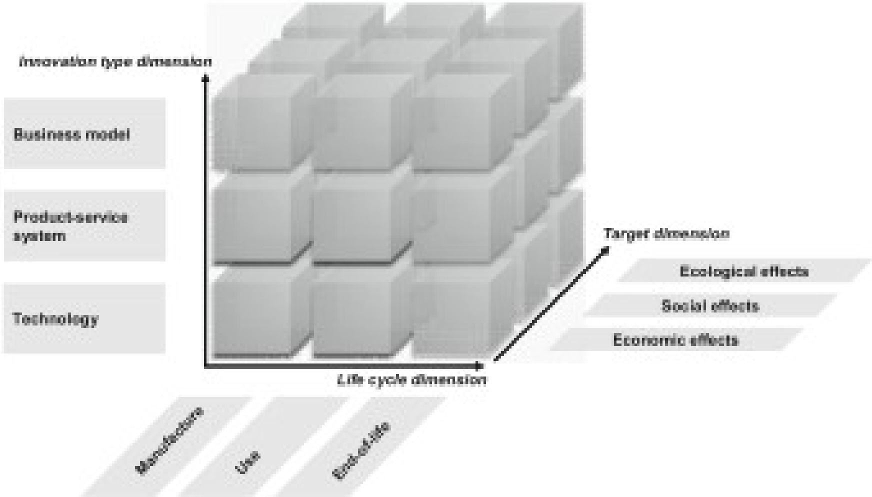

Fig. 6.2 The Sustainability Innovation Cube (SIC), used with kind permission from Hansen, Grosse–Dunker, and Reichwald (2009, p. 695), © World Scientific Publishing

2012, p. 71). In the case of the automotive industry, the managers deem sustainable materials a competitive advantage, (81%) stating that increasing the share of recycled plastics in new cars is positive (93%), and plan to increase this share by 2020 (88%) (see Chap. 4). In fact, the challenge is the practical struggle for progress, the fear of change, and the inherent risk. Currently, the automotive industry is investing little in sustainable plastics, because only 68% of companies use recycled plastics to a very slight extent (less than 11%, stated by 63% of those questioned). The question is whether this lack of walking the talk and realising ecological sustainability programmes and claims is based on restrictive reasons, such as insufficient quantities of recycled plastics, performance of materials, and a lack of suppliers of recycled plastics (see Chap. 4), or possibly whether these reasons are an excuse for a lack of commitment. However, if a company is committed, they can and will find a way to walk the talk, because the automotive industry is very innovative and capable. One positive example is BMW, who managed to become the most sustainable corporation in the world and ranked number one in the Global 100 by Corporate Knights, due to improving resources and energy efficiency as well as implementing renewable energy (Corporate Knights Inc. 2016). A possible hindrance to achieving a higher level of sustainability might be to favour 'business as usual' instead of true innovation (Kiron et al. 2012). Walking the sustainability talk is widely discussed and research has provided numerous guidelines, such as Lubin and Esty (2010, p. 4), who describe "the four stages of value creation", to manage the transformation towards an (ecologically) sustainable business:

> "Stage 1: Do old things in new ways", where companies incorporate new methods for production, such as using a small share of recycled plastics

"Stage 2: Do new things in new ways", where companies transform whole systems, such as redesigning products made from solely recycled plastics
"Stage 3: Transform core business", where sustainability is established as the root of economic growth
"Stage 4: New business model creation and differentiation", where companies focus heavily on sustainability as their business model, such as recycling material on their own or in a joint-venture

Since companies are trying to reach stage 4, which is the ultimate goal, there are several rules to increase the efficiency and the speed of the transformation process. A subsequent strategy to change into a sustainable enterprise is provided by Nidumolu et al. (2009). They succeeded in analysing companies incorporating sustainability and encountered the five stages of change:

"STAGE 1 - Viewing Compliance as Opportunity"
"STAGE 2 - Making Value Chains Sustainable"
"STAGE 3 - Designing Sustainable Products and Services"
"STAGE 4 - Developing New Business Models"
"STAGE 5 - Creating Next - Practice Platforms"

The study by Nidumolu et al. (2009) is strongly recommended for further reading since it is a practical analysis of the quest to corporate sustainability peppered with examples. Another reliable source of help to achieve the transition towards a sustainable corporation is the "ABCD Process" and the "Future-Fit Business Benchmark" by Robèrt (2002); The Natural Step (2013). The next step now is to help companies to put the stated theories into practice.

6.1.3 Step 3: Use Tools and Practical Methods to Achieve Circular Plastics

Especially for readers with a practical background or those who plan on taking action, practical concepts, methods and tools are now introduced. The ideas and notions are ordered from general to specific, respectively from easy to challenging. During the scientific and economic journey for this book, the author has met dozens of sustainability experts, CEOs, Ecodesigners, quality managers, policy officers as well as politicians, and (un-)fortunately, there is no one simple tool to achieve circular economy, or circular plastics. It depends on everything within the system the company is embedded in. The country, the company size, the (raw) materials, the product, the employees, the legislative framework, and so on. Consequently, every company has to find its own way and select from the available strategies, tools and methods. Luckily however, one key aspect of corporate sustainability is of paramount importance, and it has something to do with communication.

6.1.3.1 Value Chain Collaboration

When new products and materials are developed and put to market, it is often the case that the negative aspects of the material or product seem to be discovered much later or even too late. One example is carbon fiber reinforced plastics and the costly troubles it causes when reaching the end-of-life. Another prejudice or even allegation is that the negative aspects are known, but ignored. In any case, to reach corporate sustainability with regard to materials such as plastics, there is one simple, effective and unbeaten strategy: to share knowledge. Not just within the company, but within the entire value chain. Companies at one point of the value chain often do not know that other companies and people are dealing with their product at another life-phase of the product. In fact, communication is key to improve corporate sustainability, which can reveal potential synergy effects which offer additional value for the companies. This notion is called "Value Chain Collaboration". This notion that environmental challenges can be solved via supply chain management was successfully analysed by (Lamming and Hampson 1996), and with the focus on recycling by (Roy and Whelan 1992). In short, by knowing the entire product and material value chain, companies will get to know the challenges along the entire life-cycle and therefore be able to adapt their products and materials accordingly. One easy strategy is to host *value chain meetings* with as few participants as possible, in the following order: First, the technical issues have to be solved together with technical experts, engineers and executives, then management issues together with a broader range of managers, and finally the political issues to adapt the framework together with politicians and the executives. This enables an exchange of knowledge and prepares for the implementation of changes at a corporate and political level. Additionally, excursions to the facilities improve the collaboration, and it is wise to make use of cooperation platforms such as business clusters. Possible participants in the case of the automotive plastics production and recycling system which are suitable for a value chain collaboration are raw material suppliers, plastics producers, plastics compounders, automotive suppliers converting the plastics, automotive OEMs using the plastic products, car users, and finally the end-of-life businesses dealing with the automotive plastics. Possible alternative end-of-life businesses can be conventional companies, for example from the chemical or steel producing industry, in the case of plastics waste treatment due to possible synergistic treatment in existing processes. Additionally, the manufacturers of the respective machineries, as well as the scientific researchers, and politicians are relevant due to their strong influence on the main actors in this system (see Fig. 6.3). The more important participants regarding impact on circular economy (compounders, suppliers, OEMs and end-of-life businesses, machinery manufacturers) are depicted in a darker shade.

6.1.3.2 Design for Circular Plastics

To achieve sustainability-oriented innovation specifically within automotive plastics, several strategies, methods and tools are available for implementing circular economy

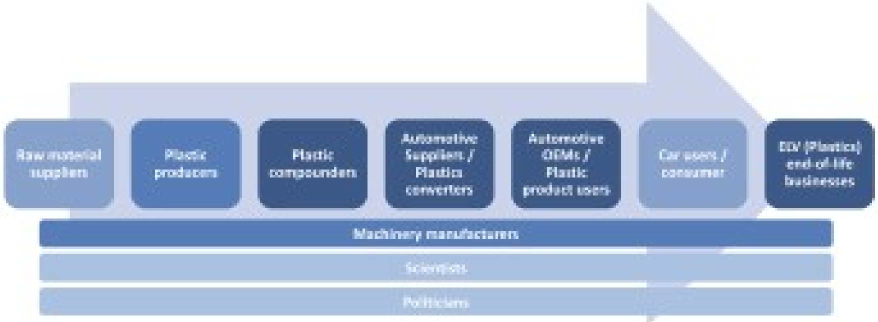

Fig. 6.3 Value chain of automotive plastics

practices. The main principle is "Design for Sustainability" (DfS) as mentioned by Mayyas et al. (2012), Programme (2009), Spangenberg (2013). This is the meta-strategy for circular economy and circular plastics, and therefore it includes a wide range of aspects (see Jawahir et al. 2007; Mayyas et al. 2012), but is often too general for specific application. In terms of circular plastics, naturally "Design for Circular Economy" (DfCE) is the suitable strategy to go for. There are already concepts and trials of implementing DfCE, for example for a circular mobile device (Poppelaars 2014), supported by the Ellen MacArthur Foundation, which is a strong player in this context (see www.ellenmacarthurfoundation.org). General guidelines and tools on DfCE are abundant, as outlined in an overview by Medkova and Fifield (2016).

However, for circular plastics, specified guidelines and tools are required. For example, Partners for Innovation (2015b) and Smit (2014) developed a guideline for designing with recycled plastics, and even provide best-practice examples (see Partners for Innovation (2015a)). In this guideline, a step-by-step plan from the electronics company Philips to introduce recycled plastics in a company Partners for Innovation (2015b, pp. 22, 23) outline a chronological approach:

1. "Catalogue the use of plastics within the company"
2. "Focus on commonly used polymers"
3. "Focus on non-visible and dark parts"
4. "Identify and approach suppliers"
5. "Decide on the most important requirements for the product"
6. "Start with application in existing products"
7. "Design for recycled plastics"
8. "Test moulds and components"

For more details on each step, please refer to the quoted guideline. However, this approach suggests that recycled plastics are currently not sufficient for visible and coloured parts. This could change if "Design for recycling" (DfR), "Design for recyclability", or sometimes "Design for End-of-Life" is offered more attention. However, the definition according to Mayyas et al. (2012, p. 1847) of the mentioned principles should include "Design for disassembly" or dismantling to reduce the effort and cost, "Design for Remanufacturing" to use parts directly without the need of reprocessing, and "Design for Recycling" to enable easy dismantling, reuse of parts and components, and high-quality recycling of materials. Moreover, due to the fact that design for circular plastics requires a strong focus on the product, a focus on automobiles is now provided in the following, regarding sustainable design in the entire life-cycle of the car.

The CSPD - A Checklist for Sustainable Product Development

In order to incorporate the mentioned strategies for circular automotive plastics several guidelines are available, for example from Mayyas et al. (2012), (2013), Maudet et al. (2012), Arena et al. (2013), Schmidt and Taylor (2006). However, one personal favourite is the "CSPD", "A checklist for sustainable product development tested in the automotive industry" developed by Schöggl et al. (2017). This checklist is suitable for designing circular automotive plastics, because of its narrow focus on the automotive industry and the relevant materials in this industry, such as plastics. Additional positive aspects are the applicability very early in the product development phase, its holistic sustainability and life-cycle approach, and that the checklist is based on one of the most renowned model for sustainability, the "Framework for Strategic Sustainable Development" (FSSD) by Robèrt (2002) (see Sect. 2.4.1). As real world applicability is key for sustainability tools, the CSPD has been developed and tested with a renown automotive contract manufacturer during the development of an ultra-lightweight vehicle, with a natural-gas engine and less than 49g CO_2/km emission.

The process of applying the CSPD is iterative (see Fig. 6.4): "During the first assessment, the designers and engineers who answer the questions must state whether they have already considered a certain aspect. Then, they must rate the relevance of this aspect for the evaluated technology and provide a qualitative description of the measures taken to consider its sustainability. If an aspect has not yet been considered in an appropriate way, necessary tasks need to be defined. The task list thus formed

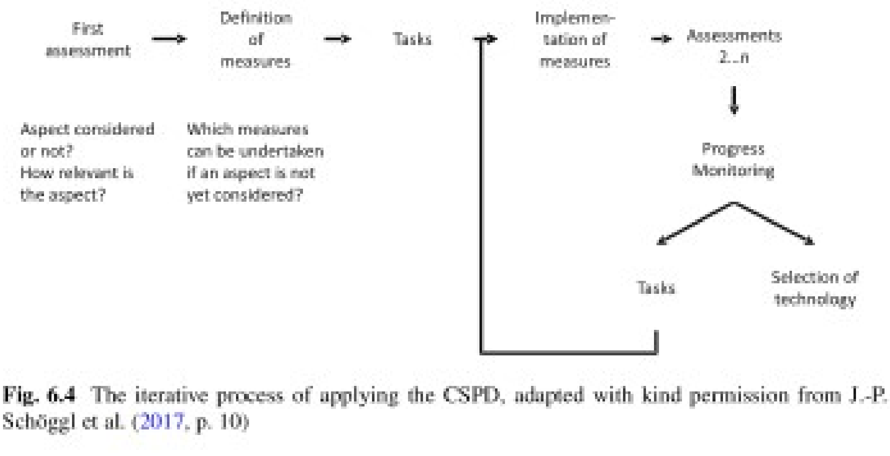

Fig. 6.4 The iterative process of applying the CSPD, adapted with kind permission from J.-P. Schöggl et al. (2017, p. 10)

helps users define measures that can be used to address the identified sustainability gap. As improvement measures are implemented, the progress is monitored and documented during follow-up sessions, in which the tasks and their resolution status are discussed." (Schöggl et al. 2017, p. 10).

The CSPD is comprised of numerous categories (see Table 6.1) including all product phases ranging from engineering, production, use, and end-of-life. 49 specific and customizable questions in total help to implement sustainability and circular economy, including recycled plastics and design for recycling in the automotive sector.

6.1.3.3 Advanced Treatment of Current Waste Streams

For some plastics and plastic products, it is already too late to call for Ecodesign, such as composites including CFRP, and with mixed plastic types and inseparable connections. To enable circular economy, the waste streams must be treated to fulfil high requirements. In a data and advice sheet on "Injection molding of high-quality parts", Covestro Deutschland AG (2015) notes several valuable aspects to consider when recycling plastics from production waste, which should be used again as recycled plastics:

"Scrap suitable for recycling:

1. short moldings
2. sprues [the excess material during molding]
3. mechanically damaged parts
4. parts with insufficient dimensional stability"

"Special points to note:

1. single-sort parts
2. use only correctly-processed material
3. no parts with signs of overheating (thermal degradation),
4. take care with parts that have streaks or bubbles caused by moisture…(hydrolytic degradation possible)
5. do not use dirty or contaminated moldings (clean beforehand if appropriate)
6. granule size should be roughly the same as for virgin material
7. comply with the drying instructions"

To summarise, Covestro Deutschland AG (2015) advises that 10–20% reclaim (recycled material) can be added to virgin plastics, and "up to 100% for parts where properties are of secondary importance (establish percentage in a performance test). In the case of 10–20% reclaim too, it is recommended to establish the amount of reclaim that can safely be added through appropriate tests (molecular weight reduction, mechanical properties, molded part test)."

Table 6.1 The CSDP categories, adapted with kind permission from Schöggl et al. (2017), simplified by the author

Life-cycle phase	Sub-category	Sustainability dimension		
		Environmental	**Social**	**Economical**
Engineering	Design for manufacturing			×
	Life-cycle costing			×
	Optimization of the materials input	×		×
	Use of renewable materials	×	×	
	Weight reduction	×		×
	Resource efficiency	×		×
	Recyclability	×		×
	Design for recycling	×		
	Consideration of the E.O.L phase	×		
	Design for dismantling	×		×
	Use of recycled materials	×		×
	Health		×	
	Design for transport	×		×
	Employee satisfaction		×	×
	Safety		×	
Production	Social and ethical issues in the supply chain		×	
	Health		×	
	Resource efficiency in the production	×		×
	Resource consumption in the production			×
	Internal material cycles	×		×
	Toxicity	×	×	
	Optimization of the materials input	×		×
	Transport efficiency	×		×
	Transport distances	×		×
	Avoidance of heavy metals	×		
Use	Total cost of ownership	×	×	×
	Resource efficiency	×		
	Serviceability	×		×
	Air pollution	×	×	
End-of-life	Reuse	×		×
	Recycling	×		×
	Further processing		×	
	Material labelling	×		×
	Disposal	×		×

6.1.4 Step 4: Start with Pilot Actions

The provided pilot actions are structured in two parts: The first part contains the solutions from experts generated in a workshop, and the second part are collaboratively researched and developed solutions to provide additional ideas to the expert solutions. These ideas serve as a catalogue of arguments, opportunities, and possibilities to optimise the automotive plastics production and recycling system.

6.1.4.1 Solutions Developed by Experts

In order to develop solutions that are practical and realistic by 2020, experts from all relevant branches along the entire life-cycle of automotive plastics participated in a workshop for this book (see Chap. 8) and were asked to come up with solutions to improve the ecological sustainability of automotive plastics that were written on a flip-chart. Then they had to evaluate these solutions through 'resistance points', meaning that they had to hand out up to 10 negative resistance points for each solution. This method is called 'systemic consensing' (originally 'systemisches Konsensieren' in German) and was developed by Paulus et al. (2010). Through this very efficient and productive method, the following ideas for solutions were developed:

Solution - Rank 1, the niche solution attempt is intended to create a prototype whose recycled plastics share is up to 100% and the design-for-recycling is maximised to allow easy and high qualitative recycling to recover the highest possible percentage of materials. This project requires a strong collaboration between an OEM or supplier that is capable of manufacturing a whole car, at least one plastics recycling company as well as scientists. As a result, the valuable insights offer a transformation of knowledge from niches to mainstream and can be used in the mass production of cars to enable a very high percentage of recycled plastics and perfected design-for-recycling. After weeks of additional consideration, the author believes that it might be very challenging to manufacture all the plastic parts from recycled plastics, therefore a satisfying compromise was developed: In a first attempt, only the most critical and challenging plastic parts (visible and structural parts) are produced from recycled material in practice, and the less demanding parts are simulated in theory, thus achieving valuable insight with reduced expenditure. Then, in a second attempt the whole car is made from recycled plastics, or recycled materials in general, which could be a corporate sustainability, CSR, and marketing marvel.

Solution - Rank 2 aims at increasing in-house recycling of plastics waste accumulating in the production combined with increased recycling of ELV-parts which offer appropriate recovery results. These depend on the type, the dismantling and separation expenditure, the deterioration based on UV irradiation, and the age of the plastic. As discussed in Sect. 4.4.3, the following ranking highlights the treatment from best option to worst. Please note the difference to the Sect. 4.2, which did not consider that when one treatment option fails, the material can be tried in the next best one, leading to a treatment cascade always including blast furnace, which is likely to be limited by input:

Treatment cascade of ELV plastics in the year 2020

1. Mechanical recycling
2. Blast furnace (= chemical recycling)
3. Energy recovery
4. Other chemical recycling treatments
5. Landfilling

Solution - Rank 3 aims at establishing advanced certifications of cars, which include ecological and social criteria such as a minimum share of recycled plastics or materials in general and raw materials from responsible sources. In fact, this idea is intended to implement a holistic LCA of cars which is stated and advertised to the public.

Solution - Rank 4 is intended to provide decision support for car producers, and especially the designers, to simplify the process of using recycled material and improve design for recycling (Ecodesign). A suitable starting point is for example the 'Sustainability Checklist' developed by Schöggl (2012, p. 97) which was "particularly designed for the sustain-ability evaluation of innovative lightweight technologies in automotive development". Further, such a tool could be implemented in the International Material Data System: IMDS (Hewlett-Packard GmbH 2013). The current issue is that recycled plastics are often not certified for usage or included in material databases. Further, a holistic LCA such as described in 'Solution - Rank 3' could be included in such a material database as well.

Solution - Rank 5 aims at legal directives across Europe to determine a minimum share of recycled plastics and materials in general.

Solution - Rank 6 is intended to promote an honest eco balance of the car producers and the suppliers, which provides insight into the whole ecological impact of a car.

However, after rating the solutions the experts from the workshop argued that the legal directives (Solution - Rank 5) and the certification (Solution - Rank 3) are a prerequisite for and should be embedded into Solution - Rank 6, the honest eco balance, which was considered in the following solutions overview. Additionally, the question was raised who should be the one to perform the honest eco balance for cars and whether they are simply implementable via laws. Therefore, further research is required in this case.

6.1.4.2 Collaborative Holistic Solutions

Generally and apart from the already very narrowed-down solutions from the experts through the systemic consensing process outlined above, further solutions have come up also during the workshops and have been developed and discussed with the experts. Furthermore, solutions and ideas which have been developed over the course of this book based on theoretical and practice-relevant approaches and sources including logical connections are all now outlined together with the experts solutions in the following and concluded by a summarising table at the end see Fig. 6.5. As a result, personal approaches were also included in this section. Due to the wide range of branches in this book, the solutions provided represent various opinions and viewpoints, possibly causing a conflict of objectives and interests.

The solutions are structured according to the actors or stakeholders (companies, politics, and independent institutions) and the respective life phases (production, usage and end-of-life phase, following the structure of Fig. 3.20. For academic transparency, the solutions from the experts are declared as such to differentiate from own ideas, which are logical developments based on the entire information gathered in this book and beyond.

Covering all the phases of automotive plastics, the idea to link the business of automobile production with the ELV-treatment could be realised through a daughter company for ELV recycling or a joint-venture with an OEM and a waste treatment facility to offer a circular plastics economy. This would enable the OEM to enjoy the advantages of recycled plastics, for example such as reduced costs, independence from crude oil from questionable and unstable countries, positive corporate sustainability, CSR and marketing, and possible financial advantages in the future because of more sustainable, energy-, and greenhouse gas-reduced products (see Sect. 5). Another solution from the experts is the (voluntary) implementation of the honest eco-balance to provide information about the whole ecological impact of a car, as outlined in Sect. 6.2.

The overview of the solutions to advance the automotive plastics production and recycling system is depicted in Fig. 6.5. The solutions with a (W) are solutions which were developed and/or discussed by the experts from the workshops.

Production Phase

In the production phase, the companies, respectively the OEMs and suppliers, should do a revision of possibly overly demanding material requirements as the applicability of recyclates might be higher then previously determined and expected, as supported by Toldy et al. (2009, p. 971): "…many automotive companies have unjustified requirements (i.e., they overinsure themselves using only primary raw materials not even allowing the reuse of own plastic waste), which may be altered taking the necessary legal measures." Now in order to increase the share of recycled plastics, and already mentioned in the survey, "Constant composition, hardness, elasticity, UV-stability, (long)-term heat resistance, recyclability …" are the factors of capital importance (Toldy et al. 2009, p. 971).

The utmost important aspect to consider within the material selection process is the hierarchy of factors. In addition, one has to consider the data basis for the consideration or inclusion of new plastic materials or new material sources, which material information is retrieved by the materials engineer and the component-release engineer, which data is accessible, and which material data is recorded at all, while also bearing verification issues in mind. Furthermore, the knowledge, but more importantly the significance and weight of innovative sustainability concepts such as Ecodesign and their implementation are of high relevance, as well as the time

	Politics		Companies / Economy			Independent Institutions
Production phase		➢ Eco social taxing (W)	➢ Revision of (too) high material requirements ➢ Decision support for designers (W) ➢ Car from recycled plastics (or even material) ➢ in-house recycling + plastics waste treatment hierarchy (W) ➢ Design for recycling ➢ Plastics labelling (virgin or recycled)			
Usage phase		➢ Positive recycling incentives (W) ➢ Legal directives		➢ Motor workshop waste plastics collection and recycling (W)	➢ OEM + daughter company or Joint-Venture to recycle ELVs and use the recycled material ➢ Honest eco-balance	Oversee honest eco balance including: ➢ Legal directives (W) ➢ Certification (W)
End of life phase	➢ Less ELV directives (W) ➢ Promote specialised recycling companies (W)	➢ Certification for an honest eco balance (W)	➢ Blast furnace recycling (W) ➢ Get recycling technologies out of laboratory into the world (W) ➢ Recycling challenge: washing → research (W) ➢ Material recycling of tires (W)			

Fig. 6.5 Overview of the solutions to advance automotive plastics recycling

frame regarding trends and future perspectives (such as end-of-life scenarios). With regard to the Ecodesign, the marketing potential of sustainable materials might not be considered in the material selection.

Therefore, another solution by the experts is an improved decision support for car producers, and especially the designers, to simplify the process of using recycled material and improve design for recycling and Ecodesign. This was recently realised through a checklist for sustainable product development (see Sect. 6.1.3.2). Further, more sustainability aspects should be implemented in material databases such as the IMDS, the 'International Material Data System' (Hewlett-Packard GmbH 2013) because these are required in the product development phase. In particular, the end-of-life options of materials have to be disclosed in detail, as mentioned by Stagner et al. (2012, p. 1050). An additional objective is to connect the key players from cradle-to-grave through interaction, connection, and knowledge transfers as mentioned in Sect. 6.1.3.1. It is possible that the new ideas and results collected by experts such as Ferrão and Amaral (2006) and Urie and Dagg (2004) could be implemented to maximise the ecological sustainability of cars very early in the design phase.

> The real challenge now, both to the automotive industry and its plastic suppliers, is to work together to develop new assemblies that not only meet cost/performance requirements but also allow easier dismantling and recycling. (EuPC 2013)

The current issue is that recycled plastics are often not certified for usage or included in material data bases. Furthermore, the honest eco-balance (as described in Sect. 6.2) could be included in such a material data base as well. Another expert solution is to improve in-house recycling of production waste on site combined with ELV plastics recycling adapted to the age and condition of the material as described in Sect. 4.2. Yet another is the attempt to build a car with a very high degree of recycled plastics or even recycled materials in general as described in Table 6.2 (the niche-solution attempt).

Concerning composite materials, the EOL is especially important, as currently, recycling is hardly possible. Consequently, EOL-compatible composites such as thermoplast carbon fiber, or even biobased thermoplast composites with natural fibers suitable for recycling via solvolysis or at least thermal recovery. Bioplastics in general could be made from bio-waste in the best case, or from non-food plants which are recyclable, also mixed with conventional plastics, or easily traceable, separable, and detectable to avoid difficulties in the EOL-phase.

Table 6.2 Ideas from experts to advance the ecological sustainability of automotive plastics

Rank	Idea	Resistance points
1	New prototype with maximized recycled plastics share (niche solution attempt comparable to BMW i3, Magna Steyr CULT)	2
2	Recycling of production waste plastics (high purity material in-house recycling) in combination with recycling of certain chosen ELV-parts depending on dismantling and separation possibility and age of ELV	4
3	Certification (ecological, social, (including share of recyclates),…) of cars (holistic LCA)	15
4	Decision support for car producers (designers)	16
5	Legal directives (across Europe) regarding the share of recyclates	18
6	Honest eco balance of the (car) producers	21

Usage Phase

Ranging from the usage to the end-of-life phase, the experts came up with the idea to recycle the waste parts from car workshops, as these parts are currently not recycled sufficiently and are more significant in quantity and quality compared to ELV plastics, which are difficult to recycle by comparison, which could pose an economically sound and ecologically sustainable opportunity.

End-of-life Phase

In the end-of-life phase, the best solutions are to increase blast furnace treatment of automotive plastics due to the fact that this treatment is substituting fossil fuel in the steel production. As the blast furnace is perfectly suitable for old (negatively changed, low-performance) plastics from ELVs, for example older than 15 years old (this depends on the exposure to UV-rays for example). Moreover, it is difficult to define blast furnace treatment: Whether it is material recycling, thermal recovery, or something in between, but it is generally considered 100% material recycling, according to communication with experts from an international steel production company. Additionally, there are currently large differences between countries concerning this definition, which causes import and export of plastics waste to increase the recycling and recovery rates (see Sect. 4.4.3). In addition, the experts from both workshops explained that highly advanced recycling technology is currently only available in the laboratory and that it might be a solution to promote putting laboratory technologies into practice. This might be possible through large-scale projects in order to create positive financial returns.

Concerning the available technologies, the cleaning (washing) of the input material is currently very demanding, requiring further research and development. Furthermore, it is advisable to achieve an economic landscape with numerous specialised recycling companies instead of few who recycle everything (similar to the solution for politics). This is the case because the input quantities are too low for one big recycling company. The question of the industrial customer of the recycled plastics is also of concern as several different material supplier companies are required for the automotive industry to guarantee reliable delivery with manageable risk. Another expert solution to manage ELV recycling is to introduce a car deposit system in which the user is paying a deposit, or is leasing the car from the producer and returns it after the usage period, receiving the deposit. The manufacturer receives the raw materials and can use them in the production. Aside from treating plastics, especially the material recycling of tires has potential according to the experts. Therefore, further research is required on tire recycling.

6.2 Solutions for Politics and Independent Institutions

According to the experts from the workshops, the power of politics is still game changing. Therefore, the following strategy to advance ecologically sustainable automotive plastics serves as a game plan:

1. Provide positive political incentives for a circular economy and raise public awareness through media campaigns
2. Companies will put the solutions (such as those provided in Sect. 6.1.4) into practice because they have to due to economic competition accelerating the circular economy

Concerning the ELV-directives, the experts thought that the politics should steer away from the recycling and recovery quotas as they are possibly not helpful because of the considerable export of ELVs out of the EU. The focus should be on the producing industry through positive incentives to promote recycling, and through eco-social taxing such as quotas for the production of materials. For example, politics should prohibit hazardous substances and stipulate to use at least, for example, 20% recycled materials. As a result, a new directive for the prohibition of substances (hazardous and virgin) could be implemented. However, experts from the workshop noted that positive incentives are the most promising approach to promote recycling, for example, by means of financial benefits for using recycled materials in the context of eco-social taxes. Even carbon taxing might be fruitful, because this would steer the plastics waste to the treatment option with the least carbon footprint. Furthermore, it is advisable to achieve an economic landscape with numerous specialised recycling companies instead of few who recycle everything (similar to the solution for companies in the end-of-life section). Another option is to introduce a holistic and honest eco-balance (an extended LCA) of cars from the raw material extraction to the end-of-life including certifications and legal directives. Partly resembling model examples are the "Blue Angel" (RAL GmbH 2013) and the "EU Ecolabel" (European Commission 2014), both environmental labels to mark sustainable products. However, the experts from the workshop concluded that politics might have no opinion, or should, or even must not have an opinion. This might also be represented by the missing feedback and the rejection from politics in the survey. It is possible that this issue is not yet important enough.

Apart from automotive companies and politics, independent institutions could help to improve the ecological sustainability of automotive plastics. For example, the supervision of the honest eco-balance of cars from the raw material extraction to the end-of-life including certifications and legal directives would require such an institution.

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Chapter 7
The Sustainability Illusion Versus the Recycling Renaissance - A Discussion

Abstract Are we even in theory on the right path? The results obtained for this book turned out to be highly controversial, especially when comparing theory with reality. Therefore, an extensive discussion provides an analysis of patterns, exceptions, relationships, and the generalisation of results. In fact, how significant are the results? What do we now understand with the results? And do they (dis-)agree with previous works? When considering the theories discussed in Chap. 2, such as human ecology, eco-efficiency and eco-effectiveness, resource and impact decoupling, as well as corporate sustainability, it becomes clear that these notions offer valuable strategies to improve sustainability in the economic world. However, the results from Chaps. 3 and 4 show that these theories still remain mostly theories. Many companies know in theory how to apply sustainability, Ecodesign, however you might call it. However, many of them incorporate sustainability not as a vision, but as a way to achieve compliance with the law. This is now unravelled in a discussion of a possible sustainability illusion followed by an investigation of the chance of a recycling renaissance, and whether this is the right path for the automotive plastics production and recycling system.

7.1 Today's Illusion: True Sustainability

When considering the theories discussed in Chap. 2, such as human ecology, eco-efficiency and eco-effectiveness, resource and impact decoupling, as well as corporate sustainability and CSR, it becomes clear that these notions offer valuable strategies to improve sustainability in the economic world. However, the results from the Chap. 3 and the empirical part starting with the Chap. 4 show that these theories still remain mostly theories. Companies know in theory how to apply human ecology, sustainability, Ecodesign, however you might call it. Yet, many companies are more concerned with their stock price. And true sustainability is not yet deemed worthy enough to have a positive impact on the stock price. In fact, green washing might be deduced as the end result of so called sustainability efforts.

And exactly this contrast between theory and reality now concerning automotive plastics was analysed in detail and confirmed firstly in the theoretical section Chap. 3,

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secondly in the conducted Chap. 4 and finally in the interviews and workshops with experts leading to the Chap. 5, and the Chap. 6. To discuss the outcome of this book, the structure of the previous chapters is reused, starting with sustainability theories and facts, followed by plastics, the automotive industry, and the automotive plastics recycling. Now, and in contrast to the scientific disquisition in the previous chapters, a personal approach, which was developed throughout this book, will also be included in this chapter as well. Additionally, the funnel-logic distillation approach (see Chap. 1) will be applied again, starting with the general and broad theory results to finally end with the detailed and narrow results of the empirical part of this book.

We, The Sustainability Hypocrites

When reflecting the knowledge gained during this book, it became exceedingly apparent that the current society is headed toward a dead end. The scientific evidence is abundant, and even the worst case scenarios concerning ecological degradation such as climate change have been calculated (Cook et al. 2013; Pachauri et al. 2014) (see Chaps. 2, 3, and especially Sect. 2.4.2). Still, society is not taking effective countermeasures. Mostly, it is not what we do, but what we say that matters, and as long as only the proclaimed action is considered sufficient, society will not change. 'The road to hell is paved with good intentions'. This saying is applicable to the current development of humanity, characterised by countless intentions and very little action.

At present times, the global economy's prevalent goal is growth, both in terms of size and financial assets. Yet, chances are high that this goal is no longer feasible. In fact, this form of growth-oriented economy is to be questioned. Even more strongly, one might conclude that this neo-liberal economic approach is to be abandoned, and a new way of thinking should be introduced, steering away from growth and money towards reduction and sustainability. But today, success is primarily equated with riches and wealth, and this is the fuel for the current unsustainable economy. In a newspaper article, DiePresse (2013) states that this drive for growth, which should be of use to humanity, might produce the egoism that is ultimately hurting humanity. Consequently, he even asks whether one can be a good *and* wealthy person at the same time, when considering the entire globalised system.

So is there generally a chance for a new way of thinking? Or does it already exist? From my experience as a teacher, I dare to say that there possibly is already a new, a more sustainable and holistic mindset, but so far primarily among the younger people. Still, there are already companies implementing sustainability into their corporate vision, but this is mostly limited to Europe. Nonetheless, the new mindset, which is truly sustainable, is still in an infancy stage and heavily challenged by the economy. Because, when young people are confronted with the choice of education at universities, potential financial success becomes significantly relevant. Moreover, a chance for change is perceptible, yet there are severe challenges ahead to change the system for the better. A mindset to aim for establishing a circular economy not focused on growth, but on true values to establish a socially and ecologically sound and sustainable economy enabling humanity and nature to live a healthy and fair life.

Additionally, this mindset has to develop amongst the rapidly growing population throughout the entire globe. In fact, together with the increase of global wealth, the automotive sector in particular is facing severe challenges (see Chap. 3), such as the subsequent increase of cars per capita. And when narrowing down to automotive plastics, this funnel of developments is the result (see Sect. 3.3).

1. Exponential population growth
2. New markets, new consumers
3. Increase of affluence/wealth = more cars per capita
4. Increase of plastics share in cars
= Increase of plastics demand
= Increase of demand for fossil fuels
! No or very little circular economy
! Extraction and emission of greenhouse gases caused by (automotive) plastics

As the negative aspects apart from the rapid global population growth are centering on fossil fuel extraction and carbon emission, the importance of these fluids for the economy and for society is to be questioned.

Our Liquid Economy - Built From Oil

Fossil fuels are the fuel for our economy on the one hand, and for climate change on the other hand. So in terms of ecological sustainability, this fuel has to be substituted rapidly or even abandoned due to the high greenhouse gas emissions [one barrel conventional crude oil (159 L) account for 28.6 kg of CO_2e; one barrel oil from oil sand accounts for 85.5 kg of CO_2e (Woynillowicz and Severson-Baker 2009)] (see Sect. 3.1.3). In fact, availability of oil is not the challenge, but rather the resilience of the ecosystems and especially the atmosphere. So what will happen if the oil price increases significantly and steadily? Or possibly a new oil crisis emerges in the future? Currently, such oil-related crises might cause a global economic breakdown due to the high dependency on this liquid in abundant branches. However, this could offer a chance for society:

> Together the 'end of cheap oil' and the emergence of carbon pricing have the potential to re-draw the map of economic activity in some interesting ways—just as previous revolutions in the cost and availability of energy to society produced distinctive geographical forms. (Bridge et al. 2013, p. 335)

As a result, an oil crisis might help create a circular economy and a major reduction of carbon emissions because of resource scarcity. And substitution of oil is possible and a manageable challenge.

The Recycling Decline

During the interviews and the workshops, numerous experts claimed that recycling in general is declining. Some mentioned that this is caused by reduced recycling efforts in politics, such as positive incentives to increase or at least hold the recycling rate. Based on this notion, an analysis on books dealing with recycling revealed that there was a significant peak in 1995 where numerous books concerning recycling were published (research tool provided by Google Inc. (2017), based on Michel et al. (2011). In 1995, 0.0007022820% of the provided 'English' corpus had the search

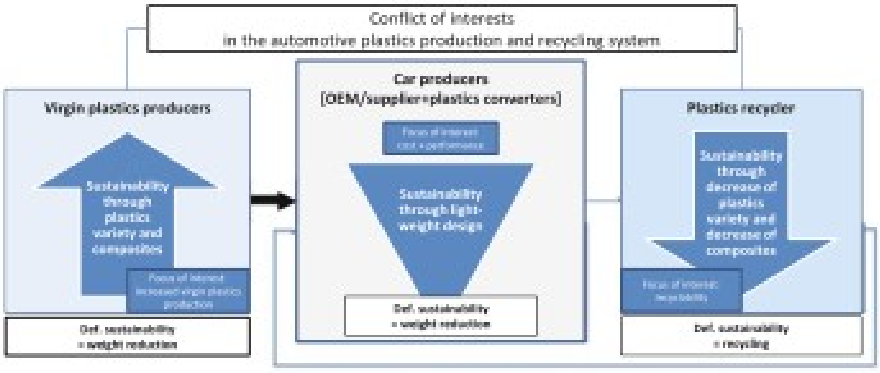

Fig. 7.1 Conflict of interests concerning automotive plastics, validated with experts

term[1] included, which decreased by 33.4% to 0.0004676883% in 2008. Please note that this is not a scientific research tool and only included books from 1500 until 2008. However, this is a significant reference point and highlights that recycling has become less important within society, which was confirmed in discussions with experts. Additionally, a similar analysis for plastics recycling was performed, which revealed an analogue decline of plastics recycling[2]). The development of publications concerning plastics recycling shows several peaks. The first rise began around 1970, then a second rise from 1988 to 1992. From then on, a decline with a little peak around 2003 continued until 2008, reaching again the low level from 1988. Unfortunately, the data was not sufficient to create book publication analyses for automotive or automobile plastic(s) recycling, which might be however possible in the future.

Virgin Plastics Industry Versus Recyclers

Considering (automotive) plastics, competition is currently not the case because of the economic difference between the virgin and the recycling industry. The former is a very potent, well established and innovative branch, whereas the latter is still in its infancy. Furthermore, there is mostly a conflict of interests within these two branches (see Fig. 7.1). Taking the definition of automotive sustainability concerning plastics for example, the virgin industry defines it by weight reduction. Because their interest is focussing on increasing the production, they try to promote ecological sustainability through an increase of the variety and the amount of plastics. The recyclers, on the other hand, define ecological sustainability by recycling, their focus of interest is on recyclability and as a result, they promote ecological sustainability through a decrease of the plastics variety. The customer of both industries is the automotive branch. They define ecological sustainability by weight reduction like the virgin

[1]For this analysis the following term without was used: "recycling + Recycling + RECYCLING".
[2]For this analysis the following term without was used: "(plastics recycling) + (Plastics Recycling) + (Plastics recycling) + (PLASTICS RECYCLING) + (plastic recycling) + (Plastic Recycling) + (Plastic recycling)".

plastics industry, and promote ecological sustainability through lightweight design. Additionally, their focus of interest concerning materials is on cost and performance. Therefore, the automotive OEM or suppliers, when solely relying on facts, should obtain from the recyclers under the condition that cost and performance are at least equally or better met than virgin material. Additionally, one has to include possible environmental and marketing benefits from recycled material, which might outweigh possible extra costs.

Due to this conflict of interests, the overarching interests of (future) humankind, which is true sustainability, is of minor concern. However, the car producers have the opportunity to bring about the vital paradigm shift by stimulating the plastics recycling industry by demanding high quality recyclates for cars.

After intensive discussions with experts from the virgin plastics industry, I discovered that most of them are stuck in the unchanged and hardened procedures of their respective company. Because actually those virgin plastics experts are thinking about or some are even trying to implement ecological sustainability in their business, but this is a demanding undertaking (see the survey results from the Sect. 4.4.3). One positive example is a virgin plastics companies from Austria, that has bought a plastic recycling company, to learn from them how the recycling technology and business works. However, to make a complete transition to an ecologically sustainable production, the virgin plastics industry has to rethink their business model.

Of course, they see the risk that recycling is opposed to their core business, but this change is essential. In fact, they have to accept the challenge. The plastics manufacturers who now rely on recycling can prevent losses by the upturn in the recycling industry. The question, of course, is which virgin plastics producers will have the courage to enter the recycling business? In my view, firms currently rewarded by 'business as usual' policies will soon be punished by consumers. A transformation that moves resource-hungry production of virgin plastics in the direction of the recycling industry is also a question of whether decisions will be made on the basis of facts or ideology, habit, or innovation-killing phrases like 'has always been this way', 'too much effort and risk' and the classic 'doesn't work'. Viewed as objectively as possible, the recycling renaissance is the only way for Europe to ensure a strong plastics industry secure in the face of future losses. And the automotive industry is already on the way, albeit hesitantly.

Automotive Ecological Sustainability - a Lie?

During the development of the point-of-view scenarios (see Chap. 5), the question was raised whether and how cars can be ecologically sustainable. Strictly speaking, abolishing unsustainable forms of individual transport would be the best solution, and cars are generally unsustainable in terms of ecology. So is it even possible to talk about automotive sustainability? Or is it at most possible to create a car with a low negative environmental impact compared to modern day cars? It seems that sustainability is currently and actually merely 'impact reduction', but not true sustainability. When talking about recycled plastics in cars for example, the actual goal is to reduce the negative impact of the car by replacing virgin plastics. In this case, the impact reduction potential is a crucial factor. However, the only true sustainable path is to avoid producing, using, and disposing a car and selecting the bicycle or public transport instead, if possible and reasonable. Currently, the automotive industry and the media proclaim the next sustainability revolution - lightweight electric cars. However, according to DiePresse (2013), this might be comparable to the hype of nuclear power in the 1960s, which was said to solve all the problems. Even nuclear powered and flying cars were predicted to solve the transportation issues at that time. Possibly, 2015 is another 1960 and we might discover in the future that our sustainable solutions have not been sustainable at all, or even worse than the original solutions. Still, it should be mentioned that compared with electric cars, nuclear powered cars have never been realised.

The automotive sector is sustainable - in theory. The best examples are the flood of sustainability reports whose goal is in fact rather unclear (Baumgartner and Ebner 2010). When analysing the ecological sustainability performance concerning plastics, the action seems to focus on written declarations of intent, insignificant small-scale projects and commonly one car model in a certain trim level which performs comparably well in a definite sustainability aspect with prominent marketing campaigns or emphasis in the sustainability reports. For example, a car model whose plastic recyclate share is up to 20% (BMW Group 2015), might be 0% in the end (see Sect. 3.2.2). Fleet-wide implementation of sustainability enhancements and communication of transparent and hard facts concerning recycling still leaves something to be desired. As a result, one can make a distinction between 'walkers' and 'talkers' (Kiron et al. 2013, p. 10):

- "Walkers — companies that report 'largely' or 'fully' addressing all significant sustainability issues
- On the Road — companies that 'largely' or 'fully' address some but not all of the sustainability issues they deem important
- Talkers — companies that only' somewhat', 'barely' or don't address all of their significant sustainability issues"

Therefore, the challenge is to convince talkers to become walkers. Consequently, Kiron et al. (2013, p. 11) conducted a survey to discover the reasons for management inertia and inaction which revealed that "[c]ompanies are struggling to settle on and rally around the important sustainability threats and opportunities they confront. Competing priorities, for example, are the most common stumbling blocks with 41% reporting them. Difficulty quantifying sustainability's intangible effects stands in the way of 35%. Short-term thinking in planning and budgeting cycles follows closely with 31%. Overcoming these issues tend to require organizational catalysts". Accordingly, companies have to give sustainability a higher priority, employ sustainability change managers or train their own managers, establish a sustainability agenda company-wide, promote ideas how to improve the ecological performance throughout the life-cycle, and manage their implementation.

The Global Life-Cycle of Cars

Cars travel the globe, especially after the supposedly last owner. A large share of vehicles deemed waste in the EU is being exported outside the EU, mostly eastwards in a circle until arriving at its final destination: Africa (Parliament 2010, pp. 10, 42). Of course, people in these regions require means of transport, but is it ecologically sustainable to ship and reuse cars which are exceedingly detrimental to the environment because of their age? Thus, massive emissions are being exported to less developed countries (LDCs). Possibly, car manufacturers and countries should keep ELVs for recycling through superior ELV laws and design inexpensive cars for LDCs and manufacture them on-site, due to a different approach to car design and reduced transportation. Consequently, the ELV or second, third, or fourth hand car export to LDCs would decrease and the environmental impact of global transportation could be improved. Of course, this would require further research but might offer a sustainable development of the global automotive sector. In addition to the export of ELVs, the durability of automobiles is also highly relevant to ecological sustainability. Cars with a real life time of 200,000 km are not ecologically sustainable. Reliable cars might decrease the negative environmental impact as the usage phase is extended preventing a new car from being produced. Therefore, car manufacturers, politics, and consumers should focus on reliability to increase automotive sustainability. However, this should be researched in detail due to high complexity concerning the life-cycle analysis.

Material Selection Decision Making Process

Due to the competition between virgin and recycled plastics and a great variety of plastic types and composites, the material decision has become a challenge for the automotive industry. Currently, the possibility of process driven decisions rather than reasoning driven decisions (see Chap. 4), the material selection process can be highly influenced by the present organisation culture and the extent of resilience, adaptability, or flexibility within. For example, when complex and time consuming request forms and paths are required to validate, register, and apply a new material. In a company, professional blinkers and lack of objectivity might arise, which could cause subjective errors. As outlined in Sect. 2.4.4, the decision making process is influenced by the possibility of egoistic action by the individual in the system which can lead to seriously negative outcome (Kulke 2013). Consequently, the material decision making process is likely to be restricted by actor behaviour, and possibly by the physical and psychological company boundaries.

On the contrary, open innovation as introduced by Chesbrough (2006) is currently hyped by the industry, but there is still room for improvement. However, companies seem to require assistance in further opening their gates to the new, innovative, and unknown, such as recycled plastics. New approaches to material selection are necessary to advance the industry. Possibly, open innovation can be such a new approach. Additionally, this book revealed that stakeholders not related to the firm should be incorporated as well to increase sustainability. Furthermore, the characterisation of the process to decide on materials in companies requires further research through decision-making channel-based analysis to reveal the decision route within a company.

Virgin and Recycled Plastics Demand in the Car Production

The companies know that the share of plastics will rise and that consumers (will) demand more ecologically sustainable materials, such as recycled and renewable plastics (see Chap. 4). Companies even acknowledge that ecologically sustainable materials are a competitive advantage, deem recycled plastics positive and competitive with virgin material, and even plan to increase the share of recycled plastics. However, this share is currently very low (63% state that the average percentage is below 11%, see Chap. 4).

Concerning the companies who might implement recycled plastics in the automotive branch, there was one question in the survey which highlighted a significant difference between OEM and suppliers: 'Did you or your company investigate possible applications of recycled plastics in your products?', which revealed that 95% of OEMs did investigate the application of recycled plastics, whereas only 73% of the suppliers did. As a consequence, the focus of ecological sustainability actions could be directed on the suppliers, possibly upon consultation of the OEMs because they are the ones purchasing and ordering from the suppliers, which might require approval. However, the usage of recycled plastic is an opportunity due to technological advancements.

So is Recycling REALLY Better?

When focusing on the production and end-of-life phase of cars, one might question whether recycled plastics are really less harmful to the environment compared to virgin plastics. There are significant weaknesses of recycled plastics such as "limited market applications for recycled plastics, low value of recycled resin and efficacy concerns" (Duval and MacLean 2007, p. 1167) and especially the recycling of mixed plastics waste. Still, recycling is the favourable option under the presumption that the average virgin plastics production uses fossil fuels, emits greenhouse gases, and requires energy as outlined in Chap. 3. To provide a short example of the environmental benefits, recycled plastics can reduce the energy consumption by 50% to 88%, and the greenhouse gas emissions (CO_2e) can be reduced by 50% to up to 75%, according to Duval and MacLean (2007), Franklin Associates (2011), and Jenseit et al. (2003). Nevertheless, Jean-Charles et al. (2010, p. 50) claim that a low share of recycled plastics (in combination in this case with a remainder of 50% concrete and 50% wood) is even worse than using no recycled material: "This means that under the assumption of a degree of virgin plastic substitution of 20%, the impacts from the recycling process are no longer offset by the benefits from the avoided material production". (Jean-Charles et al. 2010, p. 50). However, this scenario[3] is a special case through the substitution with concrete and wood, however, the underlying statement is relevant that the substitution ratio is relevant in the environmental impact calculation. Consequently, the review of 8 LCAs including 22 cases by Jean-Charles

[3] "The base scenario, for which a degree of virgin plastic displaced by recycled plastic of 100% is assumed, is compared to a scenario in which only 20% of the recyclate replaces virgin plastic (the remainder being evenly split between substituting for concrete and wood)". (Jean-Charles et al. 2010, p. 50).

et al. (2010) revealed that the benefits of recycled plastics are at the maximum when the ration is close to 100%. This claim might support companies to expand their implementation of recycled material to 100% as lower percentages might not reduce the negative environmental impact of cars. Of course, this requires further research as the degree of complexity is very high in this case due to various car models, production methods, materials, locations, recycling technologies, costs and so forth. Additionally, the possibility of inevitable downcycling has to be considered when frequently recycling the same material, which could diminish the cycles of plastic.

Moreover, it is advisable not to hype recycled material in general, as exceedingly complex recycling processes might cancel positive environmental effects. Especially when considering hazardous, toxic, and contaminated waste, incineration is sometimes the only method to dispose of these substances and remove from the system (LaGrega et al. 2010), such as with hazardous medical substances (Chartier et al. 2014). Concerning the recycled material itself, the survey participants stated that using recycled material can reduce the material and thus the product quality, and the recyclability of the recycled material is of legitimate interest as single use recyclates would only prolong the life phase of the plastic material by one cycle. However, this case is improbable, because qualitative acceptable recycled plastics show a high degree of purity which enables further recycling. Still, this issue needs to be considered as well when assessing the life-cycle of materials.

The ultimate question however is whether NOT recycling is economic in the long term as generations in the future might have to pay for not recycled plastics. And is NOT recycling in the long term even manageable due to environmental pollution resulting in human health disturbances? In all probability, recycling is the better and preferable solution, as it implies that the pollution of the environment is reduced to a great extent which might prevent significant and restrictive rebound effects one can only assume.

The Systemic Opportunity for Automotive Plastics is Recycling

The chance for the automotive industry is a chance for a sustainable society. Because currently, the system concerning automotive plastics is not ecologically sustainable, it causes negative effects on the environment such as 1.80 kg CO_2e per kg virgin HDPE (PlasticsEurope 2014) and thus on humanity. In this case, the negative effects are mostly linked to the OEM because the usual customer of cars is not aware of the complex supplier system in the car production process. This is especially of concern within the regulation of public law in the (extended) producer responsibility 'EPR' (see Sect. 3.2.3). Consequently, the OEM mostly takes the blame for environmental damage (Koplin et al. 2007, p. 1053), which consequently requires the OEM to achieve an ecologically sustainable supply chain.

However, as outlined in this book, using recycled plastics can lessen the negative effects.

7.2 Today's Chance: The Recycling Renaissance and Holistic Sustainability

The discussion of the positive outcome (the chance) of this book is starting with sustainability theories and facts about circular economy and decoupling, followed by the spatial distribution of plastic materials, the plastics recycling system, recycling as a chance for virgin plastics producers, and how to put sustainability theory into automotive practice, in a structure similar to the previous chapter.

Moving to the recycling renaissance and the holistic sustainability, it became clear that most companies are not (yet) rational and far sighted enough, or too focused on money and growth to realise their chance, the chance to transform their business for the better through implementing holistic ecological sustainability. The current path is very unlikely to be the one to continue in the long term. In fact, we have to act right now, because nature will continue to thrive likely in new forms, despite humanity changing the circumstances. But will humanity continue to thrive as well? Not environmental degradation, but human degradation might be the result in the end.

Despite the ecological necessity, the economic aspect is of high relevance as well. Especially circular economy has a growth potential for 400 billion Euros and 160,000 new jobs in the EU according to WRAP (2013), emphasising the chance for the economy. Additionally, Bernhard Merkx, president of the European Plastics Recyclers (EUuPR), mentioned in an article that more than 50,000 jobs could be created if only the export of waste plastics would be regulated, because plastics recyclers are in need for better waste streams to produce high quality recycled plastics (RecyclingToday 2010). However, this could diminish economic success in the virgin material industry and potentially reduce material thus product quality because of the weakness of recycling to date such as material purity.

Consequently, society has to introduce the 'Recycling Renaissance' together with politics for maximum productivity. In the UK, for example, EEF EEF [manufacturers' association] (2012) suggests that the government in charge should increase their efforts and develop an action plan, which should include for example a ban of recyclable materials being incinerated and disposed, if ecologically and economically wise. The European Commission (2015) is promoting circular economy, but regrettably still includes incineration as an acceptable waste treatment option, even though this is not advisable for recyclable materials. Zero Waste Europe [ZWE] (2014) recommends to

1. "pursue a real "closed loop" circular economy by banning both landfilling and incineration by 2030
2. introduce a feed-back mechanism between waste and product policy; by screening what is not reusable or recyclable today, we can send a signal to producers to redesign the product so that it stops being waste in the future".

As a result, the only waste treatment options remaining are reduction, reuse, and recycling. And nothing else, but again concerning materials that are generally recyclable. This law is therefore considerably eco-effective, through a considerable level

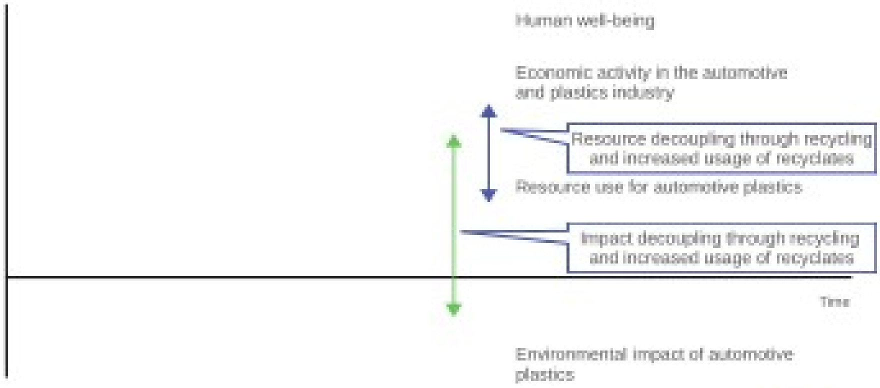

Fig. 7.2 Automotive plastics decoupling, adapted from (Fischer-Kowalski and Swilling 2011, p. 15)

of plastics production combined with equally significant recycling at the end-of-life phase (see Sect. 2.4.2). Moreover, when adapting and introducing new laws, it is vital to analyse the consequences on all levels. For example, Patterson et al. (2011, p. 41) state that certain regulations with positive intentions can cause negative effects in areas or phases, which have obviously not been sufficiently examined when drafting the law.

Circular Economy and Decoupling

As the human well-being and the economic activity is rising, and circular economy is not yet implemented to a satisfying degree, resource use and negative environmental impact is also rising, especially in the case of the automotive industry. However, circular economy provides a piece in the puzzle to achieve decoupling (Fischer-Kowalski and Swilling 2011). As the current state in the automotive sector is to be decoupled, the implementation of circular economy through recycling and increased usage of recyclates is obligatory (see Fig. 7.2). This is especially relevant when considering the apparent increasing importance of the production phase due to powertrain electrification, as outlined in the Chap. 3 and in the Sect. 3.3).

Of course, to achieve decoupling, economy and society have to transform and implement a holistic circular economy. For this reason, (Pomberger and Ragossnig 2014, p. 89) have developed strategies to advance the circular economy, called the 'future waste concept':

1. "Apply or adapt existing recycling/treatment solutions.
2. Develop and implement recycling/treatment technologies driven by target recycling rates set by regulations.
3. Construct re-use solutions, even if only minor amounts of 'future wastes' may be avoided that way.
4. Install feedback loops from the recycling sector to the production sector in order to stimulate expanded application of eco-design methodologies.

5. Foster holistic assessment of production/recycling systems connected to certain products/services in order to demonstrate the benefits of implementing the concept of eco-design.
6. Implement drivers (such as legal requirements, economic incentives or expanded research) to encourage a broader implementation of management alternatives for 'future wastes'."

When analysing this concept and adapting in to the automotive sector, it becomes apparent that the cooperation between production and recycling companies, combined with holistic political incentives and scientific life-cycle assessments, is the key to success.

The Geographic Origin of the Materials

Due to the exceeding trade complexity of the automotive sector, the geographical locations during the journey of the material are at issue. The most relevant stages are: the source of the raw materials and form of extraction, the raw material conversion, module production, the car assembly, the usage and maintenance through numerous hands, and finally the end-of-life. Currently, the routes in the automotive sector are exorbitant and unnecessary, and require rethinking to improve the holistic sustainability. However, in certain cases even the companies do not know the origin of their material, such as whether the plastic material is virgin or recycled, or whether their rare-earth metals are from socially acceptable mining industries, as interviews with experts revealed. Furthermore, the elimination of differences and the filling of loopholes in laws offer chances to prevent unnecessary trade thus increasing sustainability. In fact, global transport has become so inexpensive at the expense of the environment. However, the idea is to deal with waste as close as possible to the source.

Circular Economy, Shredder and Plastics Recycler

Is the plastics recycling market too young and technically not sufficiently developed to compete heavily with the virgin plastics industry? Yes, definitely, especially when comparing it to the metal recycling industry which established a solid branch, also due to differences in the technological challenges. However, the big lead of the virgin plastics companies compared to the recyclers is based on their long and successful presence, and their resulting size and power. By contrast, the recycling business is very young, the recycling technology has its weaknesses, collecting and sorting are challenging, and recyclers are lacking in size and a supporting structural background, such as influential interest groups, a supportive network cluster, and a lobby to steer politics. Therefore, a much stronger representation is vital for competing on the market. With respect to this issue, the recyclers should also raise awareness that certain potential technical drawbacks of recycled plastics might not be a drawback in certain fields of application. For example, in the automotive sector, the requirements for cleanliness to prevent health issues from leaking chemicals, which might occur in recycled plastics more than in virgin plastics, is lower than, for example, in the consumer plastics branch. Consequently, the marketing for recycled plastics is to be improved to demonstrate the holistic benefits when selecting the right recycled material for the right application.

Recycling - An Ecologically Sustainable Chance for Virgin Plastics Producers

The consumers are critical, more than ever. They are sceptical, they question the status quo, their daily routines, their activities, their products, and the industry. Especially the plastics branch has become discredited massively: from Bisphenol A, to plastic particles in our bodies, to new plastic continents in the oceans. In fact, the connotation of 'plastics' is primarily negative, which is very unfortunate because plastics offer so many possibilities like no other material. Still, the virgin plastics industry is far from ecologically sustainable.

Now to make the transition to an ecologically sustainable industry, virgin plastics producers have to rethink their business and implement recycling. Of course, this is bearing a risk that plastics recycling is offsetting and jeopardising the producers' core business, but this change is essential. The plastic manufacturers that rely on recycling right away can prevent losses by a flourishing recycling industry. The question is, of course, which virgin plastics producers will have the courage to enter the recycling business. In my view, this courage will be greatly rewarded in the future because unsustainable 'business as usual' will be punished by the consumers in the long run. A transformation of the resource hungry virgin plastics production towards a recycling industry is also a question whether decisions are based on facts or on the companies' ideology, habit, or killer phrases like 'it (our approach) has always been that way', 'it is too much effort and risk', and the classic 'it doesn't work'. Because, when regarding this issue as objectively as possible, the recycling renaissance is a legitimate way to protect our strong plastics industry in Europe against future losses. Many industries are already on this path, though still very hesitant. Moreover, especially profitable companies can afford to invest in sustainability (Perl-Vorbach et al. 2015, p. 11, 12), and the virgin plastics producers are successful. For these reasons, the plastics industry has to catch up, act and implement ecological sustainability through recycling thus increasing competitiveness in the long run. Possibly, parallel business lines combining virgin and recycled plastics production, or even implementing renewable raw materials for the virgin production might pose opportunities. Still, the demand for plastics is extremely high, which cannot be met by the recycling industry alone, not yet. In fact, "cradle-to-cradle" (Braungart et al. 2007) is not yet applicable, but will be applicable in the very near future. Therefore, the virgin plastics industry has to act now, instead of reacting, which might be too late to succeed in transforming into a competitive sustainable business.

So, How Good Are the Solutions to Advance Automotive Plastics Recycling?

The process to develop solutions by and together with experts has proven to be very productive. Embedded in Chap. 6, the expert solutions from Sect. 6.1.4 were developed through a successful scientific approach. As the results from the survey have been shown to and validated by the experts before discussing the solutions, basically a link between up to 225 experts from the survey and the experts in the workshop was established resulting in significant and applicable solutions. Additionally, the solutions were developed according to the strategies for transdisciplinary sustainable development by Baumgartner and Ebner (2010), Braungart et al. (2007), Fischer-Kowalski and Swilling (2011), Janschitz and Zimmermann (2010), and McDonough and Braungart (2013) as outlined in the Chap. 2. However, are those solutions any good?

The best idea according to the experts, which is the niche solution attempt to build a car made from recycled plastics, is in terms of research and knowledge build-up to gain experience with a very high share up to 100% of recycled plastics and advanced and genuinely beneficial eco design. However, the challenge is to actually try producing every car, in fact, the entire fleet according to the specifications of this prototype or niche car in terms of life-cycle sustainability and ecologically sustainable materials. The idea to increase the recycling of production waste (in-house recycling) might call for political incentives to be able to invest in the required machinery. Moreover, the certification, the legal directives, and the eco-balance are powerful solutions, but they require powerful politicians who are independent of compelling lobbies. The idea for a decision support tool for automotive designers is persuasive, but the question comes up as to who is paying for the development and maintenance. The recycling industry? Possibly. But in fact, politics or in this case the European Union should invest in this idea, because this is a great chance to walk the talk and stimulate the demand for recycled plastics. But more importantly, is it preferable to stimulate first the demand for recyclates, or to increase the quantity and quality of recyclates? Possibly the first is preferable, because the market is believed to react and meet demand.

Furthermore, the developed solutions are in accordance with proposed ideas from the "European Strategy on Plastics Waste in the Environment" (European Union 2013) to improve the eco design of products, improve collection and sorting, reduce landfilling, and take political action to establish a circular economy. Additionally, they are overlapping with the ideas from Maudet et al. (2012, p. 17) to improve the recycling industry (in this case in France), which confirms the quality of the found solutions:

1. "improving sorting techniques, developing them in the laboratory level to increase both the quantities recovered and their quality;
2. only one business exists today for sorting shredded residues: therefore this number or its capacity should be increased;
3. developing and increasing the quantity of material recovered by dismantling by setting up an industrial network on a national scale;
4. calling on new flows of material such as those from the WEEE recycling chain. …"

Additionally, the solutions from Miller et al. (2014) support the solutions developed in this book as well, but do not mention the recycling through blast furnace. However, they acknowledge that plastics from automotive shredder residue should be recycled though pushing existing technologies on the market to achieve economic viability, with the support of political incentives. And the economic viability is improving, as ATF professional (2015) points out:

> We have all seen the ever growing use of plastics in vehicles which is balanced by an ever reducing amount of metal. Plastics have never offered the values to justify their removal, sorting and baling but times are changing.

Concerning the political solutions of this book, especially the challenge of the ELV-directive, eco social taxing and incentives for Ecodesign, Baumgartner et al. (2009) also states that currently OEMs are not implementing design for recycling, but are only focussing on developing post-shredder technologies. Further, cooperations are required to achieve ecological sustainability throughout the value chain (Baumgartner et al. 2009). Following the notion of Kanari et al. (2003, p. 19), who refers to the EU ELV-directive by stating that "[t]he vehicle produced has to at least meet the following goals: low energy consumption, easy dismantling, suitable recycling, and less toxic metals", the importance of appropriate design for recycling and ELV plastics recycling solutions. Additionally, "…sustainable technical solutions to optimal ELV recycling must not only be environmentally beneficial but they must also make good business sense. Collaboration is the key to success in this endeavor". (Daniels et al. 2004, p. 32). And this value-chain collaboration is an imperative for circular economy and sustainability in the plastics industry (see Sect. 6.1.3).

In short, the developed solutions in this book are profound, holistic, and well researched due to the significant range of methods and sources which serve as a contribution to closing research gaps in science and economy. Still, it remains to be seen which solution is the best. Therefore, the next step is to put the theoretical solutions into practice, which will be a challenge, but a truly positive and definitely manageable one.

7.3 A Call to Action: Things to Be Investigated

One book on plastics recycling in the automotive sector is simply not enough. Due to the vast number of variables, and because of the importance of this field, numerous questions have come up which are still to be answered, and this list should help to advance research and practical action:

- Geographical
  - How to deal with the global material flow of virgin and waste plastics? (Import and more importantly the export of plastics waste on the globe or at least in the EU)
- Technical issues, sustainability research
  - Are virgin plastics, recycled plastics, bioplastics, or composites performing best concerning the entire life-cycle of automotive plastics materials?

- What is the real-world performance of recycled plastics in cars?
- How deal with recycling of mixed fossil and bioplastics?
- How to recycle new materials such as CFRP and other composites ensuring ecological and economic viability?
- How to deal with the material recycling of tires?
- How important is reliability of cars in terms of ecological sustainability? (Should OEMs produce cars which last longer or is this a false conclusion due to technological advances of new cars?)
- How to increase the environmental data and monitoring concerning automotive plastics recycling? (see Emerson et al. (2012))

• Economic, social

- Are consumers willing to pay for cars with recycled materials?
- Do consumers demand sustainable materials (in cars)?
- What are the effects of (for example 5%) increased recycling material demand/
  usage by OEMs and suppliers?
- What are the effects of a generally increased demand for recycled plastics in the economy?
- What are the (systemic) effects of increased ELV plastics recycling?
- How is the process to decide on materials in companies characterised? (This requires research through decision-making channel based analysis to reveal the decision route within a company to understand whether the decisions are based on facts, ideology, or bureaucracy)
- How does an increase of recycling and circular economy change society? Or is it the other way round, that society changes first, and then the economy?
- Should car manufacturers and countries keep ELVs for recycling through superior ELV laws and design inexpensive cars for LDCs and manufacture them on-site, due to different approaches to car design and reduced transportation? (possibly, the ELV or second, third or fourth hand car export to LDCs would decrease and the environmental impact of global transportation could improve)
- What are the aspects of the system landscape when analysing the relationship between one automotive producer dealing with one recycler?
- How sustainable is the automotive industry really? Where does sustainability end? Already at the sales point?
- Quantity of car workshop waste parts including quality, spacial distribution, transport routes and final treatment

• Political, social

- Who is the driving force to advance a sustainable, circular economy; the consumer with demand or politics with laws?
- How can consumers and politics intensify their driving force for a circular economy?

– How can political incentives advance circular economy? Is it preferable to stimulate first the demand for recyclates, or to increase the quantity and quality of recyclates?

Considering the high number of open questions, hopefully numerous researchers, entrepreneurs, and politicians will start tackling these issues in order to do good with their work.

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Chapter 8
Why Automotive Recycling is an Opportunity – An Executive Summary

Abstract The entire book in a nutshell: nearly impossible! But you will find a reflection of the main results to establish a concise outline of this book. The structure of this summary is similar to the general organisation of this book, starting with the issues of industrial sustainability in general, followed by reviewing the plastics life-cycle, continuing by outlining automotive plastics sustainability with the focus on the ecological aspect, and finally depicting the solutions as a chance to improve the automotive plastics production and recycling system.

The Inevitable Change

Today, the global industry is facing a severe challenge. And it is definitely the best industrial challenge for a very long time. It is the transition towards a non-destructive form of economy as the ultimate goal. Currently, the industry is still causing an abundance of negative impacts, especially on the ecological level, because the consequences are time-delayed and are not immediately perceptible. Unsustainable acting usually has no direct effects, especially for the decision maker, because the effects will be felt only somewhere down the road, at least on the scale of a human life. Few people open their mind to grasp notions beyond their own head, beyond their comparably short career, beyond their cosy office. Because those people who know, who have seen, and who have felt the terrible consequences of unsustainable acting, do not act unsustainable. Those who are able to ignore the negative impacts, the rich, those who decide on the big issues have to change. And this change for the better is inevitable. We only decide whether we do it before the negative consequences have overwhelmed us.

The following synopsis below outlines first of all the fundamental sustainability challenges caused by such unsustainable acting to date, and secondly provides theoretical solutions vital for this inevitable change, which have to be adopted within the economy:

- Humankind is the determining factor on the globe in the era of the Anthropocene (Crutzen 2002; Steffen et al. 2007).
- Certain boundaries of the earth have been transgressed or are being transgressed (Rockström et al. 2009).
- Solutions and strategies exist in theory, such as

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– resource and impact decoupling (Fischer-Kowalski and Swilling 2011, p. 4)
– eco-efficiency and eco-effectivity (Braungart et al. 2007, p. 1337)
– concepts for holistic and transdisciplinary strategies for sustainable development including the FSSD (Janschitz and Zimmermann 2010; Robèrt et al. 2002, p. 137)
– corporate sustainability and CSR (Baumgartner 2014; Baumgartner and Ebner 2010; European Commission 2011)
– ecotechnical systems knowledge and technology assessment (Ropohl 2009; Shrader-Frechette 2012; Singh et al. 2012)

Starting from this meta-level of solutions, there are several challenges we can manage, and one of them are plastics.

The Plastics Schizophrenia–A Split Identity

Plastics are brilliant. Yes, they simply are. Imagine removing every plastic part from your life just for one day. You might even die, because it is very likely that your water supply involves plastics, your food most certainly does, and definitely your clothing. Plastics enable resource efficiency, energy efficient product transportation as well as building construction, high-tech electronics, and especially medical devices. Plastics enable the economy and society we have today, because they are inexpensive, versatile, durable, and light. However, the real problem is the operator handling this important material. Especially crude oil extracted at all costs from questionable sources for the production, the final release of the stored greenhouse gases during the prominent thermal waste treatment, and plastics waste in the environment is the real nightmare. Dead seals covered in thick oil, fish stuck in plastic soft drink trays, and birds dying because their bodies are filled with waste plastic parts. They are paying the price. And this is not the worst part. Because when children are scavenging waste dumps to survive, amidst the dangers of toxic and inflammable chemicals, and when plastic particles enter our bodies through the food and water intake even in industrialised countries, it is definitely time for a change.

In short, plastics have a split identity:

The Bright Side of Plastics

- plastics are affordable
- …versatile
- …lightweight
- …durable
- …ecologically sustainable–they can reduce greenhouse gas emissions in the life-phase significantly
- plastics prove high material purity thus quality

The Dark Side of Plastics

- the virgin production of plastics requires significant amounts of fossil fuels
- plastics can contain and leach harmful chemicals such as Bisphenol-A (BPA)
- plastics emit greenhouse gases when burnt or landfilled
- plastic particles cause environmental degradation when not recycled or recovered properly because of the durability

However, there is a suitable solution available to improve plastics: recycling. And by recycling real material recovery is meant, and especially the most favourable option in this case, which is mechanical recycling. Through increased recycling and usage of recycled plastics, a circular plastics economy can be established in order to reduce environmental pollution, societal risks, and economic as well as political dependencies on fossil fuels. Currently, most of the theoretical solutions are not implemented in the plastics industry. Corporate sustainability and CSR are on the agenda, predominantly in exaggerated sustainability reports with largely optimistic and in fact meaningless 'up to' figures, because 'up to 20%' can also imply 0%. But groundbreaking solutions to achieve resource and impact decoupling are not translated into practice. In fact, the prevailing mindset is focusing on obsolete values such as economic growth and fast money without considering long-term impacts on multiple levels.

> "The results show that mechanical recycling is the best alternative regarding the climate change potential, depletion of natural resources and energy demand. It also comes out that incineration with energy recovery performs quite poorly regarding GHG emissions". (Jean-Charles et al. 2010, p. 2)

In fact, mechanical recycling is possible, and it is undertaken, but still to a very limited degree, on a global scale. Additionally, advanced and resourceful technologies are available, especially in Central Europe, such as in Germany and Austria. However, many of these new technologies are still only available in the laboratory, such as sophisticated plastics material detection and separation solutions. These recycling technologies have to be promoted and financially encouraged immediately to achieve a circular plastics economy. On the other side of the plastics life, a significant challenge lies within many virgin plastics producers up until the present. The issue is that their core ideology is not compatible with ecological sustainability, because recycling prevents the production of virgin material. A solution for these companies is to transform into a 'plastics supplier', regardless of the source of the material, whether virgin or recycled. This enables the company to make the shift towards real ecological sustainability with a truly valuable material.

Driving into the Automotive Abyss

Apart from plastics, another challenge today is the global automotive industry. The increase of the global population, the global wealth, and consequently the drive for individual traffic trigger severe issues concerning environmental and social damage on a global scale. Non-sustainable acting by automotive companies whose primary focus is growth is a serious matter. Again, the split identity of plastics is also true for automotive plastics: On the one hand, plastics reduce the environmental impact during the usage phase; on the other hand, plastics have a negative environmental impact in the production and end-of-life-phase of a car. In short, the global challenges and automotive trends with regard to the environmental impact of automotive plastics are as follows:

1. Exponential population growth
2. New markets, new consumers
3. Increase of affluence/wealth = more cars per capita
4. Increase of plastics share in cars = Increase of plastics demand

= Increase of demand for fossil fuels
! No or very little circular economy
! Extraction and emission of greenhouse gases caused by automotive plastics

Fortuitously, at least the issue of automotive plastics is manageable.

The Recycling Renaissance is a Chance—A Final Statement

> …recycling appears to be the one mid-term challenge to be confronted worldwide. This implies not only developing recyclable materials with sufficient performance but also introducing recyclable automotive parts. (Weill et al. 2012, p. 6)

Currently, recycling is not yet of particular importance to the automotive sector. So should we just let recycling die? Is it too much effort? Should we just incinerate our waste? The experts do not think so, and neither do I. The only justifiable waste treatment options for recyclable plastics remaining are to reduce, reuse, and recycle. And nothing else. We need holistic and future-oriented thinking to transform our economy for the better. We need decision makers who take a stand for sustainability. We need a change of mind:

> Implementing this 'future waste concept' sooner than later will enable waste practitioners, manufacturers, and society (through their government leaders) to bridge the gap between the production and the recycling sectors before the volumes of this waste grow. Intensive communication between these sectors is paramount in order to allow for an effective implementation of the eco-design concept on the one hand and to close loops by recycling of waste streams on the other. (Pomberger and Ragossnig 2014, p. 90)

However, the car producers have the opportunity to bring about the vital paradigm shift to ecologically sustainable plastics by stimulating the plastics recycling industry by demanding high quality recyclates for cars. And this shift is truly positive on multiple levels, because the majority of the survey participants stated that using recycled plastics instead of virgin plastics in the automotive sector is positive, it decreases the material costs, but not the final product price for the end-consumer, it significantly decreases the dependency on and the depletion of fossil fuels, and decreases the life-cycle greenhouse gas (CO_2e) emissions of the plastics. Recycled plastics also decrease land degradation and the number of waste plastic particles in the environment. These notions are especially relevant when considering that

65% of the survey participants declared that the plastics share in cars will increase more drastically than expected, and the share of recycled plastics is stated to be less than 10%. Still, they also indicated that the consumer will demand more sustainable materials in cars, including recycled plastics, which is also the plan of automotive companies.

Nevertheless, the survey participants also indicated that using recycled plastics instead of virgin plastics in the automotive sector decreases the performance and the homogeneity of the plastic materials, leading to a decrease up to no change virtually of the quality of the final products. The five main concrete reasons for industrial customers to purchase recycled plastics are 'costs', 'marketing benefits', 'demand from the end-consumer', the 'available quantity', and the 'recyclability'. In short, finance driven aspects are the predominant reason for purchasing recycled plastics. On the contrary, the five main reasons that limit the usage of recycled plastics are 'performance', 'constant composition', 'available quantity', 'optic perception', and 'number of recycled plastic suppliers'. In short, technology driven aspects and the supply are the most important reasons limiting the usage of recycled plastics. Concluding the opinions and plans for recycling in the plastics producing industry, there is a recycling mindset ladder: The vast majority of the survey participants are strongly in favour of recycling, and they believe that it would be positive for their companies. The participating companies actually do consider going into or intensifying plastics recycling, but to a lesser extent.

Promising practical solutions to the ecological sustainability issues of the automotive plastics production and recycling system are plentiful: Starting by creating a prototype with a maximised share of recycled plastics up to 100% and implementing a maximised design-for-recycling to allow easy and high qualitative recycling to recover the highest possible percentage of materials is a valuable kick-off. Another solution is to increase in-house recycling of plastics waste accumulating in the production combined with increased recycling of ELV-parts which offer appropriate recovery results. Additionally, introducing an honest eco-balance including firstly, decision support for car producers, and especially the designers, to simplify the process of using recycled material and improve design for recycling (Ecodesign), and secondly, including legal directives across Europe to determine a minimum share of recycled plastics and materials in general. Furthermore, OEMs and suppliers should do a revision of possibly overly demanding material requirements as the applicability of recyclates might be higher than previously determined and expected. Additionally, politics can contribute by promoting eco-social taxes such as financial benefits for using recycled materials, or even a carbon tax, and implementing design for recycling in the products. Taking all the mentioned fact into consideration, it becomes clear that taking action through the provided solutions and promoting further research is not only possible, but a vital necessity to advance ecological sustainability in the automotive sector.

The Book in a Nutshell

Five facts to optimise the system of automotive plastics:

- **Using recycled plastics instead of virgin plastics increases ecological sustainability significantly**, including a reduction of green house gas emissions, crude oil extraction, plastics waste in the environment, etc.
- **A high quality plastics recycling loop is technically possible** (at least in the laboratory), preferably combined with blast furnace recycling for mechanically non-recyclable plastic waste
- **Consumers focus increasingly on sustainability** when purchasing products, which renders recycling as a chance for companies
- **Politics is the strongest lever to advance sustainability** by introducing effective incentives for a circular economy and creating green jobs
- **Value chain collaboration is key** for achieving circular economy and sustainability-oriented innovation

The facts for recycled plastics in the automotive industry are sound, but too many companies do not act in accordance with the facts, but rather according to their historical ideology. The plastics and the automotive industry now have a chance, and this chance is recycling.

> True sustainability is doing more than what you are legally obliged to do. Everything else is just compliance.

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Appendix

List of Abbreviations

General Abbreviations and Explanations

ASR	Automotive Shredder Residue
CAGR	Compound annual growth rate
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	CO_2 equivalent
CSR	Corporate Social Responsibility
DIN	Deutsches Institut für Normung (German Institute for Standardization)
EC	European Commission
EIA	Environmental Impact Analysis
ELV	End-of-life vehicle
EOL	End-of-life
EPR	Extended Producer Responsibility
EU	European Union
Eurostat	Statistical office of the European Union
FSSD	Framework for Strategic Sustainable Development
GDP	Gross domestic product
GHG	Greenhouse Gases
In-house in-line recycling	Recycling of production waste within the company
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
KPI	Key-Performance-Indicator
LCA	Life-Cycle Assessment
LDC	Less Developed Countries
MSW	Municipal Solid Waste
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
OPEC	Organization of the Petroleum Exporting Countries
Post-consumer recycling	Recycling after the usage phase

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RCBA	Rist-Cost-Benefit Analysis
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RoHS	Restriction of Hazardous Substances Directive
SCOT	Analysis including Strengths, Challenges, Opportunities, Threats
TA	Technology Assessment
Tier 1, 2, ... n	Suppliers for OEMs (varying commercial distance)
WEEE	Waste Electrical and Electronic Equipment...

Plastic Types

ABS	Acrylonitrile Butadiene Styrene
ASA	Acrylonitrile Styrene Acrylate
CE	Cellulose
CFRP	Carbon Fiber Reinforced Plastics
GRP	Glass Reinforced Polyester
GFRP	Glass Fiber Reinforced Plastics
HDPE	High Density Polyethylene
HIPS	High Impact Polystyrene
LDPE	Low Density Polyethylene
LLDPE	Linear Low density Polyethylene
PA	Polyamide (nylon)
PBT	Polybutylene Terephthalate
PC	Polycarbonate
PE	Polyethylene
PET	Polyethylene Terephthalate
PMMA	Polymethylmethacrylat
POM	Polyoxymethylene
PP	Polypropylene
PS	Polystyrene
PUR	Polyurethane
PVC	Poly Vinyl Chloride
SMA	Styrene Maleic Anhydride...

Glossary

LCA related terms, used with kind permission from PlasticsEurope (2011)

ADP Abiotic depletion potential

"An environmental impact category, measuring the extraction of primary resources, such as minerals, metals, and fossil fuels."

AP Acidification potential

"An environmental impact category »(acid rain)«. Emissions (e.g. sulphur oxides, nitrous oxides, ammonia) from transport, energy generation, combustion processes, and agriculture cause acidity of rainwater and thus damage to woodlands, lakes and buildings. Reference substance: sulphur dioxide."

EP Eutrophication potential

"An environmental impact category (also in some cases, nutrification potential). Emissions such as phosphate, nitrate, nitrous oxides, and ammonia from transport, energy generation, agriculture (fertilisers) and wastewater increase the growth of aquatic plants and can produce algae blooms that consume the oxygen in water and thus smother other aquatic life. This is called eutrophication and causes damages to rivers, lakes, plants, and fish. Reference substance: phosphate."

GWP Global warming potential

"An environmental impact category (»greenhouse effect«). Energy from the sun drives the earth's weather and climate, and heats the earth's surface. In turn, the earth radiates energy back into space. Atmospheric greenhouse gases (water vapour, carbon dioxide, and other gases) are influencing the energy balance in a way that leads to an increased average temperature on earth's surface. Problems arise when the atmospheric concentration of greenhouse gases increases due to the »man-made« (or anthropogenic) greenhouse effect: this additional greenhouse effect caused by human activities may further increase the average global temperature. The index GWP is calculated as a multiple equivalent of the absorption due to the substance in question in relation to the emission of 1 kg of carbon dioxide, the reference substance, over

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100 years. The term carbon footprint is considered to be synonymous with the GWP of a product."

ODP Ozone depletion potential

"An environmental impact category (»ozone hole«). The index ODP is calculated as the contribution to the breakdown of the ozone layer that would result from the emission of 1 kg of the substance in question in relation to the emission of 1 kg of CFC-11 as a reference substance."

POCP Photochemical ozone creation potential

"An environmental impact category (photooxidants, »summer smog«). The index used to translate the level of emissions of various gases into a common measure to compare their contributions to the change of ground level ozone concentration. The index POCP is calculated as the contribution to ozone formation close to the ground due the substance in question in relation to the emission of 1 kg of ethene as a reference substance."

Methods of the Empirical Research for this Book

To answer the proposed research questions (see Chap. 1), an empirical part was designed to complement and close gaps in the theoretical findings in the previous chapters with primary data gathered from numerous sources. The methods were selected first of all according to the mixed methods approach of this book, based on Creswell and Clark (2011), secondly based on expected complementary data and available resources as outlined in Chap. 1. Concerning the structure, the following empirical part is divided into three main operations: First of all, I conducted expert interviews for understanding and discussing the state to date, to validate findings mainly during the literature research phase in the beginning of the book, and additionally in later stages, as well as to optimise the research focus and questions. Secondly, I hosted two expert workshops for developing and validating real-world data together with the Autocluster Styria and the Department of Geography and Regional Science at the University of Graz. Thirdly and most importantly, I conducted an online Chap. 4 involving key players and stakeholders of the automotive plastics production and recycling system throughout Europe. Additionally, this survey served as a basis for a validation, interpretation and critique conducted in the second workshop which is featured in the survey, directly below the factual and clinical outline of the results. Thus, the survey and the workshop methodologies are blended together for concise information.

Expert Interviews

To discover current developments in this fast changing field of automotive plastics recycling and ascertain the truly relevant facts and opinions, I held 13 interviews with different experts on account of their long-time and successful professional background from all relevant branches at that time, such as the virgin plastics production, the automotive industry, shredders and recyclers as well as science and research:

- Univ.-Prof. Dipl.-Ing. Dr. mont. Roland Pomberger, Head of the Chair of Waste Processing Technology and Waste Management, Department of Environmental and Energy Process Engineering, Montanuniversität Leoben, Austria
- Dipl.-Ing. Dr. mont. Gernot Kreindl, Chair of Waste Processing Technology and Waste Management, Department of Environmental and Energy Process Engineering, Montanuniversität Leoben, Austria
- o. Univ.-Prof. Dipl.-Ing. Dr. mont. Reinhold W. Lang, Head of Institute, Institute of Polymeric Materials and Testing (IPMT) Johannes-Kepler University Linz, Austria
- Dr. Simone Lempa-Kindler, Projectmanagement Sustainability BMW i, BMW, Germany
- DI Dietmar Hofer, Senior Engineer Environment & Materials, Magna Steyr Engineering, Austria
- Jasper Ettema, MSc., Project Clean Mobility, Autocluster Styria, Austria
- Christoph Müller, MSc., Project Clean Mobility, ACstyria Autocluster, Austria
- DI Dr. Christian Buchgraber, Project Manager Clean Mobility, ACstyria Autocluster, Austria
- Dr. Brian Riise, Director of Research Development, MBA Polymers, UK/USA
- DI Georg Jussel, MBA, Operations Manager, MBA Polymers Austria, Austria
- Mag. Alfred Ledersteger, Saubermacher Dienstleistungs AG, Austria
- Mag. Martin Dupal, co-owner, Walter Kunststoffe GmbH, Austria
- DI Nina Kieberger, Environmental Department, voestalpine Steel Division, Austria

The plan was to maximise the output of the interviews by developing a guide. Yet in the end, the interviews were used differently as originally intended, which is outlined below. However, for the mostly one-hour long interviews, I relied on a triangulation method based on Flick (2011), starting with (1) providing background information about my research. Then, (2) an open interview following the oral history notion by Ritchie (2003) was carried out, by stating two key ideas: 'recycling of plastics from end-of-life vehicles' and 'usage of recycled plastics in the automotive sector'. The person questioned had to talk about what they associated with the ideas and what came to mind, without any input from my side to prevent influencing the interviewee. Next, (3) a structured guideline interview was carried out. This interview strategy was improved iteratively. However, in many cases, the interviewees did not respect the guideline and structure despite the effort, and the interview developed into a discussion or sometimes even a monologue, as most of the interviewees had a mission to convince me of their opinion. Notwithstanding the difference between plan and reality, these discussions were truly helpful and exceedingly beneficial to the research, but in a different form than originally planned. For this reason, the interviews were not evaluated in terms of quality or quantity, as this was not beneficial to the overall outcome, because the workshops and especially the survey supplied exceedingly valuable data rendering the evaluation of the interviews less valuable, and somewhat redundant. Consequently, the interviews served as a method to validate research findings (such as the conflict of interests between the virgin and recycling industry), discuss directions for the book, discover faults and flaws, as well as to gather insights into the different mindsets and opinions of the various branches and experts. Therefore, the interviews continuously enhanced the quality of this book through real-world expert knowledge.

Expert Workshops, SCOT Analysis and Solutions

The expert workshops to validate results to guarantee high real-world generalisability, perform analysis and develop solutions were created with the background that less is sometimes more. This means that in contrast to other workshops I have participated in, the number of participants is comparably small, mostly only one person per branch, which encourages them to express their own perception, knowledge, and opinion. The chosen experts are representatives of their branch or interest group due to their professional background. Additionally, only a very low number of representatives for each economic branch down to one were invited, so they had to defend themselves and their branch more actively, which encouraged discussion and led to valuable results. This approach has proven very successful due to the fact that plenty of valuable data was collected, and already acquired data was validated in two comparably short and thus productive workshops, which was also attested to very positively by the participants:

The first workshop was hosted at the Autocluster Styria headquarters and was designed to validate the findings of the theoretical part (see Chaps. 2 and 3), to develop the Chap. 5, and to discuss possible solutions and projects. The first draft of the SCOT was developed by the author, based on the knowledge gathered during the literature review and expert interviews, which are to be found in this book. Subsequently, the SCOT analysis was tested and revised during a workshop together with leading experts from the relevant industries. Then, a second revision was performed after finishing the analysis of the data from the survey. Finally, this second revision was used and tested in the second workshop together with experts from the scientific community and the industrial sector. The first workshop included participants from all relevant sectors who delivered valuable information during the 3-h workshop. At this stage, I have to say that I owe a huge debt of gratitude to all participants and especially the Autocluster Styria, foremost to Christoph Müller and Christian Buchgraber, who supported me in developing the workshop content and schedule.

Participants workshop 1

- DI Sabine Seiler, Project Management Green Tech, Eco World Styria, Austria
- DI Franz Lückler, CEO, ACstyria Autocluster GmbH, Austria
- Christoph Müller, MSc., Project Manager Clean Mobility, ACstyria Autocluster GmbH, Austria
- Ing. Walter Kletzmayr, CEO, Arge-Shredder GmbH, Austria
- Manfred-Mathias Geyer, Purchasing & Sourcing Manager, MBA Polymers Austria Kunststoffverarbeitung GmbH, Austria

- Mag. Thomas Ladstätter, Business Development, CTR Carinthian Tech Research AG
- Ing. Christian Pölzl, Binder+Co AG

The second workshop was hosted at the Department of Geography and Regional science at the Karl-Franzens-University Graz and was designed to validate the survey results to guarantee high generalisability and scalability as well as to develop and evaluate concepts for solutions. Again, experts from all relevant branches took part and validated and discussed the results of the survey (Chap. 4) and the SCOT Analysis (Chap. 5). After the validation of the survey, each of the experts was asked to come up with solutions on how to achieve a ecologically sustainable automotive plastics production and recycling system in the future, based on the principle of backcasting (Holmberg and Robèrt 2000; Robèrt 2002; The Natural Step 2013). Due to limited resource and time, the solutions were not structured into steps, but instead ranked according to prospect. The stated solutions from the experts were written down on a flip-chart and then they had to evaluate and rank these solutions through 'resistance points', meaning that they had to hand out up to 10 negative resistance points for each solution. This method is called 'systemic consensing' (originally "systemisches Konsensieren" in German, translated through a linguistic derivation process by adding a suffix to the original noun) and was developed by Paulus et al. (2010). Additionally, the two key factors required for the development of the scenarios were identified. Generally, the second workshop was exceedingly successful as the experts validated the survey results as well as developed and evaluated numerous solutions in a 4-h session. Again, I have to say that I owe a huge debt of gratitude to all participants including Prof. Rupert Baumgartner and Prof. Friedrich Zimmermann, who supported me in developing the workshop and even participated very actively to encourage the critical discussion.

Participants workshop 2

- DI Sabine Seiler, Project Management Green Tech, Eco World Styria, Styria
- Christoph Müller, MSc., Project Manager Clean Mobility, Autocluster Styria, Austria
- Ing. Walter Kletzmayr, CEO, Arge-Shredder GmbH, Austria
- DI Monika Daucher, Project Management, Kunststoff-Cluster, Austria
- Josef Peter Schöggl, MSc., Project Staff, Institute of Systems Sciences, Innovation and Sustainability Research, University of Graz, Austria
- Dr. Peter Perstel, MA., Research and Teaching, Institute of Systems Sciences, Innovation and Sustainability Research, University of Graz, Austria
- Univ.-Prof. Dr. mont. Rupert Baumgartner, Head of Institute, Institute of Systems Sciences, Innovation and Sustainability Research, University of Graz, Austria
- O.Univ.-Prof. Dr. Friedrich Zimmermann, Head of the Department of Geography and Regional Science, University of Graz, Austria

The Survey - Methods

Within the research on plastics recycling in the automotive sector, it quickly became clear that a survey was required to gather real-world data from the key players to achieve highly relevant results. Further arguments for conducting a survey were the fact that no public scientific survey on this topic was available at that time, and that data was needed as a scientific basis to ultimately develop the SCOT analysis, prognoses, scenarios, and solutions for current issues concerning this topic. Fortunately, a survey from 2012 "about relevant sustainability aspects in the automotive and electronics supply chains" was carried out within the SustainHUB-Project (www.sustainhub-research.eu), which served as a point of reference.

The system boundaries of the survey are in terms of geographic reach set to Europe due to the focus of the research on this geographic area and mainly because of limited resources. To gather holistic data, all the key players in the automotive plastics production and recycling system have been included, ranging from virgin plastics producers, automotive industries including OEMs and suppliers, shredders and recyclers as well as research institutions. Politics was included in the survey as well, but only two politicians participated, rendering this data useless. However, the industry showed great interest and a substantial number of experts participated in the survey. As scientific rigour is a key element of this research, a concern regarding the survey was the statistical representativeness. First of all, the population of the key players with vast numbers of employees posed a significant challenge to achieving a representative sample due to limited financial and timely resources. The employee numbers[1] estimated based on ACEA (2013, p. 27), PlasticsEurope (2013, p. 6), and Plastic Recyclers Europe (2014) are as follows: 2,200,000 in the automotive industry, 1,375,000 in the plastics industry, and 30,000 in the plastics recycling industry, amounting in total to 3,605,000 employees in the European automotive plastic production and recycling system.

Secondly, the focus group for the survey consisted of decision-makers and people with specialised knowledge. The challenge with this requirement was that information regarding the structures of the companies and ultimately to discover the number of employees who fit the requirements was hardly or not at all available. Therefore, scientifically profound conclusions on the population for the survey could not be drawn. As a result, classical sampling could not be performed due to the impossibility with the available means. Instead, a procedure to locate and extract the contact information of "information-rich cases" (Patton 2005) suitable for the survey was developed and executed, which is outlined below. To further ensure high quality of the data, the results of the survey were validated within a workshop with experts from all relevant sectors. In this way, profound results could be achieved. Additionally, no significance enhancing processes (p-hacking) were performed leading to completely honest results. In the following, the detailed procedure for the survey is outlined.

[1] The 30,000 employees in the plastics recycling industry represent 80% of the plastics recycling capacity in Europe.

Chronological Procedure for the Survey:

1. Gathering questions since the start of the research process for this book
2. Focused development of questions after finishing the first draft of the theoretical part, the Chaps. 2 and 3
3. Research on similar surveys
4. First draft of the survey in English
5. Optimisation sessions with doctoral advisers
6. Two extra optimisation sessions with Univ.-Prof. Dr. Klaus Kraemer, expert in the field of economic sociology
7. Pilot study with 6 participants
8. Revision of the survey (44 questions and 7 groups in the final version)
9. Additional translation for German version
10. Well-considered formulation of invitation to the survey with psychological strategies
11. Email address gathering of information rich participants (experts) from personal contacts and internet research
12. Official start of the survey
13. First round of sending the invitation via email
14. Sending of personal letters to members of the board of directors, to selected members of the supervisory board, and CEOs from automotive OEMs, virgin plastics production clusters and plastics recycling clusters throughout Europe (this is the only way to establish first contact without a personal connection)
15. International telephone sessions to gather addresses of information-rich experts
16. Intensified support seeking from personal network to forward the mail to additional experts
17. Continued email address gathering
18. Continued sending of the invitation via email to the newly gathered addresses
19. First reminder to participate in the survey
20. Second reminder to participate in the survey
21. Official end in 2014 - two weeks before unofficial end due to expected latecomers (12 participants)

Statistics of the Survey Procedure

Total direct emails sent (invitation and two reminders): 11991 (excluding forwarded mails from direct and indirect addressees)
Total number of direct email contacts (excluding forwarding to further contacts): 3997
Breakdown of sent invitations personalised according to addressed industrial sector (including scientific addresses):
Plastics DE (German version): 926
Plastics EN (English version): 1036
Automotive DE: 972

Automotive EN: 527
Recyclers DE: 324
Recyclers EN: 90
EU-Politics EN: 100
Mix: 22 (newly gathered email addresses from replies)
Complete responses: 163
Incomplete responses: 89
Total responses: 252
Valid responses: up to 225 (depending on question)
Response rate: 4.08% (only counting the complete answers)
Response rate: 6.3% (counting the total responses)

Structure and Question Design of the Survey

The survey was divided into four main parts: First, demographic questions concerning the branch of the participant were asked, or more precisely, those questioned could choose from semi-clustered answer possibilities. Secondly, general questions to all participants were raised, which is the most important part. Thirdly, depending on the selected branch at the demographic questions, customised questions were raised, splitting it up into four parallel blocks of questions (automotive group, recycling group, plastics producing group, and the academia, science, research group). If no clear answer has been given concerning the branch, the questionnaire skips to the end, fourthly, the background matter, which contains classical 'abort questions' such as gender and age. In this survey, most questions were closed with given response options to enable quantification and statistical calculations.

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