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ETHICS IN CHEMISTRY: BUSINESS MODELS, RISK MANAGEMENT AND GOVERNANCE

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Anni 2008/2015

To my family

”All things are difficult before they are easy.”

- Dr. Thomas Fuller

“Science may set limits to knowledge, but should not set limits to imagination.”

- Bertrand Russell

CONTENTS

LIST OF ARTICLES

This thesis is based on the following articles, which will be referred to in the text by their Roman numerals.

I. **Chemical Leasing — a review of implementation in the past decade.** Moser F, Jakl T (2014) Environmental Science and Pollution Research, forthcoming. DOI: 10.1007/s11356-014-3879-3.

II. **Chemical Leasing and Corporate Social Responsibility.** Moser F, Jakl T, Joas R, Dondi F (2014) Environmental Science and Pollution Research, forthcoming. DOI: 10.1007/s11356-014-3126-y.

III. **Chemical Leasing in the context of Sustainable Chemistry.** Moser F, Karavezyris V, Blum C (2014). Environmental Science and Pollution Research, forthcoming. DOI: 10.1007/s11356-014-3126-0.

IV. **Environmental protection between chemical practice and applied ethics: a critical review.** Moser F, Dondi F (2015). Toxicological & Environmental Chemistry, forthcoming. DOI: 10.1080/02772248.2015.1025786

V. **University and the Risk Society.** Dondi F, Moser F (2014). Toxicological & Environmental Chemistry, forthcoming. DOI: 10.1080/ 02772248.2014.968160.

VI. **On the road to Rio+ 20: the evolution of environmental ethics for a safer world.** Moser F, Dondi F (2012). Toxicological & Environmental Chemistry, 94: 807-813. DOI: 10.1080/02772248. 2012.684952.

VII. **L'università e la ricerca nella società del rischio.** Dondi F, Moser F (2014). Ecoscienza, 4: 18-21.

VIII. **Chemical Leasing: ethical approach in the management of chemical substances?** Moser F (2009). La Chimica & L'Industria 9: 105-107.

My contribution to the articles included this thesis was:

Article I: conceptualized the research questions, undertook literature research, incorporated input from co-author, and wrote the article.

Article II: conceptualized the research questions, undertook literature research, selected two case studies on Chemical Leasing activities, incorporated input from co-authors, and wrote the article.

Article III: conceptualized the research questions and evaluation methodology in cooperation with co-authors, undertook literature research, compiled of case studies relating to projects implemented at the local level, incorporated input from co-authors, and wrote the majority of the article.

Article IV: conceptualized the research questions, undertook literature research, incorporated input from the co-author, and wrote the article.

Article V: conceptualized the research questions and undertook literature research, incorporated input from the co-author, and wrote the majority of the article.

Article VI was published as an opinion in the Journal Toxicological and Environmental Chemistry and was not peer-reviewed. I have conceptualized the research questions, undertook literature research, incorporated input from the co-author, and wrote the article.

Article VII has been published in Italian in the non-peer reviewed journal Ecoscienza as part of the thesis. The English translation of this publication is contained in article V.

Article VIII has been published in the non-peer reviewed journal La Chimica & L'Industria. I have conceptualized the research questions, undertook literature research and wrote the article.

For the sake of completeness, articles VII and VIII have also been reproduced in the annex to this thesis.

All work included in these articles were performed under supervision of Prof. Francesco Dondi, University of Ferrara.

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List of Acronyms

CAQDAS	Computer Assisted Qualitative Data Analysis Software
CLTS	Chemistry Large Technological System
CMS	Chemical Management Services
COP	Conferences of the Parties
CSR	Corporate Social Responsibility
DDT	Dichlorodiphenyltrichloroethane
EC	European Commission
EU	European Union
EuCheMS	European Association for Chemical and Molecular Sciences
GC	Governing Council
GRULAC	Group of Latin America and the Caribbean
ICCM	International Conference on Chemicals Management
INC	Intergovernmental Negotiating Committee
LTS	Large Technological System
MSDS	Material Safety Data Sheet
NCPC	National Cleaner Production Centre
NGO	Non-Governmental Organization
POP	Persistent Organic Pollutant
POPRC	Persistent Organic Pollutants Review Committee
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
SAICM	Strategic Approach to International Chemicals Management
SDSN	Sustainable Development Solutions Network
SENCER	Science Education for New Civic Engagements and Responsibilities
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
WSSD	World Summit on Sustainable Development

1 INTRODUCTION

1.1 Introduction to the research topic of Ethics in Chemistry

Chemicals undisputedly contribute to a large extent to economic growth and social welfare of modern societies. With a global chemicals turnover of € 3,127 billion in 2012, the chemical industry is one the largest industries worldwide. Companies producing and selling chemicals in the European Union (EU) have employed a total staff of about 1.9 million and contribute to 1.1 per cent to the EU Gross Domestic Product in 2012 (CEFIC 2013).

At the same time many chemicals can pose threats to human health and the environment once they are released. Given severe accidents involving chemicals in the past century, such as the Seveso and Bhopal disasters in 1976 and 1984, the international community has responded with the development of laws and legally binding instruments, such as the Basel, Rotterdam and Stockholm Conventions, or voluntary frameworks, such as the Strategic Approach to International Chemicals Management (SAICM).

The importance that chemicals play for the economic growth of countries and the everyday life of their citizens and the severity of short- and long-term adverse effects, warrants a closer analysis of the underlying ethical considerations that govern the production, use and, sometimes, misuse of chemicals.

1.2 'Chemistry' as a social construct

Chemistry is a widespread field that include a broad variety of sectors of modern society, such as industrial production, supply chains, consumer goods or higher research and education. For the purpose of this thesis, chemistry is not simply considered as a scientific discipline, but defined as a Large Technological System (LTS) in line with definition proposed by sociologists like Hughes. While LTSs are believed to be social constructs, they, at the same time, have the ability to shape society itself (Hughes 1987). Examples for LTSs include electrical power and distribution systems, the Internet or public health systems. LTSs consist of both 'physical' and 'immaterial' components, including equipment or machines; organizations; and scientific or legislative artefacts.

In the context of this thesis, the physical components of chemistry as an LTS comprise, for example, chemical factories, research laboratories, transport and supply chain entities, storages facilities, chemical products and other physical artefacts, such as scientific equipment. Other organizational entities, such as companies manufacturing or disposing chemicals or entities that are tasked with the regulation and enforcement of laws, universities and their teachers and researchers belong to those physical components as well. Immaterial components are usually referred to as scientific artefacts and include, for example, chemical literature and books as the repositories of chemistry knowledge or research programmes. Laws and regulations at the national and international levels as well as industry self-regulation also belong to the immaterial components of such a Chemistry LTS (CLTS).

All the above components are constructed by society as a whole, but they do not exhaust the CLTS. This is because to function they require the availability of natural resources. Accordingly, mines, lakes for hydropower or oil wells are also qualified as artefacts belonging to this system. CLTS is thus a field that covers a broad range of aspects, each of them with their own unique ethical concerns. The complexity of the CLTS is even further increased, given that the borders of these aspects are not yet, or in some cases never will be, well-defined. Prigogine and Stengers (1988), for example, attribute the scientific domain of chemistry as a part of the universe in evolution. As a general feature, the different components of the CLTS interact with each other. This, in turn, increases its overall complexity. Invention and discovery constitute further aspects inherently linked to these systems. CLTS hence foster development, evolution and innovation. Also, CLTS are characterized by the ability to support the transfer of technologies, which is fundamental for economic growth and competition of countries in global markets.

Given the complexity of the CLTS, investigating its underlying ethical principles needs to rely on a multitude of humanistic and scientific disciplines, such as environmental ethics or the philosophy of science. In the context of this thesis, the latter area is of particular importance. This has been recognized by scholars like Pozzati and Palmeri, who have provided an historical account of the various areas of this specific field of philosophy (2007: chapter 9). For the ensuing discussions, it will be useful to differentiate between the theoretical and the practical branches within the area of philosophy of science. While the former focuses on the general aspects of science and technology, the latter deals with the actual implementation of ethics in science in real world systems and the methodologies used for this work. The following section takes into account this distinction between the practical and theoretical approaches.

1.3 Chemistry, Philosophy and Ethics

Society's perception of technology has changed significantly from the time of Bacon, who was of the view that human beings cannot command nature except by obeying to her (Bacon 2000), to the Promethean view of technology to transform and conquer nature that was assumed by many scientists in the last century, who have seen nature as a playground for their experiments (Buchanan 1976, Landes 2003).

Modern philosophy seeks to underline both the positive and the negative aspects of technology and highlight its intrinsic duality. Martin Heidegger, on the one hand, defined technology as an ordering of the world to make a so-called 'standing-reserve' available. Heidegger described technology as 'Enframing', which, in this context, "means the gathering together of that setting-upon which sets upon man, i.e., challenges him forth, to reveal the real, in the mode of ordering, as standing-reserve. Enframing means that way of revealing which holds sway in the essence of modern technology and which is itself nothing technological." (Heidegger 1977: 20) Jonas, instead, underlined the destructive capability of technology, which calls for the responsibility of individuals as an imperative feature of society (Jonas 1984).

As is evident, the ethical aspects of the technological age were an important stream in the fields of philosophy and sociology in the 20th century. Heidegger and Jonas' theoretical contributions were instrumental for improving the general understanding of the implications of technological advancements on societies and the environment and to pinpoint related ethical concerns.

More recently, a new branch of philosophy of science has emerged, putting particular emphasis on the practical aspects of this field. Scholars like Kristin Shrader-Frechette and Ulrich Beck focused their work on assessing methodologies used in science and risk management (Beck 1992, Shrader-Frechette 2014). A practical aspect of the philosophy of science that gained widespread attention was the hypothesis that 'flawed science' can lead to 'flawed ethics'. Shrader-Frechette (2014) addressed practical ethical questions, such as how to make valid causal inferences from data arising from experiments, or how to deal with value judgements in scientific methodologies. Beck, in the context of his discussion of a risk society, identified 'flawed ethics' deriving from 'flawed science' as an origin for many technological risks. Addressing 'flawed', i.e. incomplete or defective, science is hence a central topic of this thesis. Section 2.2 below on "Ethics in Chemistry: Education and the Role of Universities" outlines practical approaches to prevent 'flawed science' that can be implemented by scientists in general and chemists in particular.

While this thesis does not attempt to be a philosophical investigation, it nonetheless will examine the contact points between chemistry and philosophy, with a particular focus on the topic of ethics in chemistry.

1.4 'Environmental Ethics' and Ethics in Chemistry

Chemical substances are artefacts of the field of chemistry that interact with real world systems. Differing, and sometimes non-apparent, ethical principles and approaches guide the discussions on the control and management of chemical substances in industry, universities and the United Nations. Given this apparent diversity, this thesis holds the position that there is no unified field 'Ethics in Chemistry'. It rather consists of specific fields, each of which have their own specific ethical concerns.

This thesis is an attempt to analyse such underlying ethical considerations for three selected fields in chemistry. The first chapter deals with the ethics of business models to sell chemical substances. The second chapter outlines ethics in chemistry education in universities. Finally, the third part of this thesis looks into ethics in international chemicals governance.

The objective of this thesis is to analyse the underlying ethical principles in each of these three specific topics and to show, where applicable, the interdependencies between these different strands of ethics in chemistry.

In order to provide a framework for ensuing discussion of ethics in chemistry in the context this thesis, an overview of the relevant theories on environmental ethics, drawn from the Stanford Encyclopaedia of Philosophy, are provided in the following (Brennan and Lo 2011).

The field of environmental ethics is to some extent rooted in the anthropocentrism of traditional ethical theories, which provide intrinsic value predominantly to human beings and not to nature (see also Crutzen 1986 and Lovelock 1979). Particularly important in this regard are the deontological ethical theories, which state that rightness or wrongness of an action does not depend on the goodness or badness of its outcomes. An inherent feature of the deontological theory is moral rules and duties. These rules can be obeyed or disobeyed, which makes an action right or wrong irrespective of the consequences of this action. With regard to the topic of this thesis, these ecosystems and the beings that live in them, which have an intrinsic value, have the moral right to be respectfully treated. If releases of chemicals substance, for example, would cause harm to them, we have, according to the deontologist perspective, a prima facie moral duty to avoid such harm. While some authors focus on such harm being done to species, biocentrism is an example that belongs to this field of deontological theories (Regan 1983, Taylor 1981 and 1986), others go beyond this focus on individual members of a biotic community and maintain ecological wholes as well have an intrinsic value. Callicott's land ethical holism and Fox's theory of 'responsive cohesion' are examples for this believe (Callicott 1980 and 1989, Fox 2007). These aspects will be considered in the special topic devoted to 'education' within universities.

Another strand of ethics that needs to be mentioned here is the theory of virtue ethics, which seeks to evaluate the outcomes of actions taken in terms of them being kind, honest, sincere or just. Virtue ethics puts emphasis on the moral character and the moral reasons for taking certain action. The fact that it is often applied in the context of the discussions on sustainability and environmental protection (Sandler 2007) is a reason why the theory of virtue ethics assumes a central position for this thesis. This is amplified by the belief, that, from a virtue ethics point of view, it is not possible to separate the motivation and justification of a certain action from the character traits of the one that acts, i.e. the moral agent. This will be particularly important in the discussion on the responsibility of individuals, such as scientists, in managing the risks of chemical substances by applying, for example, a precautionary approach (Løkke 2006), but also for developing ethical business models such as Chemical Leasing (Moser and Jakl 2014), which are extensively discussed in the present thesis.

1.5 Ethical 'targets' in the present thesis

In this line of thought, the key assumption of this doctoral thesis is that any approach by the private and public sectors that follows the precautionary principle and that is capable to reduce threats of serious or irreversible damage connected to the production and use of chemical substances can be considered as strategy to mainstream ethical approaches in chemistry, if its underlying objective is to avoid harm to human health and the environment.

In the context of this doctoral thesis, any change of process or behaviour that leads to the minimization of negative effects of chemicals shall be considered as ethical approach if the following two conditions are met: first, the underlying objective of the measures undertaken shall be to avoid harm to human health and the environment and, second, the approach should confirm to the basic rules of society embodied in law and in general ethical customs.

Several risk reduction strategies for chemicals management have been identified, which allegedly have a vast potential to facilitate the mainstreaming of ethical approaches in chemistry. These strategies include the reduction of consumption of chemicals; the optimization of processes in which chemicals are produced or applied; the phase out of the use of hazardous chemicals in products and articles; and the implementation of general safety measures throughout the life cycle of chemicals. These risk assessment strategies are to be supported through awareness raising and education of all stakeholders that are involved in the risk management of chemicals.

While risk reduction strategies have been identified in the CLTS, this thesis focuses on three specific subsystems: chemical industry, university education and international governance of chemical substances. The structure and research questions dealt with in this thesis relate to these three specific fields. They are outlined in the following section.

1.6 Structure and research question

The overarching research question that this thesis seeks to address is as follows:

> *To what extent did the activities undertaken in the past decades in the three subsystems of the CLTS – chemical industry, university education and international governance of chemical substances –take into account ethical approaches?*

In order to be able to respond to this question, each CLTS subsystem will be investigated with a set of specific secondary research questions, which will be introduced and analysed in the respective chapters of the thesis as outlined in the subsequent paragraphs.

In a first part (chapter 2.1), this doctoral thesis seeks to evaluate of the potential of identified solutions in chemical industry to facilitate the implementation of the above-mentioned risk reduction strategies and, as reasoned above, the mainstreaming of ethical approaches in chemistry. This includes the further evaluation of business approaches, such as Chemical Leasing business models, that cover the entire life cycle of chemical substances. The thesis will investigate the ethical consideration for the application of Chemical Leasing Business Models. Here, the lack of transfer of proprietorship and/or ownership of the chemical to the user fosters ethical behaviour in business at the user side. This also includes the supply chain and other parties involved in the application of chemicals in businesses, such as suppliers of machines and other services.

In a second part (chapter 2.2) this doctoral thesis investigates the apparent lack of ethical considerations that can be observed in the natural science curricula of universities. Universities, in general terms, are focusing on teaching future generations how scientifically sound conclusions can be derived from experimental findings. The need of impartiality of science, in this regard, is translated into the necessity to disfavour any preference of type I errors (false positives) over type II errors (false negatives) and vice versa. While for most research questions in natural science it is mandatory to maintain this strict impartiality, this may not hold when assessing the risks of environmental pollution. A literature research on this topic revealed that the underlying uncertainties or value judgments of science and of the risk assessment methodologies themselves, however, remain largely disregarded. Moreover, the thesis looks more closely into the basic principle of the organization of a general multi-stakeholder approach. This is particularly important for this research since the assessments of risks affecting public welfare intrinsically involve both policy and scientific judgments. The work during this doctoral thesis also focused on the changes in paradigm in which the risks of chemicals are perceived and managed by society. Here, the thesis will investigate the important role that universities can play in this change process as the principal provider of higher education and research in modern societies.

In a third part (chapter 2.3), the thesis will put emphasis on the role of the United Nations in setting the context for the ongoing debates on environmental risks and the use of environmental law. Focus is given to the progress made by science and politics in the past decades in assessing and managing risks associated with the production and use of chemicals, which has been summarized in a publication that looked into the aspects of sustainable management of chemicals in the wake of the Rio+20 Conference and how the risks emanating from chemicals can best be managed (Moser and Dondi 2012). Here, the thesis seeks to provide a response to the question whether the particular structures of the United Nations in terms of chemicals and waste management support the new critical theory of the nascent society – the so-called cognitive society – of the twenty-first century (Strydom 2002). For this, the thesis seeks to demonstrate if and to what extent the particular institutional setting of a specific United Nations body, the Stockholm Convention on Persistent Organic Pollutants, provides a platform for a shift towards a cognitive society.

The findings of this doctoral thesis is based on the preparation of five distinct publications on Chemical Leasing and the role of universities in the mainstreaming of ethics in chemistry, the results of which are described in the chapters 2.1, 2.2 and 2.3 below. The respective publications are contained in the annex to this thesis. While the thesis represents a first attempt to describe the different developments in social and moral ethics in chemistry in a concise and coherent manner, it does not encompass other ethical fields such as plagiarism, data manipulation and other ethical concerns related to the praxis of conducting research.

2 RESULTS AND DISCUSSION OF THE ARTICLES

2.1 CLTS Subsystem 1: The Need of 'Ethics' in Chemical Industry and Trade

Chemicals are ubiquitous and play an important role in modern society. A large number of new chemicals are developed and introduced in national and international markets, often through complex supply chains (McKinnon 2004) as quoted by Mont et al. (2006). They are contained in products people use in their everyday life or used in the manufacture of products. Many industrial processes critically depend on chemicals performing a broad range of diverse functions, such as lubrication, cooling, solvation, cleaning or catalysis (Stoughton and Votta 2003).

With a global chemicals turnover of €3,127 billion in 2012, chemical industry is a key sector in global trade. The economic success of chemicals industry is based, among other things, on base chemicals, such as petrochemicals and their derivatives, and basic inorganics; specialty chemicals like auxiliaries for industry, paints and inks, crop protection, dyes and pigments; and consumer chemicals like soaps and detergents, perfumes or cosmetics (CEFIC 2013).

While the functioning of modern societies largely depends on the use chemicals in a broad variety of different sectors ranging from industrial processes to households, many of them have a dual nature. Toxic chemicals, for example, can be used as chemical weapons or, peacefully, in the production of goods (Trapp 2008). Chemicals that are used as cooling agents are another example. These substances, such as polychlorinated biphenyls, have physical properties such as inertia and low flammability, which make them the favourable choice in production processes or products in a controlled environment. However, when released into ecosystems, due to the same properties, these chemicals can cause adverse effects to human health and the environment (Letcher et al. 2010). The international community has addressed these risks through the negotiation of legally binding international treaties, like the Stockholm Convention on Persistent Organic Pollutants.

The predominant response of policy-makers to manage this dual nature since the early 80's has comprised the adopting legislation and treaties to address specific environmental problems associated with the production and use of chemicals. At the regional level, this included, for example, the Convention on Long-Range Transboundary Air Pollution, which entered into force in 1983, or the European Union Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals or REACH (EC 2006). At the international level, the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade and the Stockholm Convention on Persistent Organic Pollutants have been adopted in 1998 and 2001 respectively. The fact that some toxic chemicals can be used not only in the production of goods, but also as chemical weapons (Trapp 2008) led to the negotiation of the Chemical Weapons Convention, which entered into force in 1997. This global treaty requires states that are a Party to adopt, among other things, the necessary measures to ensure that toxic chemicals and their precursors are only developed, produced, otherwise acquired, retained, transferred, or used within their territory or in any other place under their jurisdiction or control for purposes not prohibited under the Convention.

The overarching objective of these regulatory measures and agreements was to reduce the risks that certain toxic chemicals pose to human health and the environment. They were also put in place with a view to support the sustainable development agenda, in general, and sustainability in chemistry, in particular. These goals were reached through reducing the use of chemicals and their turnover (Jakl and Schwager 2008).

These regulatory approaches were in stark contrast to the traditional sales concept in the chemicals industry in the past, as the economic success of a chemicals producer was generally linked to the overall volume of chemicals a producer would sell in the market. For this reason, there was no incentive to change the traditional sales concept, since any reduction of use or turnover of chemicals would result in a decrease of revenues for the producer (Jakl et al. 2004: 3). To overcome this apparent misalignment of the objectives of policy makers and chemicals industry, there was a growing understanding that chemicals policy would need to pursue both an ecological as well as an economic objective to enable companies to succeed in global competition (Jakl and Schwager 2008).

This changing approach was supported by landmark events, such as World Summit on Sustainable Development (WSSD) in 2002, which called for a renewal of the commitment to the sound management of chemicals and of hazardous wastes throughout their life cycle and set the ambitious goal to use and produce chemicals in ways that do not lead to significant adverse effects on human health and the environment by 2020 (WSSD 2002).

These sustainability objectives gave impetus for the development of innovative business models to manage the risk of chemical substances. An essential feature of such business models is the focus on virtue ethics, by which business partners are to adopt a more trusting and cooperative attitude towards each other.

Both the necessity and the advantages to adopt ethical attitudes in the conduct of business within chemical industry has been underlined by Frank et al. and Rossi in their contributions (Rossi 2007, Frank et al. 2011). Scholars like Morin (1999) call for the strengthening of education systems to achieve a more ethical conduct of business. Universities and their unique function as a provider of higher education and research play an important role in preparing future decision-makers in chemical industry to achieve these changing and often complex requirements of modern societies.

The role of education, in general, and universities, in particular, in ethics in chemistry will be discussed in chapter 2.2 below.

2.1.1 Chemical Leasing as 'Ethical' Business Model

Chemical Leasing business models have been introduced as a new and innovative approach of using chemicals for industrial applications. Chemical Leasing aims at reducing the risks emanating from hazardous substances (Ohl and Moser 2007) and, at the same time, ensuring long-term economic success within this global system of producing and using chemicals.

In order to understand the basic principles of Chemical Leasing business models, Joas (2008) provides a succinct overview of them. He starts his introduction by outlining the traditional sale concept of chemical substances. Here, the producer sells chemicals to the user, who uses them in its production processes to perform certain specific functions. The economic gains of the producer are linked to the overall volume of chemicals sold to the user. Joas, supported by Stoughton and Votta (2003), outlines that the traditional sales concept, and with it the traditional supplier-user relationship, contains perverse incentives with regard to the volume of chemicals used in the production process. The producer has an incentive to increase its earnings through selling its chemicals at higher prices or in larger quantities. Joas (2008) adds that the intense global competition on the chemicals market may provide a price ceiling for certain chemicals, which, in turn, hampers the producer to increase its earnings through higher prices. The user, in turn, has the opposite incentive to decrease the volumes of chemicals to save costs. However, according to Ohl and Moser (2007 and 2008), the user may neither have the technological means nor the knowledge required to achieve this goal. That is because the chemicals' application is seldom part of the users' core competencies.

These conflicting objectives may persist for the following reasons. For the user, the costs of acquiring new technologies or of increasing the knowledge on the chemical and its application may be prohibitively high (Ohl and Moser 2007). The producer, in turn, may need to focus on larger sales volumes in order to increase its revenues. This, in turn, raises concerns at the societal level, as augmenting the sales volume of chemicals likely results in increased releases of chemicals into the environment (Perthen-Palmisano and Jakl 2005: 49) and hamper resource availability for future generations. Joas (2008) concludes that the continuous application of the traditional sales concept hence may not represent a sustainable solution for any of the involved stakeholders, i.e. chemicals' producers, users, and society as a whole.

The impetus to introduce Chemical Leasing business models is explained by their inversion of the incentive embodied in the traditional sales concept to increase the production and use of chemical substances. Joas (2008) continues by stating the core principle of Chemical Leasing: the payment of producer shifts from the volume of chemicals sold to a service provided to the user. The producer, now being a service provider, has a clear incentive to avoid any unnecessary consumption of chemicals in the processes, since this would decrease its revenues. Chemical Leasing thus turns resource efficiency into an economic asset – even for the chemicals' provider. According Ohl and Moser (2007 and 2008) the producer has a vast knowledge of the chemicals it produces, which enables it to use its know-how for the optimization of processes in which the chemical is applied. Joas (2008) further argues that the optimization of processes not only leads to reduced amounts of chemicals required in the process, but also in additional cost savings thanks to reduced energy consumption.

The current literature also describes the collaborative aspects of Chemical Leasing. Here, Lozano et al. (2013 and 2014) maintain that collaboration is an integral aspect of Chemical Leasing. By introducing the Japanese philosophy of *kyosei* (a Japanese word that can be best translated as "spirit of cooperation") as a strategy to foster cooperation and collaboration between companies, the authors argue that with the introduction of Chemical Leasing companies are able to reap the benefits of collaboration. This includes the sharing of information and knowledge between the producer and user of the chemical (see also Ohl and Moser 2007), the creation of win-win situations and strengthening of their environmental performance. Chemical Leasing, according to Lozano et al. (2013), also addresses the problem of free riding.

Joas (2008) maintains that with the application of Chemical Leasing models, producer and user share a common interest to reduce the consumption of chemicals. On the one hand, the producer has an incentive to reduce the chemicals' use. That is because by selling a service linked to the chemical, any overconsumption of chemicals would now decrease its revenues. The user, irrespective of the business model it applies, has an incentive to reduce the amount of chemicals used, since this decreases its costs. Chemical Leasing generates an added value mainly by reducing the chemicals consumption. The resulting cost savings are shared between producer and user (Beyer 2008a, Schott 2008). Perthen-Palmisano and Jakl (2005) add that Chemical Leasing increases both the environmental as well as economic competitiveness through the introduction of best available technologies and best environmental practices. Lozano et al. (2013) add that a successful implementation of Chemical Leasing might benefit from the use of a facilitator. By introducing an example of a project that was implemented with support of a United Nations Industrial Development Organization (UNIDO) National Cleaner Production Centre (NCPC)[1], the authors were able to show the benefits of using a facilitator. In their example, the facilitator played a key role in promoting Chemical Leasing, which was important for identifying and attracting

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[1] see http://www.unido.org/ncpc.html

[2] See also: http://www.chemicalleasing.com/sub/faq.htm# or

potential partners. During the implementation of the Chemical Leasing project the facilitator also assisted in monitoring, evaluation and reporting activities. Other specific activities included calculating potential savings and the analysis of baseline scenarios.

As is evident from this analysis, Chemical Leasing fosters a closer collaboration between producer and user, since both partners have a clear incentive to increase the efficiency of the application of chemicals. In some cases, the implementation of Chemical Leasing may benefit from using a facilitator, such as NCPCs, who could also take over tasks such as third party quality assurance. This may be particularly relevant if the Chemical Leasing project is implemented in developing countries or countries with economies in transition.

Table 1 provides an overview of some typical Chemical Leasing business models that vary as a function of integration in and responsibility of the producer in the processes of the user.

Table 1. Classification of Chemical Leasing business models

Producer of chemicals responsible for			**Name of model**	**Responsibility of producer**
supply of chemicals	*application of chemicals*	*management of wastes*		
X	X	X	'Traditional sales' model	
X	X	☑	Responsible Care' model	
☑	X	X	'Supplier service' model	
☑	X	☑	'Client Operation' model	
☑	☑	X	'Supplier cooperation' model	
☑	☑	☑	'Total care' model	

Source: Jakl et al. (2014), Perthen-Palmisano and Jakl (2005)

Chemical Leasing and Chemical Management Services: Overlaps and Differences

Another important aspect for the introduction of the basic principles of Chemical Leasing is the relation to other service-oriented approaches for the management and application of chemicals. The conceptual framework of Chemical Management Services (CMS) is such a service-oriented approach. In recent literature, the concept of CMS is mentioned frequently in publications on

Chemical Leasing and vice versa. A clear understanding of the concepts of Chemical Leasing and CMS, and the possible overlaps and differences between the two, is therefore important for this review and the ensuing discussion.

CMS, according to Stoughton and Votta (2003), is a services-oriented business model, in which a manufacturer of goods uses an outside chemical supplier – the service provider – for the application of chemicals in its production processes. The current findings in the literature suggest that the development of CMS is driven by stringent chemicals policy. The provision of serviced solutions is a prominent feature of CMS. According to Mont (2003), CMS thus can be seen as a Product Service System (PSS) (see also White et al. 1999 and Reiskin et al. 1999).

Stoughton and Votta (2003) define CMS as follows:

> *"Chemical management services is a business model in which a customer engages with a service provider in a strategic, long-term contract to supply and manage the customer's chemicals and related services."*

The United States Environmental Protection Agency (US EPA 2014) defines CMS as follows:

> *"Chemical Management Services (CMS) is a business model in which a customer purchases chemical services rather than just chemicals. These services can encompass all aspects of the chemical management lifecycle including: procurement, delivery/distribution, inventory, use (including chemical substitute research), collection, monitoring/reporting, training, treatment, disposal, information technology, and even process efficiency improvements; each of which poses its own costs and risks. Under CMS, the service provider is compensated based on the quality and quantity of services provided that reduce chemical lifecycle costs, risks, and environmental impacts, not on the volume of chemical sold. Therefore the service provider has the same objective as the customer: to reduce chemical use and cost. Both participants achieve bottom line benefits through reduced chemical use, cost, and waste. This model is now widely used in the automotive, aerospace, and microelectronics sectors where environmental benefits observed include reduced chemical use, reduced emissions, and reduced waste generation, as well as substantial cost savings. A total average cost reduction of 30% has been achieved in the first five years.*
>
> *Different to Chemical Leasing where process optimization is given central attention, CMS "might" encompass process efficiency improvement, in most cases, however, there is little transfer of know-how between chemicals supplier and chemicals user."*

With the application of CMS, the service provider is directly involved or is responsible for the handing and use of the chemical in the production processes. According to Mont (2006: 282), this can include for the purchase of chemicals, their identification, sourcing, and procurement. For the preparation of inventories, this can include receiving, inspection and verification, testing, labelling, and warehousing. For the application of the chemical itself, it can include the movement to the application area and its use. For data management, it can include the order tracking, material safety data sheet (MSDS) management, and chemical use tracking. For disposal activities, it can include the handling, collection and actual treatment of waste. For the Environmental Health and Safety services, it can include the provision of data for reporting, safety procedures, emergency preparedness, and response planning. As a value added, CMS can also include process changes to improve efficiency, chemical management advice and training services.

The profits of the service provider are a direct result of the cost savings realized by decreasing the unit production costs with the application of CMS. Some authors see the potential of realizing these cost savings in the 'hidden costs' of managing chemicals, which arise from the expenses that occur at different stages of the life cycle of the chemical, such as storage, transport, handling or disposal (Oldham and Votta 2003, Reiskin et al. 1999, Bierma and Waterstraat 1999).

With regard to the interlinkages with Chemical Leasing, there is no clear conclusion in literature about the relationships between these two concepts. Some authors use the terms Chemical Leasing and CMS synonymously to the extent that they describe Chemical Leasing as a CMS initiative designed promote CMS-type principles, such as the increase of eco-efficiency and sufficiency of chemicals use; an increased focus on services instead of material products; delinking economic success from the quantity of chemicals sold; fostering integrated approaches by changing the traditional customer-supplier relationship; and transfer of responsibility from the user to the chemical supplier for the application, handling, storage or disposal of the chemicals (Mont et al. 2006, Geldermann et al. 2009, Anttonen 2010). Other authors conclude that CMS and Chemical Leasing, while sharing many common features, differ in some characteristics. Stoughton and Votta (2003: 841), for example, describe Chemical Leasing as a sub-set of CMS, and note that there is clear delineation between these two concepts. They argue that while Chemical Leasing can be a feature of a broader CMS programme, the terms CMS and Chemical Leasing should not be confused.

For Stoughton and Votta, the "term 'leasing' implies a transfer of liability from manufacturer to supplier that is often not possible in the US regulatory context." It is evident that some of these differences in the specifics of these concepts stem from the fact that Chemical Leasing and CMS have been initially developed in different locations: CMS in the United States and Chemical Leasing in Europe. Nevertheless, there is consensus in literature that both concepts support a shift to a service-based economy, long-term cooperation between the suppliers and users, and an extended responsibility of the supplier that spans over the entire life-cycle of the chemical (Stoughton and Votta 2003, Lozano et al. 2013).

The fact that there is no unique definition of CMS makes it difficult to pinpoint the major differences between these two approaches. A key difference can certainly be seen in the scope of the services. Chemical Leasing focuses predominately on the processes by which the chemicals are applied, whereas CMS has a much larger scope and includes other services such as supply, handling and storage as well. Moreover, the switch to the services delivered by the chemicals as the basis of payment is specific for Chemical Leasing. In the context of CMS, the company that offers such services may not supply the chemicals themselves, which is instead a key feature of Chemical Leasing.[2]

Following this introduction to the basic principles of Chemical Leasing, the subsequent description of three research articles published in the context of this thesis provides an overview of the implementation of Chemical Leasing business models in the past decade (article I) as well as an analysis of two specific aspects of Chemical Leasing: the interrelation with Corporate Social Responsibility (article II) and the potential of this business model to support the principles of Sustainable Chemistry (article III).

2.1.2 Article I: Chemical Leasing – A Review of Implementation In The Past Decade

This article describes how innovative business models can serve as a solution of industry and research to manage the risk of chemical substances and to achieve the goals of the WSSD (WSSD 2002). The WSSD called for a renewal of the commitment to the sound management of chemicals and of hazardous wastes throughout their life cycle and set the ambitious goal to use and produce chemicals in ways that do not lead to significant adverse effects on human health and the environment by 2020.

Chemical Leasing is such an innovative business model that supports the goals of the WSSD. It shows a vast potential to increase the effective risk management of chemical substances. This is done either by resolving undesired information asymmetries by transferring knowledge to the user, or by shifting responsibility for applying and disposing of the chemical to the producer. Any unnecessary consumption of chemicals in production processes can be avoided, as this would now decrease the revenues of the producer. Chemical Leasing also helps to reduce the amounts of chemicals required in the application thanks to the optimization of processes. It thus saves costs, also thanks to reduced energy consumption. Communication between the producer and user can be strengthened, since both partners now have a clear incentive to increase the efficiency of the application of chemicals. Chemical Leasing also fosters cooperation between the user and the

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[2] See also: http://www.chemicalleasing.com/sub/faq.htm# or http://www.epa.gov/osw/hazard/wastemin/minimize/cms.htm

producer, since the producer has increased responsibility for the processes in which the chemicals are applied. Finally, it increases the environmental performance and the economic competitiveness through the introduction of best available technologies and best environmental practices. Chemical Leasing also creates a positive business environment, in which companies can grow in competitive global markets. At the same time, companies are able to reduce the overall amounts of chemicals applied in their production processes (Ohl and Moser 2008, Joas 2008, Lozano et al. 2013).

Chemical Leasing hence shows a great potential to become "a worldwide perspective for sustainable development within chemicals management." (Jakl 2008b: 224) This review intends to outline the current standings of literature regarding the implementation of Chemical Leasing at the national and international levels. The following research questions have been addressed in recent literature on Chemical Leasing:

1. Can Chemical Leasing business models align the objectives of policy-makers and industry regarding the production and use of chemical substances?
2. What are the contributions of Chemical Leasing to other voluntary global initiatives on the management of chemical substances?

This article reviews the responses of literature towards these research questions. In doing so, the potential of this business model to serve as an approach for dematerializing production processes and managing the risks of chemicals at all levels are highlighted. The article also provides an outline of how Chemical Leasing has supported the alignment and implementation of the objectives of chemicals policy-makers and industry regarding the production and use of chemicals, and analyses to what extent Chemical Leasing contributes to the implementation of a number of voluntary global initiatives, such as Cleaner Production, Sustainable Chemistry and Corporate Social Responsibility. This is followed by systematic analysis of the gaps identified in literature regarding the implementation of Chemical Leasing business models. Based on this analysis, specific aspects in the field of Chemical Leasing are outlined that need to be further elaborated in order to increase the understanding and applicability of this business model.

First research question: aligning the objectives of policy-makers and industry regarding the production and use of chemical substances

The main finding of this article with regard to the first research question is that the implementation of Chemical Leasing convincingly contributes to the achievement of all five chemical policy objectives (Jakl et al. 2004, Ohl and Moser 2008, Lozano et al. 2013), which are:

1. Awareness raising objective: the intrinsic risks of producing and using chemicals are known.
2. Risk management objective: the risks of the produced and used chemicals are being minimized risks at every stage of the chemicals' life-cycle.

3. Process optimization objective: the quality of practices used in the application of chemicals is increased.
4. Communication objective: communication regarding the risks of chemical substance is intensified along the supply chains.
5. Ownership objective: industry itself is responsible for the documentation, evaluation and minimisation of risks resulting from chemicals.

The following two specific examples of policy approaches for the sound management of chemicals at the regional and at global levels provide further evidence that the implementation of Chemical Leasing is a convincing response to achieve an alignment of the objectives of policy-makers and industry regarding the production and use of chemical substances.

Example 1: Chemical Leasing and REACH

There is broad consensus in literature that Chemical Leasing is a convincing means to implement REACH. A key component of the REACH regulatory framework will be the reversal of the "burden of proof", which, in turn, bolsters a "no data – no market" approach. As a precondition for market access, producers or importers of substances are obliged under REACH to deliver documentation regarding properties of chemicals. This is to include information on possible risks during their applications. Jakl (2008b: 214) states that this implies a "real shift of paradigm: Although the current legislation also was based to a certain extent on the producers' responsibility – the actual burden of proving a certain risk and of demanding risk-appropriate management measures however was with the authorities."

Jakl (2008b) maintains that the implementation of REACH requires intensified cooperation, networking and communication based on documentation, evaluation and minimisation of hazards. Chemical Leasing fosters an intensified dialogue as well as cooperation and collaboration between the supplier and user of chemical substances and can therefore serve as a basis for the implementation of REACH. Lozano et al. (2013) also share this view, stating that the relationship built between the provider and the user of a chemical thanks to Chemical Leasing fosters knowledge sharing among these actors. They further argue that this would constitute a prerequisite for REACH and REACH-like regulatory frameworks.

REACH also requires chemicals to be handled with care. This implies that chemicals and their applications are not only monitored but also managed with maximum accuracy. Jakl (2008b: 217) outlines that REACH and Chemical Leasing share the same philosophy: "REACH represents the regulatory driver for this attitude aiming at protecting human health and the environment […] whereas Chemical Leasing is additionally driving it from the economic point of view since resource efficiency simply increases profit." Moreover, Chemical Leasing, according to Jakl (2008b: 217), "is the ideal business environment to identify and apply the use and exposure category concept in particular within the Chemical Safety Report – jointly by suppliers and users." Jakl (2008b: 218) concludes that "Chemical Leasing is making use of REACH structures and is turning them into economic advantages while at the same time catalysing REACH compliance".

In particular within the "Authorisation" regime REACH is establishing for substances of very high concern, applicants might document their commitment towards safe handling and accurate monitoring by basing their applications on the Chemical Leasing concept. Tracing chemicals involved throughout all stages of application while at the same time optimising the resource efficiency are specific characteristics of Chemical Leasing aiming at risk mitigation, a prerequisite for authorisations to be granted. On the other hand it is a central aim of authorisation to ensure substitution of authorised chemicals as soon as benign alternatives are available. Authorisation under REACH and Chemical Leasing thus are mutually supportive instruments.

Similarly, Ohl and Moser (2007 and 2008) demonstrate that the implementation of Chemical Leasing models supports a transfer of knowledge from the producer to the user or transfers the responsibility for applying and disposing of the chemical to the supplier. The authors conclude that the implementation of Chemical Leasing is in line with the objectives of REACH, since these business models address these undesired information asymmetries between the user and the supplier of chemicals.

Also, a recent report of the European Commission has shown that REACH discouraged chemical suppliers to continue competing in the markets of certain chemicals. The report showed that this market concentration and the resulting increased prices could positively influence the development of business models, such as Chemical Leasing. It can be expected that this trend may increases the safety of using and producing chemical substances (EC 2013).

Example 2: Chemical Leasing and the Strategic Approach to International Chemicals Management

The International Conference on Chemicals Management (ICCM) adopted in 2006 the SAICM as a policy framework to foster the sound management of chemicals. The SAICM, according to Jakl (2008a), constitutes a framework of measures that seeks to increase the eco-efficiency of chemicals and, with that, the minimisation of their releases into the environment. Chemical Leasing, according to Jakl (2008a), complies with the new paradigm of environmental policy, and of chemicals policy in particular as set out in the SAICM, as it addresses not only the characteristics of chemicals but also the optimization of the processes in which chemicals are applied. The author confirms that it is therefore evident that Chemical Leasing can support the implementation of the SAICM and could be disseminated as a 'Best Practices' as called for in SAICM's "Global Plan of Action". He concluded by stating that Chemical Leasing shall become a central element of that instrument and its implementing processes. Chemical Leasing was prominently featured at the ICCM in an event in which the Austrian Federal Minister for the Environment and the UNIDO

Director General committed to Chemical Leasing as their common political priority.

Joas (2008) also agreed that the concept of Chemical Leasing is in line with the policy framework set out by SAICM. That is because Chemical Leasing adopts a life-cycle approach for the sound management of chemicals in industrial processes and fosters a responsible use of chemicals that ultimately leads to the minimization of adverse effects on human health and the environment. Chemical Leasing also supports the transfer of technologies from developed to developing countries and hence is a suitable vehicle to implement the objectives of SAICM to strengthen the capacity of developing countries for the sound management of chemicals.

The evidence provided in this article further supports the argument that Chemical Leasing business models are able to align the objectives of users and producers of chemicals. However, the analysis of further examples is needed to evaluate whether the implementation Chemical Leasing, particularly at the national level, is aligned with chemical policy objectives also in other regions of the world.

Second research question: contributions to other voluntary global initiatives on the management of chemical substances

The article also analysed the findings of literature on the possible impact Chemical Leasing has on the implementation of other global initiatives that are implemented by industry on a voluntary basis and aim at protecting the environment from the adverse effects of chemicals and related waste. It focused on three specific fields. The first example is taken from the field of Cleaner Production, which is an industry-centred initiative that seeks to strengthen industrial processes and sustainable production patterns as well as to minimize the generation of wastes. The second example focused on Sustainable Chemistry, which is specific field of the sustainable development agenda and the third example is taken from the field of Corporate Social Responsibility. The second and third examples are described more in detail in article II (Moser et al. 2014a) in section 2.1.2 and article III (Moser et al. 2014b) in section 2.1.3 below.

Definition

Based on the implementation of Chemical Leasing in the past decades, several scholars have provided definitions that outline the scope and limitations of this business model. UNIDO has played an important role in the introduction and promotion of this business model at the global level in the past decade. Accordingly, UNIDO (2011) has developed a definition of Chemical Leasing. Other authors provide definitions of Chemical Leasing and related approaches. Lozano et al. (2014: 59), based on the findings of their research, also suggest definition of Chemical Leasing. In addition, Moser et al. (2014a) further describe the term 'Grey Chemical Leasing' and suggest that Chemical Leasing business models are called 'grey' if certain conditions are not fulfilled.

Since all aspects proposed by the above authors are important for a proper definition of Chemical Leasing, this article hence proposes a working definition of both Chemical Leasing and 'Grey Chemical Leasing', as outlined in Table 2 below.

Table 2. Working definitions of 'Chemical Leasing' and 'Grey Chemical Leasing'

Organizational dimension	Chemical Leasing: • Is a service-oriented business model • Is based on collaborative approaches between two or more industrial partners: at the minimum a user of the chemical and a provider[3] of a service[4] • Allows selling the functions performed by the chemical • Extends the responsibility of the producer and/or service provider and may include the management of the entire life cycle • Requires high-quality standards and mutual trust between the industrial partners • Requires unlimited access to the chemical by the user
Environmental dimension	Chemical Leasing: • Aims to increase the efficient use of chemicals while reducing the risks of chemicals, and protecting human health • Reduces the environmental impacts of hazardous chemicals • Reduces the consumption of hazardous chemicals • Improves the environmental performance of all involved partners
Economic dimension	Chemical Leasing: • Shifts the focus from increasing sales volume of chemicals, toward a value-added approach • Uses functional units and the main basis for payments[5] • Enhances the access to new markets of all involved partners • Requires proper benefit sharing between all involved partners • Improves the economic and environmental performance of all involved partners, thus striving for a win-win situation
Technical dimension	Chemical Leasing: • Focuses on non-reactant chemicals that are easy to recovery[6] and that are not part

[3] The service provider can be the producer of the chemical

[4] The service is usually connected to a function performed by the chemical

[5] Functions performed by a chemical might include: number of pieces cleaned; amount of area coated, etc.

[6] E.g. solvents and catalysts

	of the final product • Focuses on chemicals that are high risk for human health or the environment • Focuses on chemicals that have a high value
Grey Chemical Leasing	Chemical Leasing is called 'Grey Chemical Leasing' if: • The ownership of the chemical changes to the user (purchase of the chemical) • Functional units are not the main basis for payments • Sustainability criteria for Chemical Leasing are not or incompletely fulfilled[7] • The chemicals of concern are reactant chemicals that are difficult to recover or that become a part of the final product

Source: adapted from UNIDO (2011), Lozano et al. (2014), Moser et al. (2014a)

Gaps in the theoretical and practical understanding of Chemical Leasing business models

The article has identified certain gaps in the understanding on specific aspects of Chemical Leasing in theory and in praxis. A first identified gap is the lack of a more detailed analysis of the inhibiting factors to the successful implementation of Chemical Leasing. Joas and Schott (Jakl et al. 2004: chapter 4), Lozano (2013 and 2014), Plas (2008) and Beyer (2008b) provided an overview of such inhibiting factors. For example, existing trade structures often do not facilitate direct relationship between the manufacturer and the user of the chemicals. Also, the establishment of communication chains between the potential partners, investments in logistics and training activities, financial security in the case of economically weak partners, or use-specific liability aspects may incur in additional costs and thus discourage the implementation of Chemical Leasing. For the user, implementing Chemical Leasing may result in dependency owing to a closer contractual relationship with the supplier. Related to that an increased dependency may also result in a reduced flexibility in case other suitable solutions become available from competing manufacturers. Also, the user may be fear intellectual property theft and industrial espionage due to the closer involvement of Chemical Leasing partner in its production. While these insights are useful, case studies on Chemical Leasing, at the practical level, often fall short of providing conclusions on how and if at all these inhibiting factors can be addressed. At the theoretical level, there is a general lack of empirical evidence in the literature. For example, a more thorough understanding of whether Chemical Leasing is only applicable to non-reactant chemicals that are indirectly used in processes would provide a solid foundation for the implementation of this model in the future. For such cases, there has been an attempt to define 'Grey Chemical Leasing'. However, a more thorough empirical

[7] See Moser et al. (2014a)

application of this is still pending. Gaps also exist in the understanding of the legal and regulatory frameworks of countries. Wittmann (2008) highlighted the Austrian situation, but a thorough analysis of the legal frameworks of other countries is yet to be done.

As outlined by Joas (2008), gaps in the following four main areas still exists. First, the question of what are the right partners for Chemical Leasing and how these partners can be identified. Second, how to ensure confidence between all involved partners. Third, how to implement quality assurance measures in a cost efficient and effective manner. And, fourth, how to develop fair contracts that meet expectations of partners.

2.1.3 Article II: Chemical Leasing And Corporate Social Responsibility

This article focuses on the implications of Chemical Leasing on Corporate Social Responsibility (CSR). Recent pilot projects have shown the economic benefits of introducing Chemical Leasing business models in a broad range of sectors. A decade after its introduction, the promotion of Chemical Leasing is still predominantly led by the public sector and international organizations.

It is shown in this article that awareness-raising activities to disseminate information on this innovative business model mainly focus on the economic benefits. Moreover, selling Chemical Leasing business models solely on the grounds of economic and ecological considerations falls short of branding it as a corporate social responsibility initiative, defined as a stakeholder-oriented concept that extends beyond the organization's boundaries and is driven by an ethical understanding of the organization's responsibility for the impact of its business activities.

The field of CSR encompasses a broad array of different theories and approaches. The concept evolved from a perception that a company's main objective is to provide services and goods to society (Chamberlain 1973, Friedman 1968, Friedman 1970) towards the perception that a company is to contributing to the general welfare of society (Carrol 1979, Steiner et al. 1997, Wood 1991). This view was further amplified by the changing public perception towards the social responsibility of companies, which was to go beyond the economic interests of the company and its legal obligations. This, together with the occurrence of social movements and non-governmental organizations (NGOs) (Doh et al. 2006), were the reasons why some scholars began to see a company's relationship with society, in the essence, as a relationship with its stakeholders (Clarkson 1995, Smith 2000, Maignan et al. 2004, Ingenbleek et al. 2007). Freeman in 1984 even went as far as stating that "managers bear a fiduciary relationship to stakeholders" as opposed to its shareholders, which was a well-accepted view in that time (Freeman 1984: xx).

The perception of a company's responsibility towards society was coined as 'stakeholder theory' (Evan et al. 1988, Bowie 1991, Donaldson et al. 1995, Freeman and Philips 2002). It defined stakeholders as a group of persons that have a legitimate interest in the activities of a company, including, for example, suppliers, customers, employees, or the local community. According to this ‘normative’ CSR approach, companies are to take into account the views of all their stakeholders. This was seen as beneficial, since the views of all stakeholders are considered to have an intrinsic value, each of which should be considered individually and not because of their potential impact on shareholders (Donaldson et al. 1995).

This stakeholder-centric approach is a CSR theory merited attention in the context of this article for the following reasons. First, the implementation of Chemical Leasing involves chemical substances, which are either non-toxic but perceived with a negative connotation, or are actually hazardous. In other words, chemical substances have a vast potential to polarize various stakeholders of companies producing or applying them. And, second, the negative impact of inefficient use or accidents of chemicals on the stakeholders of the company can often be costly and damaging to the company’s reputation. In such a demanding and risk-prone environment, a CSR approach that seeks to foster relationships and takes into account the views of all its stakeholders seems to us particularly suitable fundament for the further analysis of Chemical Leasing business models.

For this article, CSR is defined accordingly “as a stakeholder-oriented concept that extends beyond the organization’s boundaries and is driven by an ethical understanding of the organization’s responsibility for the impact of its business activities, thus, seeking in return society’s acceptance of the legitimacy of the organization” (Maon et al. 2008: 72).

Stakeholders, according to Clarkson (1995: 106), are defined as “persons or groups that have, or claim, ownership, rights, or interests in a corporation and its activities, past, present, or future. Such claimed rights or interests are the result of transactions with, or actions taken by, the corporation, and may be legal or moral, individual or collective.” Clarkson further distinguishes between primary and secondary stakeholder groups. The former represents a group of stakeholders that is of crucial importance for the survival of the company and typically includes employees, customers, suppliers and the broader public such as the government or communities that provide infrastructures and markets. The latter represents a group that is not essential for the survival of the company, but nevertheless is able to either influence or affect, or be influenced or affected themselves by the company (Clarkson 1995).

Assessment methodology

The assessment of Chemical Leasing business models in the context of this article focuses on a specific sub-set of stakeholder groups of the company introducing Chemical Leasing: employees, representing a primary stakeholder group, and local communities, representing a secondary stakeholder group.

Employees handle the chemicals that the company applies and therefore are potentially at risk if exposed to such chemicals. An integral aspect of the field of occupational health and safety is the protection of workers from workplace related risks (Erickson 1996, Reese 2003, Montero et al.

2009).

It is assumed that applying chemicals poses a certain risk to workers and that this risk is positively correlated with the acute and long-term adverse effects of the involved chemicals to human health. A reduction of the exposure of employees to these chemicals will therefore decrease workplace related risks. In line with the stakeholder theory, it is further assumed that the employees of the company introducing Chemical Leasing value an increase of the occupational health and safety standards at their work place. The criterion used in the ensuing analysis is the level of the occupational health and safety within the company. The assessment measures the extent to which this criterion is met by evaluating exposure rates of workers to chemicals of concern before and after the introduction of Chemical Leasing. Local communities in the geographical vicinity of the company, on the other side, are a group of stakeholders that are immediately affected by the inefficient use of chemicals or chemicals-related accidents.

Another key assumption in the context of this analysis is that applying chemicals poses a certain risk that those chemicals are released into the environment and that this risk is positively correlated with the acute and long-term effects of the involved chemicals to human health and the environment. A reduction of the releases of these chemicals into the environment will therefore decrease risks to the health of local communities as well as the degradation of ecosystems. In line with the stakeholder theory, it is further assumed that the local communities will value measures to protect human health and the environment from the adverse effects of chemicals. The criterion used in the analysis is the ability of the company to protect the environment from the adverse effects of the chemicals it applies. The assessment measures the extent to which this criterion is met by evaluating the level of releases of involved chemicals into the environment before and after the introduction of Chemical Leasing.

The assessment undertaken in the context of this article involves two case studies that outline the introduction of Chemical Leasing in two different sectors: the oil and gas and the surface cleaning sector.

The results of both case studies showed that the introduction of Chemical Leasing improved occupational health and safety standards in the two companies in which the chemical substances are being applied, and strengthened their ability to protect human health and the environment from the adverse effects of the used chemicals through the optimization of processes. In the water purification case, the involved chemicals were less toxic in their nature. Nevertheless, the article showed that the potential of Chemical Leasing to largely reduce the use of chemicals of 120 tonnes per year shows a similar level of significance as the degreasing example, in which the involved chemicals have a much higher carcinogenicity and toxicity and hence pose a higher level of risk to human health and the environment. Both case studies therefore successfully meet the established criteria.

The findings of this article therefore allow the conclusion that it is justified to brand both Chemical Leasing case studies as a CSR initiative that would help the companies to foster relationships with their key stakeholders.

2.1.4 Article III: Chemical Leasing In The Context of Sustainable Chemistry

This article on Chemical Leasing focuses on how the consumption of chemicals, energy, resources and the generation of related wastes can be reduced through Chemical Leasing. Its purpose is to show that Chemical Leasing as a business model contributes to Sustainable Chemistry. For this, the article provides a definition of Sustainable Chemistry and Chemical Leasing and establishes a distinction between conventional chemistry and Sustainable Chemistry.

In order to avoid ambiguity in the definition of Chemical Leasing, the article introduces the term ‘grey’ Chemical Leasing, which is a model similar to the typical Chemical Leasing as defined in section 2.1.1 above. While ‘grey’ Chemical Leasing can include various chemical services models, the difference between ‘grey’ and typical Chemical Leasing is often not evident in individual cases. Within the context of typical Chemical Leasing the following aspects are fulfilled:

1. No change of ownership of the chemical (no purchase, the chemical remains property of the provider).
2. Change to use-related payment (dimension of allocation e.g. € / m2 cleaned surface). This may greatly reduce the chances of environmental burdens predominantly by reduction of chemical consumption.
3. Complete fulfilment of the sustainability criteria for Chemical Leasing.

In contrast to this, within ‘grey’ Chemical Leasing all of these aspects, or only some, are not fulfilled.

As regards the assessment of the potential of Chemical Leasing to contribute to Sustainable Chemistry, the article proposes to evaluate the sustainability of a target system by using different indicators. While this approach has been extensively discussed in literature (Singh et al. 2009), the assessment methodology proposed in this article follows a top-down approach for the selection of the conceptual framework and indicators as suggested by Lundin (2003). It also takes into account the Bellagio Sustainability Assessment and Measurement Principles (Pinter et al. 2012).

For this, a number of basic goals and sub-goals have been selected to assess the sustainability within a given Chemical Leasing system. Table 3 outlines the conceptual framework and indicates what aspects or domain of sustainability the indicator measures.

Table 3: Conceptual framework outlining basic goals and related sub-goals for promoting sustainable chemistry through Chemical Leasing

Basic goals (g_i)	Sub-goals (g_{ij})
g_1 Increase overall resource efficiency	g1,1 Use less energy
	$g_{1,2}$ Use less raw and auxiliary materials
	$g_{1,3}$ Use less water
	$g_{1,4}$ Produce less waste / wastewater
g_2 Reduce adverse effects on health and environment of the chemicals of concern	$g_{2,1}$ Reduce impacts on labour health
	$g_{2,2}$ Substitution of carcinogenic, mutagenic and toxic for reproduction (CMR) chemicals
	$g_{2,3}$ Substitution of persistent, bioaccumulative and toxic (PBT) chemicals
	$g_{2,4}$ Reduce impacts on water
	$g_{2,5}$ Reduce impacts on air
	$g_{2,6}$ Reduce impacts on soil
g_3 Increase economic value and strengthen chemicals management	$g_{3,1}$ Increase output with desired properties
	$g_{3,2}$ Optimise handling / storage / logistics
	$g_{3,3}$ Increase economic gain: increase revenue for supplier
	$g_{3,4}$ Increase economic gain: increase revenue for user
	$g_{3,5}$ Increase competiveness for supplier
	$g_{3,6}$ Increase competiveness for user
g_4 Increase sustainability in surrounding systems	$g_{4,1}$ Use less fossil resources
	$g_{4,2}$ Reduce impacts on health of consumers
	$g_{4,3}$ Promote recycling / use in cascades
	$g_{4,4}$ Increase economic gains in the region / country: increase revenue for trade
	$g_{4,5}$ Increase economic gains in the region / country: increase revenue for other stakeholders in the supply chain
	$g_{4,6}$ Reduce poverty in the region
	$g_{4,7}$ Increase employment in the region
	$g_{4,8}$ Reduce impacts on water in the region
	$g_{4,9}$ Reduce impacts on air, including reduction of greenhouse gases
	$g_{4,10}$ Reduce impacts on ecosystems / biodiversity

Source: Moser et al. (2014a)

Assessment methodology

The purpose of this article is to analysis whether Chemical Leasing is suitable to foster a substitution of hazardous chemicals as a tool to protect environmental health and safety and hence to ensure compliance with sustainability criteria. For this, an assessment methodology is proposed to provide an answer to the following research questions:

1. Does the application of Chemical Leasing promote sustainability in comparison to an existing chemicals production and management system?
2. If various Chemical Leasing project types are envisaged, which is the most promising in terms of sustainability?

The assessment methodology has been developed in order to ensure comparability of the different case studies. The benchmark for measuring the impact of a Chemical Leasing project will be a 'business as usual scenario' in which Chemical Leasing is not applied. In order to assess whether a Chemical Leasing project promotes sustainability or not, the article proposes the following assessment methodology.

A nominally scaled variable with a score of {1, 0, -1} is assigned to each sub-goal g_{ij}. A score of {1} indicates that the implementation of a Chemical Leasing project has achieved the respective sub-goal. A score of {0} indicates that a sub-goal is either not relevant for the implementation of the Chemical Leasing project or no data is available. A score of {-1} indicates that the implementation of a Chemical Leasing project has not achieved the respective sub-goal.

To arrive at these scores, the different sections of the case studies are coded. For this, qualitative information provided in the case study is screened to decide, in a first step, whether any of the sub-goals g_{ij} are not relevant for the case study. All non-relevant sub-goals are given a score of {0}, which is then recorded in a specific table (see Table 4) below. In a second step, the case study is screened to decide whether it provides data for each relevant sub-goal. All sub-goals that the case study fails to provide data are given a score of {0} and the score, again, is recorded in that table. In a third step, the remaining relevant sub-goals are screened to decide whether the implementation of a Chemical Leasing project has or has not achieved the respective sub-goal. The respective scores of {1} or {-1} are transferred into that table. In a last step, the scores for each sub-goals g_{ij} are summed to obtain a value for the 'Total Score', which is defined as follows:

$$Total\ Score = \sum_{i=1}^{4} \sum_{j=1}^{n} g_{ij} \qquad (1)$$

This value, which is also recorded in the table, represents the indicator proposed for assessing the sustainability of a project.

Table 4: Evaluation of the potential of Chemical Leasing to promote sustainable chemistry

Promoting sustainable chemistry through chemical leasing		**Case study n**	
Basic goals	**Sub-goals**	*Achievement [Yes/No/NR*/ MD**]*	*Score [0/1]*
1 - Increase overall resource	1.1. Use less energy		
	1.2. Use less raw and auxiliary materials		

Promoting sustainable chemistry through chemical leasing		Case study n	
Basic goals	**Sub-goals**	*Achievement [Yes/No/NR*/ MD**]*	*Score [0/1]*
efficiency	1.3. Use less water		
	1.4. Produce less waste / waste water		
	Sub-total basic goal 1		
2 - Reduce adverse effects on health and environment of the chemicals of concern	2.1. Reduce impacts on labour health		
	2.2. Substitution of CMR chemicals		
	2.3. Substitution of PBT chemicals		
	2.4. Reduce impacts on water		
	2.5. Reduce impacts on air		
	2.6. Reduce impacts on soil		
	Sub-total basic goal 2		
3 - Increase economic value and strengthen chemicals management	3.1. Increase output with desired properties		
	3.2. Optimise handling / storage / logistics / processes		
	3.3. Increase economic gain: increase revenue for supplier		
	3.4. Increase economic gain: increase revenue for user		
	3.5. Increase competiveness for supplier		
	3.6. Increase competiveness for user		
	Sub-total basic goal 3		
4 - Increase sustainability in surrounding systems	4.1. Use less fossil resources		
	4.2. Reduce impacts on health of consumers		
	4.3. Promote recycling / use in cascades		
	4.4. Increase economic gains in the region/country: increase revenue for trade		
	4.5. Increase economic gains in the region/country: revenue for other stakeholders in the supply chain		
	4.6. Reduce poverty in the region		
	4.7. Increase employment in the region		
	4.8. Reduce impacts on water in the region		
	4.9. Reduce impacts on air, including greenhouse gases		
	4.10. Reduce impacts on ecosystems / biodiversity		
	Sub-total basic goal 4		
Total score		*(insert sum of all scores [0/1])*	
Promotion justified (every criterion > 0, i.e. at least 1)?		*(insert [Yes/No])*	
Missing data		*(insert sum of all entries MD)*	

**MR: not relevant; **MD: missing data*

Source: adapted from Moser et al. (2014a)

Scope of the methodology

The scope of the proposed methodology is limited to the comparison of different Chemical Leasing projects in terms of their relative contribution to Sustainable Chemistry. It hence allows a relative assessment of specific case studies among each other. It is also assumed that all sub-goals and goals have equal weights.[8] The ‘Total Score’, as defined above, is a single, qualitative indicator that shows a possible increase in sustainability after the introduction of Chemical Leasing.

Subject to certain conditions, this methodology allows to conclude ‘with certainty’ that introducing Chemical Leasing has increased sustainability. For this, any basic goal must positively contribute to sustainability. This means that the aggregated scores $\sum_{j=1}^{n} g_{ij}$ for each basic goal g_i must be larger than zero. This is set out in equations (2) to (5):

$$\sum_{j=1}^{4} g_{1j} > 0 \qquad (2)$$

$$\sum_{j=1}^{6} g_{2j} > 0 \qquad (3)$$

$$\sum_{j=1}^{6} g_{3j} > 0 \qquad (4)$$

$$\sum_{j=1}^{10} g_{4j} > 0 \qquad (5)$$

Accordingly, an increase in overall sustainability is ‘uncertain’ if the above conditions are not fulfilled. In this case, the respective value of the ‘Total Score’ shall have no further relevance.

In addition, it is assumed that case studies may not be suitable to contribute to Sustainable Chemistry if the following two conditions are met. First, the aggregated score for a specific basic goal g_i is zero and, second, no sub-goal g_{ij} of that specific basic goal has achieved the sustainability criteria, i.e. a score of $\{1\}$. This can be the case if either data for the respective sub-goals is not available at all or such data is not relevant.[9] Case studies that fall under these conditions will not be considered by this methodology.

Limitations of the methodology

As regards its limitations, the methodology will not reveal to what extent a Chemical Leasing project has achieved or not achieved the respective sub-goals. Also, the conceptual framework will not allow deriving conclusions on whether Chemical Leasing business models are sustainable per se, or to what extent Chemical Leasing promotes Sustainable Chemistry. The assessment rather seeks to identify the limitations of typical Chemical Leasing systems to Sustainable Chemistry and/or whether such systems can be used as a benchmark.

Practical considerations

Case studies are characterized according to their size, number of sectors covered and their geographic scope to facilitate the interpretation comparability of the different case studies. The

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[8] The calculation of the scores for each sub-goal will not be adjusted through weighting factors.

[9] Or any other combination of ‘no data is available’- and ‘sub-goal not relevant’-entries.

following categories have been established: smaller case studies that are implemented as a single standing project at a local level in one specific sector fall in category A. Instead, larger case studies that are implemented in several sectors or at the national, regional or sub-regional levels fall in category B.

The impact of case studies on surrounding systems (basic goal 4) may differ between these two categories. It is evident that this has implications for the comparability of case studies belonging to different categories. Consequently, case studies are compared as part of this evaluation within each category in the first place.

Results

The assessment undertaken in the context of this paper was limited to the relative assessment of eight specific case studies and allows the comparisons of different projects in terms of their relative contribution to Sustainable Chemistry. The findings of the assessment demonstrate that Chemical Leasing can be regarded as promoting Sustainable Chemistry in five case studies with certainty. However, on the grounds of our assessment, it cannot be concluded with certainty that Chemical Leasing has equivalent contribution to Sustainable Chemistry in respect of three further case studies.

2.2 CLTS Subsystem 2: Education And The Role of Universities

2.2.1 Introduction

In the introduction (Chapter 1), Chemistry was described as a Large Technological System, a so-called CLTS, which consist of several subsystems with different functions and features. Due to their unique role of provide higher education and research, universities play a critical role for the functioning of the CLTS. As a consequence, universities have a moral duty in modern societies to ensure that research is conducted with the highest possible ethical standards as well as to educate students in the topics of ethics, integrity and responsibility. Richard R. Ernst, Chemistry Nobel Laureate in 1991, pointed to this extended responsibility of researchers and university teachers in his contribution in 2003 by underlying “the function [of universities] within our society, to educate future generations and to act as truth-seeking centers” (Ernst 2003). Ernst’s thought-provoking contribution was in stark contrast to the predominant understanding of university as an “Ivory Tower” (Bok 1982).

The necessity of scientist assuming responsibility in their work was echoed in many fields in the second half of the last century. In the field of philosophy, Hans Jonas in his contribution “The Imperative of Responsibility” (1979) called for a renewal of ethics in the technological age. In the field of university education, Piero Pozzati, in his contribution to the celebrations of the nine hundredth anniversary of the University of Bologna, pointed out the problem of ethics and responsibility in relation technological innovation and its implication in the cultural preparation and education of young people (Pozzati 1988).

The ‘culture of responsibility’ can thus be seen as a new ethical paradigm, which aims at unifying science and praxis in university research (Pozzati and Palmieri 2007: 14). It is a logic answer to Henry Bergson’s argument about the increased potency of mankind due to technological advancements: “Now, in this body, distended out of all proportion, the soul remains what it was, too small to fill it, …the body, now larger, calls for a bigger soul…” (Bergson 1935).

The requirements for scientists and in particular for chemists to be aware of ethical concerns have indisputably changed due to the increasingly complex tasks that chemists in general, and analytical chemists in particular, nowadays have to carry out in modern chemical industries. In a chemical factory of the first half of last century, analytical chemists usually received samples in a passive manner. Their job profile was limited to provide plant chemists the most accurate and precise answer about the sample composition. The plant chemist, in turn, was tasked to obtain the best results in terms of production yields, quality and costs. Both chemists, by that time, would have likely had a similar approach towards possible emissions, i.e. that chemicals would simply disappear once released into the environment (see chapter 4 for a more detailed discussion of this matter). In present times, the laboratory of an analytical chemist is not limited anymore to the content of the sample flask. With its operations and analytical equipment addresses the surrounding environment in its entirety and vastness, often with a focus that transcends national boarders and continents. Samples became more complex in their scope, larger in their quantities and increasingly undefined in their composition. Likewise, the responsibilities of plant chemists nowadays include not only to find the best technical and economical solutions to a chemical problem, but also to take into account how such solutions may impact the environment. It is evident that the moral duty of a scientist to ‘seek the truth’, as advocated by R. Ernst (2007), becomes increasingly demanding in modern societies.

It is fair to assume that exercising chemistry as a profession or as a researcher nowadays requires a completely different set of skills, attitudes and approaches in comparison with the last century. At the technical level, the task of ‘seeking the truth’ requires the development of advanced chemical concepts and techniques. Here, the limitations of the traditional description of a closed chemical system at equilibrium, for example, call for and open, non-equilibrium statistical and stochastic thermodynamics description of such systems. Other problems can be encountered with the application of apparently effective and scientifically sound methodologies. In the field of chemometrics, conclusions derived from the assessment of risks with low probability values may have only limited validity and accuracy. Similarly, type I and type II errors in statistical testing procedures need to be taken into account because of their underlying ethical implications (Shrader-Frechette 1994 and 2014). Other methodological problems can be encountered when using ‘soft modelling' and flexible fitting procedures in the interpretation of experimental data. While these procedures are popular thanks to the availability of efficient computer programs, there are several methodological drawbacks that can hamper a more in-depth investigation and therefore the advancement of scientific knowledge (Shrader-Frechette 2014). The ethical concerns and practical limitations related to the theory of 'conventionalism' need to be considered as well, if decision-making is based on this theory, particularly in sensitive environmental projects such as underground storage options for atomic waste (Poincaré 1902, Duhem 1954, Pozzati and Palmeri 2002, Ben-Menahem 2006).

It is imperative for researchers to be aware of the limitations of these methodologies, especially when the results of their work may affect environmental and public health. Too often, the application of 'flawed science' leads to 'flawed ethics', which in turn may result in 'flawed policies'. As a consequence, the often-claimed requirement that scientists are to change their attitude towards methodological norms and their underlying ethical norms and principles, requires a much closer involvement of the humanities. Kristin Shrader-Frechette claims that it is imperative to include the scientific fields of philosophy and sociology in the search for new technologies and scientific approaches (Shrader-Frechette 2014). The philosophy of science makes use of logics that are formally exact and independent from the topic for which they are applied. Applying the concept of logics support scientists in avoiding flawed scientific conclusions, which, in turn, may lead to flawed ethics. This can, for example, help avoiding errors in deduction or inference procedures in experimental settings, especially in an undefined and complex context, as described above.

While it can be assumed that research chemists generally know and apply the concept logics systematically in their research activities, this thesis argues that there is nevertheless room for improvement. This is due to fact that experimental settings are often multidimensional and complex in their nature. Also the results of scientific experiments or the experiments themselves may inadvertently affect human health and the environment.

This aspect is critical and relevant for a chemist, especially when working outside of the usual experimental setting in an unknown or not perfectly known environment. In these cases, application of the above-mentioned theory of 'conventionalism' can be particularly problematic. Pierre Duhem, one of the founding fathers of conventionalism, stated in this regard that "[t]he physicist can never submit an isolated hypothesis to the control of an experiment, but only a whole group of hypotheses. When the experiment is in disagreement with his predictions, it teaches him that one at least of the hypotheses that constitute this group is wrong and must be modified. But the experiment does not show him the one that must be changed" (Duhem 1954: 185). Deducing expected consequences from a hypothesis also requires knowledge of auxiliary assumptions and background conditions (Mayo 1997, Shrader-Frechette 2014: chapter 10). This is particularly relevant when a Bayesian approach is used as the method of deduction. Here, scientists may need to make informed decisions about the ethical character of a scientific procedure or outcome of an experiment. Assuming moral behaviour in terms of precaution, benevolence and care requires an understanding of virtue ethics. Richard Ernst concludes that "heading towards a better world" requires the virtues of "wisdom, compassion and personal responsibility" (Ernst 2007a and 2007b).

Universities have important mission in this respect. They arguably have a moral duty, not only because they are largely publicly financed, to use their unique role as provider of higher research and education for the benefit of the society as a whole. The United Nations Educational, Scientific and Cultural Organization also called for this moral duty of universities in Edgar Morin's publication on "Seven complex lessons in education for the future" (1999). Morin, in his publication, addressed the following seven specific subject areas: detecting error and illusion; principles of pertinent knowledge; teaching the human conditions; earth identity; confronting uncertainties; understanding each other; and ethics for the human genre.

The question how to translate these topic areas in specific contents for education in chemistry has been discussed extensively by Dondi (2009) and by Frank et al. (2011). The present thesis seeks continue the work of these scholars in the field of education in chemistry.

The thesis also seeks to investigate the relationship between the role of universities and the context of the CLTS, as described in chapter 1, which is particularly important in the context of the deep-rooted environmental problems that the world faces nowadays. Here, emphasis is given to the apparent conflict between science and experts, on the one side, and laypersons and other actors of the CLTS, such as industry, governments, press or civil society organizations on the other.

Moreover, the thesis provides a critical review of the evolution of environmental protection activities in the context of chemical practice and applied ethics from the second half of the last century to the present time. For this, the thesis seeks to investigate the so-called concept of 'risk society' and the pertinent role of universities in it.

Ulrich Beck, in 1992, described the social order of the new modernity as 'risk society'. According to Beck, society is exposed to risks that have their origins in the attempt of society to control the hazards and insecurities that have emerged as a product of modernization (Beck 1992: 21). At the same time, the public perception of environmental risks has fundamentally changed in the last four decades, a trend that continues to gain momentum.

While in the past the discussions on environmental risks have taken place within exclusive groups of experts, this is no longer the case. Today, the discussion has entered the public spheres with debates among different types of collective agents, such as the public and private sectors, academia, or social movements (Strydom 2002: 2). While many collective agents in the risk society cooperate with each other in a constructive manner (Strydom 2002), conflicts among the different players still exist. Exerting power in political and scientific debates or the conflicting interests of different agents are often the cause of these divergences.

Universities as institutions of higher education and research are well positioned to act as a mediator for conflicts between collective agents of the risk society.

Following this introduction, the subsequent description of two research articles published in the context of this thesis provides a critical review of environmental protection between chemical practice and applied ethics (article IV) and an evaluation of the role of universities in a risk society (article V).

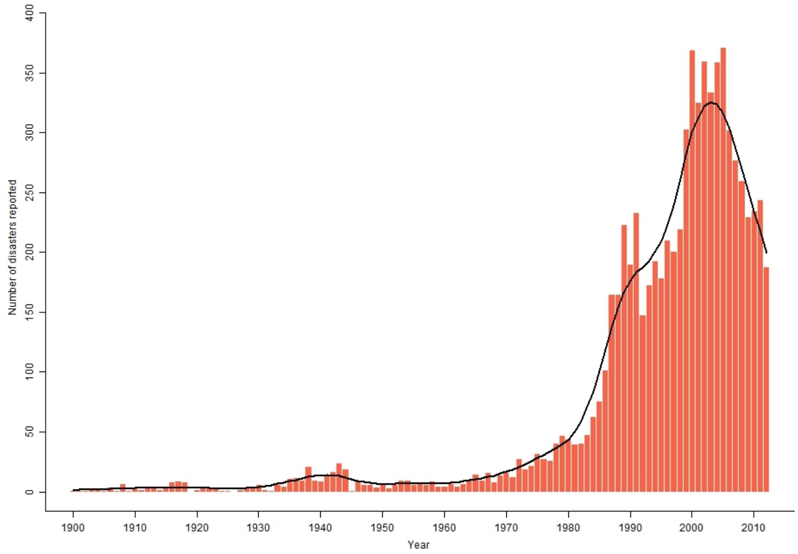
2.2.2 Article IV: Environmental Protection Between Chemical Practice And Applied Ethics: A Critical Review

This article focuses on a critical review of the role of universities in environmental protection between chemical practice and applied ethics. Many chemicals pose threats to human health and the environment through emissions to air, water and soil as well as through the generation of wastes. Direct risks of some chemicals to human health were already perceived in the early twentieth century, but their indirect impacts on the environment were only recognized when their production volumes and open applications tremendously increased in the second half of the last century.

As a consequence, new laws and international treaties have been introduced at the national and global levels. This has happened often from the moment societies became aware of the respective global ecological problems (Moser and Dondi 2012). Industrial chemical accidents, such as the ones in Bhopal and Seveso in the 1970ies and 1980ies, brought the risks of producing and managing hazardous chemicals into the public sphere. Serious flaws in the production processes of chemicals have been a result of the trend to minimize production and labour costs at the expense of safety standards, as well as the growing pressure of fast moving markets to decrease the time to bring products to the market.

Figure 1 shows that technological disasters have increased exponentially since the chemical accidents in Seveso and Bhopal and still remain at a high level nowadays. The article identifies the shift of industrial production of chemicals to developing countries as a reason for the continued high rate of accidents. This is because these countries often lack the technical and institutional capacity to ensure that chemicals are produced according to international safety standards.

Figure 1: Technological disasters reported from 1900 to 2012



Source: database of the Universitè Libre de Louvain (http://www.emdat.be/database) accessed on 13 February 2015

While chemistry represents a root cause for environmental degradation, it also provides solutions to identify and better understand the risks of chemical pollution.

This article argues that chemists have a particular responsibility to find solutions to these problems. Nobel laureates like Roald Hoffmann and Richard Ernst have been showing dedication and keen interest in reforming the mission of scientists. Both were of the standpoint that scientists should no longer work purely to advance the scientific knowledge. Instead, they should strive to perform their work with the highest standards in ethics and responsibility (Hoffmann 1990; Kovac and Weisberg 2011, Ernst 2007a and 2007b).

An obstacle to achieve this objective has been identified in the strains between experts and scientists from the natural and social sciences on one side and the broader public and laypersons on the other side (Strydom 2002, Shrader-Frechette 2010). Whiles these strains have been a driving factor for the debates on environmental protection, these groups often entered the discussions with diverging backgrounds and objectives. These groups not only often have opposing opinions of what frames an environmental crisis, they also used diverging methodological norms to assess and manage the risks of environmental pollution. The inhomogeneity of the various groups of collective agents is a key hypothesis of Piet Strydom's work. He concludes that many collective agents cooperate with each other, but conflicts among the different actors are more the norm than the exception (Strydom 2002: 2).

The article introduces a methodological norm to overcome these strains, which can be summarized as 'naïve positivism'. It claims that the process of evaluating risks is generally objective. An increasing sophistication of analytical methods and equipment in the 1980s and 1990s allowed experts to better understand the complex relationships of chemicals in the environment. Technical engineers or health and toxicology experts were the key advocates of this norm. According to the approach of 'naïve positivism', risks that differ in their nature can be appraised by the same rules. Proponents of this concept also argued that risks below a certain probability are insignificant.

Key aspects of Shrader-Frechette's proposed norm of 'Scientific proceduralism' remain highly relevant in the debates on how modern societies are assessing technological risks. Scholars like Piet Strydom (2002) have concluded that these debates have entered the public spheres and introduced a new critical theory of the so-called cognitive society. Strydom's theory is discussed more in detail in section 2.3 below.

The views and opinions of laypersons, public advocacy groups or non-governmental organizations need to be taken into account in finding solutions for management of risks of chemicals at the global level. Contributions by specific groups of society, such as laypersons, are equally important. Authors like Lovelock have no doubt that "actions taken by individuals […] could halt the growing depredation of the Earth" (Lovelock 1979: 120).

The article also maintains that the past decades have also witnessed a deep and radical change of how the environmental crisis is perceived by society. It is not anymore a nature in danger, but a world at risk. This warrants a deeper understanding that the relationship between men and nature is also an important aspect. Prigogine and Stengers proposed that men should move away from the common notion that nature can be possessed. Men should rather form an alliance with nature (Prigogine and Stengers 1984). Recognizing the underlying ethical principles of well-established approaches of addressing environmental problems, such as Environmental or Green Chemistry, became an increasingly important undertaking. Also many entities involved in the environmentally sound management of chemicals and wastes, such as the United Nations Development Programme, the Secretariat of the Basel, Rotterdam and Stockholm Conventions and the Global Environment Facility, are increasingly acknowledging the necessity to promote gender equality in their operations. Accordingly, they have recently developed actions plans that seek to promote gender mainstreaming in hazardous chemicals and wastes management in developing countries. (UNDP 2011; BRS 2014; GEF 2014) Given these new viewpoints and the changes in the perception of chemical risks, universities have a moral duty to prepare future scientists to fulfil their important role within society. Morin (1999) maintains that "education should include the study of uncertainties that have emerged in the physical sciences […], the sciences of biological evolution, the historical sciences." Other scholars, like Shrader-Frechette, support this by underlining that researchers "have a moral obligation to question the value-laden interpretations of alleged facts that they and others use" (Shrader-Frechette 1994: 61).

It is evident that addressing the risks of chemicals and the implications to sustainable development are far too complex to be solved within the boundaries of the field of chemistry alone. The tasks ahead concern as much the field of chemistry as a discipline as they concern the social sciences. This warrants a closer integration of the humanities in the continuing debates on addressing the risk of chemicals for human beings and the environment with a view to better understand the underlying ethical considerations.

The article argues that universities have the right setting to make them lead institutions for spreading knowledge about the underlying ethical and scientific principles of assessing chemical risks, with a view to help level the societal playing field to promote equal opportunities and protection from harm. (Shrader-Frechette 2014) First, modern universities benefit from a high professional competence of their teachers and staff and high-tech equipment. Second, they have the organizational structures in place to ensure, in principle, their independence from external influences. Third, the recent development of technologies to manage and share information also means that information is more readily available. Universities may therefore have more time available to shift the attention of their curricula more towards a focus on ethical considerations.

2.2.3 Article V: University And The Risk Society

This article focuses on the social order of the new modernity, which is often referred to as “risk society.” This work looks into the growing complexity of the new modernity that generates hazards and insecurities at unprecedented pace and level of severity, necessitating a more informed discourse on the underlying sociological and ethical principles within universities as part of the curriculum and with universities as a collective agent of the risk society.

Collective agents can be either collaborative or in conflict with one another. This article seeks to analyse their roles in the debate on environmental risks. Literature has broadly examined the roles of the public and private sectors as well as those of social movements in the past decades (Worster 1994, Cranor 1993, Carson 1962, Colten 1994, Commoner 1971, Hays and Hays 1989). It will therefore focus chiefly on the role of universities. Particularly the growing complexity of society in the new modernity requires a more informed discourse on the underlying sociological and ethical principles within universities as part of the curriculum and with universities as a collective agent of the risk society.

A significant number of contributions from researchers on the societal role of universities can be found in scientific journals, magazines or interviews. In the field of chemistry, reference must be made to the contributions of Richard R. Ernst, Chemistry Nobel Prize laureate (Ernst 2003, 2007a and 2007b) and Piero Pozzati, who has written an important book on “Verso la cultura della Responsabilità” (Pozzati and Palmeri 2007). Both authors claim that that the debate on environmental risks must be addressed both from the natural and social science points of view

(Pozzati and Palmeri 2007: chapter 7). They further claimed that such a synergistic approach requires a thorough consideration of the underlying ethical principles and, as a precondition, the development of a sense of environmental responsibility among scientists (Pozzati and Palmeri 2007: chapter 8).

A key concept of this article is 'dual nature' of science, which represents one of the main root causes for the occurrence of environmental risks in the reflexive modernity. Many products of science that are developed to provide benefits are at the same time capable of doing harm (Tucker 2012). An example of this duality from the field of chemistry is the topic of chemical weapons (Trapp 2008).

The complexity of this dual nature of science calls for a coordinated approach of all collective agents in the assessment and analysis of risks. Beck claims that such an approach could be based on the concept of cognitive sociology (Cerulo 2005) and adds that the "theory of the risk society is in essence cognitive sociology, not only the sociology of science, but in fact the sociology of all the admixtures, amalgams and agents of knowledge, in their combination and opposition, their foundations, their claims, their mistakes, their irrationalities, their truth and in the impossibility of their knowing the knowledge they lay claim to" (Beck 1992: 55). Shrader-Frechette (2007) agrees with these views by stating that arriving at sound conclusions when assessing environmental risks cannot be fully achieved with the application of pure or 'classic' science alone, but requires the input of other disciplines, such as philosophy or sociology.

Universities as the main provider of both research and higher education can provide a valuable contribution to address the uncertainties stemming from this dual nature of science. Edgar Morin (1999: 2) agrees that "education should include the study of uncertainties that have emerged in the physical sciences […], the sciences of biological evolution, the historical sciences." The concept of 'cognitive sociology' can guide universities in their attempts to collectively address this duality and the resulting uncertainties.

According to Strydom (2002), universities as a collective agent of knowledge have a particular responsibility in understanding the methods of cognitive sociology and the way in which sociocultural factors shape and guide scientific processes. This holds particularly true for scientific processes that, for example, result in the assessment of environmental risks and hence should be free of errors.

Environmental risks therefore can be effectively mitigated if ethical considerations, such as taking into account sociocultural factors, are integral parts of scientific processes. It is also evident that 'classic science' is still indispensable to arrive at sound conclusions, for example, in assessing the risks of a specific technology. But the prerogative of science, and thus of universities, to hold the monopoly on truth may become an obstacle in modern societies for arriving at sound conclusions regarding environmental risks. It is rather the conscious application of the principles of cognitive sociology, taking into account the duality of science that provides universities with a constructive role within the plurality of collective agents and their inherent interrelationships.

The article further examines the unpredictability of some catastrophic evens. A common feature of socio-economic systems is the ability to enter into a 'critical state', which can get catastrophically unstable (Bak 1996, Buchanan 2000). Catastrophic events originating from such an unstable organization of critical states have proven to be unpredictable. The unpredictability does not stem from imperfect knowledge of scientists, bus has its origin rather in natural or socio-economic processes themselves. This is the case, for example, when systems are far from their equilibrium state and are characterized rather by chaotic behaviour dominated by fluctuations and by pitchfork bifurcations (Prigogine and Nicolis 1989). Under these chaotic conditions, the laws of nature are rather expressed in possibilities rather than in certainties (Prigogine 1996), which implies that the status of unpredictability within science could not be attributed anymore to imperfect knowledge or of insufficient control (Stengers 1977: 39).

The status of unpredictability is inherently linked not only to natural and socio-economic systems, but also to the scientific methods of investigation themselves. As a conclusion, analysing the impact of unpredictability on the assessment of risks therefore must be addressed both from a scientific and a philosophic point of view.

The article further looked into a related issue, which is the lack of knowledge and the relationship with liability and responsibility. For this, the ramifications of two case studies of accidents are analysed that happen due to a lack of knowledge for liability of actors involved in these accidents: the story of Oedipus from Sophocles' tragedy 'Oedipus Rex' and the Chernobyl nuclear accident. The consequence for the main actors of the tragedy of Oedipus Rex and the Chernobyl disaster both depict a legal system that is based on moral responsibility, where a lack of knowledge is no excuse (Luban et al. 1992). This conclusion is highly relevant for the daily work of scientists that may not be always fully aware of the consequences of their actions.

The interrelationship between the lack of knowledge and liability also calls for a closer discussion of the specific responsibilities of scientists within a risk society. The responsibility to 'expect the unexpected' is best translated in the formulation of the precautionary principle (Golkany 2001). It states that "(w)here there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation" (UNCED 1992). The unpredictability of catastrophic events may have serious ramifications for the liability of scientists. Recognizing their special responsibility, this gives rise to a more widespread application of the precautionary principle. Here, the article states that universities as institutions of higher education and research are particularly well-placed to teach young scientists the principles of unpredictability, responsibility and precaution in the context of a risk society.

The article also examined the interrelationship between science and ethics and the fact that the outcomes of ethical debates, in fact, are often implicitly and explicitly applied in science and research. It addresses the issues of error and illusion (Morin 1999) by highlighting errors of the first and second kind in statistical testing (Cranor 1993, Shrader-Frechette 1994, Frank et al. 2011, Vandenginste et al. 1997), the existence of "blinding paradigms" and the issues of multidimensionalism (Morin 1999: 8 and14). For this, three cases are examined: soft modelling as surrogate of hard modelling (Falk and Miller 1992, de Juan et al. 2000), dimensionality reduction methods in the context of pattern recognition in multidimensional data analysis (Vandenginste et al. 1997) and the application of conventionalism in the assessment and management of risks (Poincaré 1902, Ben-Menahem 2006, Pozzati 2004 and 2007).

These issues contain a call for action for universities in general, and scientists in particular. By recognizing the multidimensionality of complex systems, scientists would imperatively need to take into account ethical and, if appropriate, other dimensions of the scientific investigation methods they use. A researcher would therefore need to avoid presenting categorical conclusion from the data he or she generates. On the contrary, this researcher would need to be aware of and report on the degrees of uncertainties that may occur in the application of the scientific method of his or her choice.

Another topic that is addressed in this article is the issue of choices between two options and the irreducible role of values. In certain contexts of environmental governance, decision-makers have the choice between two or more options. In order to arrive a defendable political decision, it is often necessary to assess the risks of all involved options. Here, the article concludes that is not possible to simply compare two alternatives based solely on the respective probabilistic risk, which shows the ethical dimension of the respective selection procedures. A deeper understanding of the principle of naturalistic fallacy, as coined by G.E. Moore, and the application of the precautionary principle (Golkany 2001) can support decision-makers in arriving at ethically sound decisions when choosing between alternatives.

Finally, the article examines the topic of collaboration and conflicts between collective agents of Risk Society in a macro-ethical context. The concept of 'scientific proceduralism' is an approach that links science and democracy (Shrader-Frechette 1991: 93). Following the concept of scientific proceduralism, risk evaluations are still undertaken by experts, but scientific objectivity can only be guaranteed if the opinion of laypersons that are likely affected by the risks are taking into account in the debate (Harremoës et al. 2002: 198). Likewise, the sociologist Piet Strydom developed a new critical theory that calls for a "cognitive perspective" based on the "concatenation of risk, knowledge and communication". According to Strydom, not only knowledge in the sense of content, but also communicative processes are important ingredients of evaluating risks in modern societies (Strydom 2002).

The collective responsibility of the different actors in the risk society is an important fact, which also opens new perspectives and opportunities for university and scientists. Research should be conducted at a slower pace and be accompanied by constant reflection on critical threshold values undertaken jointly by science and the broader public. Progress should be monitored and regulated by global reflexive institutions, such local or national committees, as described by Pozzati (2007: chapter 9), that operate at a level that corresponds to the impact of the potential risks. It is also stated that whistleblowing and the protection of whistle-blowers can be a useful means to mitigate risks. This holds particularly true if such risks originate from misconduct or from hazardous activities that can result in accidents or major disasters (Shrader-Frechette 2007, Benchekroun and Pierlot 2011).

2.3 CLTS Subsystem 3: The Governance Of Chemicals And The United Nations

2.3.1 Introduction

The topic of environmental ethics in general, and of risk management more specifically, has evolved from its beginnings in the 1950s and has progressively broadened. The evolution followed the progression from a restricted and purely expert and scientific based approach of risk calculation and assessment in the 1950s and 60s, to the more current open discourse of these topics characterized by a broad participation of the public and social movements in the discursive construction of risks. Public communication has been crucial for this development. The article "On the road to Rio+20: the evolution of environmental ethics for a safer world" (article VI) outlines the regulatory action taken by many states as a response to the growing sensitization of the public towards the risks emanating from toxic chemicals. Although the article has not been published in peer-reviewed process, it nevertheless provides a sound basis for the ensuing analysis of this chapter of the present thesis. Its main findings are provided in the subsequent section.

2.3.2 Article VI: On The Road To Rio+20: The Evolution Of Environmental Ethics For A Safer World

Direct risks of some chemicals to human health were already perceived in the early twentieth century. However, the perception of environmental risks associated with the production and use of chemicals was initially based on the fairly naıve supposition that chemicals would simply disappear once released into the environment. This only changed in the 1960s, when the scientific community, lawmakers, and the general public started to realize that this hypothesis was based on an insufficient understanding of the properties and behaviour of chemicals in the environment. The article describes Carson's (1962) book 'Silent Spring' as a key contribution to raising the awareness of the general public with regard to environmental problems and the degradation of ecosystems caused by the increasing production and use of chemicals in the second half of the last century. It concludes that Carson's work greatly contributed to growing general public awareness of a nature in danger. Furthermore, a series of industrial accidents raised attention to the fact that chemical production involving hazardous chemicals may be associated with health risks to neighbourhoods when accidents occur, such the industrial accidents in Seveso, Italy, in 1976, or in Bhopal, India, in 1984.

The article maintains that the growing sensitization of society gave impetus to a change of paradigm of governments toward the regulation of chemicals and hazardous waste at the national, regional, and international levels (Løkke 2006). An outline of the action taken by states from the 1950s onwards at the national, regional and international level to regulate the production, use, and release into the environment of certain hazardous chemicals is subsequently provided and summarized in Table 5.

Table 5. Landmark events and treaties on the protection of the environment from industrial and agricultural chemical pollution

Year	Description
1948	International Union for Conservation of Nature
1972	United Nations Conference on the Human Environment
1972	Establishment of United Nations Environment Programme (UNEP)
1972	Club of Rome (Limits to Growth)
1979	Convention on Long-range Transboundary Air Pollution
1985	Vienna Convention on the Protection of the Ozone Layer
1987	Montreal Protocol on Substances that Deplete the Ozone Layer
1987	Our Common Future Report of the World Commission on Environment and Development
1989	Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal
1992	United Nations Conference on Environment and Development/Agenda 21
1992	United Nations Framework Convention on Climate Change
1997	Kyoto Protocol
1997	Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction
1998	Aarhus Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters
1998	Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade
2000	Protocol on Liability and Compensation for Damage Resulting from Transboundary Movements

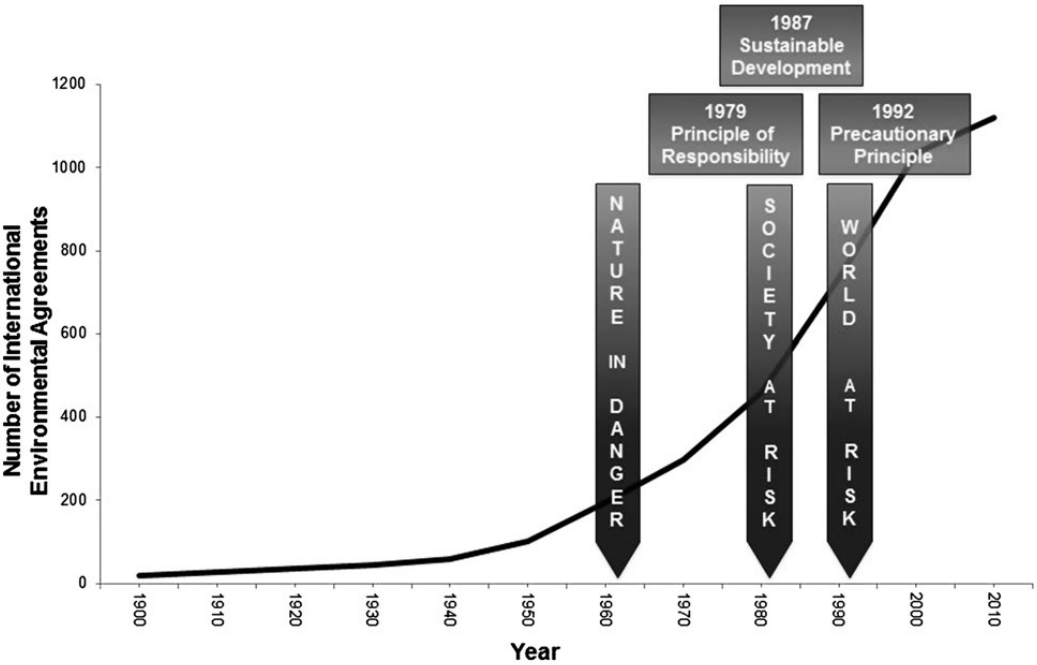
Year	Description
	of Hazardous Wastes and Their Disposal
2001	Stockholm Convention on Persistent Organic Pollutants
2003	Kiev Protocol on Pollutant Release and Transfer Registers to the Aarhus Convention
2002	Johannesburg Declaration on Sustainable Development
2003	Protocol on Civil Liability and Compensation for Damage Caused by the Transboundary Effects of Industrial Accidents on Transboundary Waters
2006	EU REACH regulation
2013	Minamata Convention on Mercury

Source: Moser and Dondi (2015)

The article then introduces the ground-breaking publications of Jonas (1984) on 'The Imperative of Responsibility: In the Search of an Ethics for the Technological Age' and of Beck (1992) on the 'Risk Society: Towards a New Modernity'. It maintains that these publications marked a further change of paradigm toward the perception of risks in society. It also introduces a third key area – the concept of sustainable development – which emerged with the publication of the report of the Club of Rome (Meadows et al. 1972) and culminated in the 1987 report of the World Commission on Environment and Development on 'Our Common Future' (Brundtland 1987). The article then outlines the United Nations Conference on Environment and Development, which was held in 1992. The Conference adopted the Rio Declaration and the 27 so-called Rio Principles, which are a key feature of the Rio Declaration (UNCED 1992). The article put particular emphasis on the 'precautionary principle' (Principle 15) as an important aspect for the management of the risks of chemicals.

A summary of the above findings is contained in Figure 2 below, which outlines the evolution of international environmental governance outlining an exponential increase of the number of multilateral environmental treaties in the last 60 years, showing the key turning points of public opinion about risks, such as a 'Nature in Danger' (1960s), the 'Society at Risk' (1980s), and the 'World at Risk' (1990s), and the evolution of environmental ethics with 'The Imperative of Responsibility' (1979), the concept of 'Sustainable Development' (1987), and the 'Precautionary Principle' (1992).

Figure 2. International Environmental Governance and environmental ethics: evolution of the perception of risks by public opinion, ethical theories, and the increase of the number of international treaties in the last 115 years



Source: Moser and Dondi (2012)

The article then continues to outline unresolved issues in managing risks. In doing so, it states that some aspects of the question on how such risks can best be managed still remain unanswered. Here, particularly Kerns (2001) and Shrader-Frechette (2002) support the argument of the need to change the way in which we are assessing risks of modern threats. Both authors maintain that risk assessments in their current form are often based on insufficient understanding of the complexities of the natural environment, and that the use of simple models and of aggregated data in an attempt to cope with the complexity of the real world may lead to inaccuracies, particularly when determining long-term consequences of continued exposure to low levels of hazardous chemicals. The article states another aspect, which is important for the subsequent analysis contained in this chapter: risk assessments are often based exclusively on scientific methods determining cause-and-effect relationships. It is further argued that assessments of risks affecting public welfare intrinsically involve both policy and scientific judgments and that authorities must therefore ensure that risk assessments are not exclusively based upon scientific methods (Shrader-Frechette 2010). The article concludes that this requires an integrated approach with a full participation of representatives of the public as stakeholders of a truly democratic society. Adopting an integrated approach for the management of risks emanating from the production and use of chemicals will be a key aspect for the subsequent discussion on the shift towards a cognitive society, as called for by

Strydom (2002). It will be further elaborated in the following sections of this chapter.

2.3.3 The Shift Towards A Cognitive Society

As shown in section 2.3.2 above, the 1970s and 80s witnessed a drastic erosion of the once taken-for-granted "techno-corporatist" assumptions and their replacement by pronounced anxiety and uncertainty. This was further fuelled by conflicts due to the often-opposing assumptions of social groups towards the assessment of risks.

The emergence of new cultural and institutional forms, as well as new communicative structures in the public sphere from the 1990s onwards allowed an increased mediation between the conflicting groups. This resulted in more channelled debates and more constructive contestation of the conflicting arguments and approaches of these groups.

The highly discursive and mediated nature of the debates calls for a deeper involvement of social science. The tensions between the critical theory of risk society (Beck 1982) and the sceptical theory of the contingent society (Luhmann 1998) give rise to "theoretical choices on the basis of an evaluative position favouring the possibility of learning and of democracy, without excluding the awareness of obstacles and ambivalence" (Strydom 2002: 70).

As regards the social construction of risks, the generation of knowledge on risks is seen as being collectively produced through a creative, reflexive, and discursive cognitive process. This led sociologists, such as Eyerman and Jamison, to the conclusion that society is socially constructed (Eyerman and Jamison 1991). The discursive nature of the cognitive processes is considered to provide for a structured approach and collective acceptance of knowledge.

At the same time, the social actors or collective agents started to perceive environmental problems as a global issue with the emergence of culturally structured social practices and action (Yearly 1996). This ranged from economic activities to promotional, protest and political activities of social movements, NGOs, firms, states and supra-national organizations, such as the United Nations.

Risks are therefore commonly considered as having their roots in reality. People compete over risks and discuss their conflicts by means of public communication. Risks become collectively interpreted, defined and accepted in and through a mediated discursive process to which the different participants make contributions from their own unique perspectives.

This thesis places particular emphasis on the role the United Nations plays in setting the context for the ongoing debates on environmental risks and the use of environmental law, both of which have been instrumental in elevating a broad number of environmental issues to the global level.

It seeks to provide a response to the question whether the particular structures of the United Nations in terms of chemicals and waste management can be adapted to the new critical theory of nascent society of the twenty-first century, as called for by Strydom (2002). In line with a general shift towards a cognitive approach in sociology, the new critical theory rethinks a reflexive society as a knowledge and communication theory. "The basic cognitive assumption […] is that both risk and responsibility, while having roots in reality, are discursive constructions that on the one hand emerge from intersubjective process of attribution and on the other require critical intersubjective testing". (Strydom 2002: 146).

Society, here, is considered as a knowledge and communication – or cognitive – society. Its different collective agents possess distinct competences, power resources, and opportunities. They hence can draw on different types of knowledge. Given the existence of different types - as well as the subjective and intersubjective dimensions of - knowledge it is not possible to reduce contemporary society to a simple 'science' or 'information' society.

A cognitive society can be described as a society that embraces "acts of recognition and knowing, processes of the generation of knowledge and the micro, meso and macro cognitive structures shaping, forming and containing knowledge from the outset and throughout." (Strydom 2002: 148)

The cognitive turn in society also questioned the functions of norms in society. It particularly rejected the traditional paradigm that norms are consistent and exert a determining influence. In turn, it emphasized the need to develop the sensitivity for and the ability to identify the whole range of culturally defined alternatives available to practices.

In the field of chemicals management, the negotiation in the 1990s and early 2000s and entry into force of the Rotterdam and Stockholm Conventions in 2001 and 2004, respectively, constitute landmark events in the chemicals and waste cluster for the management of the risks emanating from chemicals at the global level (see Table 5). The debates during the negotiations and ordinary meetings of the bodies of the two conventions have their roots in the evolution of the risk assessment approaches in the past decades. The thesis will focus on the Stockholm Convention.

The structures established by states include Intergovernmental Negotiating Committees (INCs), scientific subsidiary bodies, such as the Persistent Organic Pollutants (POPs) Review Committee (POPRC) and the Conferences of the Parties (COPs). A broad range of collective agents such as experts, NGOs, industry, industry associations, developing countries, developed countries, bilateral aid agencies, and international organizations participate in the meetings of the COPs, the POPRC and INC.

The nexus between the scientific (POPRC) and the policy-related bodies (COPs) of the Convention is an important feature of the institutional setting of the Convention. It translates science-based recommendations of the POPRC into the policy-based decisions taken by the COPs.

The POPRC debates to add new chemicals to the Convention is a stepwise approach that consists of the development of a risk profile, a risk management profile and, upon approval by the

Committee, a recommendation to list a specific chemical of concern. The first steps of the process require the application of pure science based information for the development of a risk profile (Article 8 and Annex E of the Stockholm Convention). This includes, among other things, the submission of science-based information on sources; hazard assessment for the endpoint or endpoints of concern; monitoring data; exposure in local areas and, in particular, as a result of long-range environmental transport, and including information regarding bio- availability; or national and international risk evaluations, assessments or profiles and labelling information and hazard classifications.

The second step, that is the development of the risk management profile (Article 8 and Annex F of the Stockholm Convention), requires the gathering of socio-economic information, including, among other things, the efficacy and efficiency of possible control measures in meeting risk reduction goals; alternative products and processes; positive and/or negative impacts on society of implementing possible control measures; waste and disposal implications; access to information and public education; status of control and monitoring capacity; and any national or regional control actions taken, including information on alternatives, and other relevant risk management information.

The particular institutional setting of the Stockholm Convention depicts an environment that could be well adapted to provide a platform for the called-for shift towards a cognitive society.

The policy-science nexus requires the involvement of a broad range of different collective agents with their own unique knowledge bases. Risks emanating from the chemicals of concern in fact become collectively interpreted, defined and accepted in the processes undertaken in the technical and policy bodies of the Stockholm Convention. This appears to be a mediated discursive process to which the different collective agents, such as experts, states, industry associations or NGOs, make contributions from their own unique perspectives.

The consensus-based processes of the United Nations system provides for a well-structured approach to collect and process information, thus ensuring a collective acceptance of the knowledge generated during the meetings.[10]

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[10] See "Information in International Environmental Governance: The Prior Informed Consent Procedure for Trade in Hazardous Chemicals and Pesticides" http://belfercenter.ksg.harvard.edu/publication/2766/information_in_international_environmental_governance.html?breadcrumb=%2Fproject%2F7%2Fglobal_environmental_assessment_project%3Fpage%3D2 and publications developed as part of the following project: http://belfercenter.ksg.harvard.edu/project/7/global_environmental_assessment_project.html?page=1

This chapter of the thesis will hence investigate if and to what extent the particular institutional setting of the Stockholm Convention provides a platform for a shift towards a cognitive society. It seeks to provide an answer to the following research question:

> *Do the decision-making processes during the negotiation of the Stockholm Convention support the basic assumption of a cognitive society - that contemporary society would need to evolve from simple 'science society' towards a 'knowledge and communication society'?*

The scope of this chapter will focus on a specific aspect that would provide evidence of such a shift, i.e. the reliance of the processes on information other than 'science-based' information, as outlined in section 2.3.4 below.

The ensuing analysis covers the negotiation phase of the Stockholm Convention (see Table 5) from 1998, the year of first meeting of the INC, to 2003, which is when the last of the seven INCs was held. It also includes the Diplomatic Conference and the related preparatory meeting, which were held after INC-5 in 2001.

The argument of placing emphasis in this analysis on the Stockholm Convention only, and here specifically on the negotiation phase, are outlined at the end of this section and are as follows. The choice to give preference to the Stockholm Convention was informed by several arguments. First, the time of the start of negotiation of the Convention in 1998 was in the midst of a larger societal change process that was spurred on one side by the changing perception of society itself about the risks of technological advancements (Jonas 1984, Beck 1992) and the aftermath of the Rio Earth Summit in 1992 (UNCED 1992). With regard to the timing, it is evident that the choice could have equally fallen on Rotterdam Convention, whose negotiation started in the 1990s as well. However, the preference accorded to the Stockholm over the Rotterdam Convention stems from the fact that the first Convention covers a larger part of the life-cycle of chemicals, covering production, use and disposal. Since the Rotterdam Convention only covers trade-related aspects and the prior informed consent procedure, it was felt that focusing on the Stockholm Convention would provide for a deeper discussion of the socio-economic aspects of chemicals management. At the same time, preference was given to the Stockholm over the Basel Convention. Here, the argument was that the latter Convention was negotiated in the 1980s, which was perceived too early for the scope of this thesis. Finally, prevalence was given to the negotiation phase over the implementation phase of the Convention after its entry into force in 2004. The argument here is that in the INCs, unlike the COPs, a multitude of collective agents are recorded, including NGOs. Given the rules and procedures of the COPs prevents a recording of views of non-Parties to the Convention (unless a Party would officially support such a intervention), it was felt that focusing on the INCs would provide for a more inclusive discussion and analysis.

2.3.4 Methodology

The chapter seeks to respond to the above research question by means of a qualitative and quantitative analysis of unstructured data contained in the following nine official and publicly available reports of the Stockholm Convention's negotiation phase:

- Reports of the INCs (7 reports)
- Report of the Diplomatic Conference: Final Act and preparatory meeting (2 reports).

As a means of investigation, the Computer Assisted Qualitative Data Analysis Software (CAQDAS) software Nvivo[11], which is a tool to manage, shape and make sense of unstructured information, will be used.

The research question:

> *"Do the decision-making processes during the negotiation of the Stockholm Convention support the basic assumption of a cognitive society - that contemporary society would need to evolve from simple 'science society' towards a 'knowledge and communication society'?"*

will be addressed only in a qualitative manner.

In order to discuss a shift towards a 'knowledge and communication society' the Stockholm Convention must in fact be entirely or, at least, predominantly based on 'science-based' principles. Only once this hypothesis has been validated, it will be possible to find an answer in ensuing analysis to the question of whether the negotiation phase of the Convention marks such a shift.

In order to validate this hypothesis, it is necessary to recall the key objective of the Stockholm Convention, i.e. to protect human health and the environment from the adverse effects of POPs. At the core of the Convention is a list of chemicals that exhibit characteristics that make them a POP. The type of the characteristics will inform the conclusions upon which of the above principles – 'science' or 'socio-economic' – the Convention is predominantly based.

Annex D to the Convention describes the very first step in the decision of whether a chemical constitutes a POP and therefore is to be regulated under the Convention. Therefore, assessing this Annex allows drawing conclusions regarding the foundations of the Convention.

The candidate POP at hand should have a clear and unambiguous chemical identity. A first criterion outlined in Annex D is whether the chemical at hand persists in the environment. For this, evidence is to be provided that the half-life of the chemical in water is greater than two months,

[11] QSR International Pty Ltd, Doncaster, Victoria, Australia

that its half-life in soil is greater than six months, or that its half-life in sediment is greater than six months. This also includes the provision of data on bio-accumulation and evidence that the bio-concentration factor or bio-accumulation factor in aquatic species for the chemical is greater than 5,000 or, in the absence of such data, that the log Ko/w is greater than 5. Other evidence can also indicate that a chemical presents other reasons for concern, such as high bioaccumulation in other species, high toxicity or ecotoxicity. A further criterion is that the chemical at hand needs to show potential for long-range environmental transport. This includes measured levels of the chemical in locations distant from the sources of its release that are of potential concern, as well as monitoring data showing that long-range environmental transport of the chemical, with the potential for transfer to a receiving environment, may have occurred via air, water or migratory species. Alternatively, data on environmental fate properties and/or model results can be provided that demonstrate that the chemical has a potential for long-range environmental transport through air, water or migratory species, with the potential for transfer to a receiving environment in locations distant from the sources of its release. For a chemical that migrates significantly through the air, its half-life in air should be greater than two days. A final criterion is whether the chemical causes adverse effects. Here, evidence of adverse effects to human health or to the environment are to be provided that justifies consideration of the chemical within the scope of this Convention or toxicity or ecotoxicity data that indicate the potential for damage to human health or to the environment.

It is evident that all of the above screening criteria are founded entirely on scientific data that needs to be collected by researchers by means of sophisticated and specialized equipment. In light of this, it is fair to conclude that the core of the Stockholm Convention is founded predominantly on 'science-based' principles. This will be taken into account in the subsequent analysis of the interventions, which will be described in the next sections.

Criteria for the shift towards a 'knowledge and communication society'

To respond to the question on the evolution from a 'scientific' towards a 'knowledge and communication' society, two proxy variables will be used:

1. Mentions of the need for communication and information exchange;
2. Mentions of socio-economic considerations.

To define whether an intervention of a collective agent belongs to the 'communication and information exchange' and 'socio-economic' spheres, the reports of the meetings will be screened for key terms, as outlined below. The source for the 'socio-economic'-related search is Annex F of the Convention, since it deals with information on socio-economic considerations. In the following the key terms that are used for the screening of the reports are outlined.

Key search terms for proxy variable 1:

- Technical feasibility
- Efficacy
- Control measures
- Risk reduction
- Release reduction
- Alternatives
- Disposal
- Agriculture
- Biodiversity
- Social costs
- Environmental costs
- Health costs
- Public health
- Environmental health
- Occupational health
- Society
- Sustainability
- Liability
- Compensation

Key search terms for proxy variable 2:

- Communication
- Information exchange
- Information access
- Public education

Based on the above criteria, the interventions of the collective agents at the meetings and committees will be then analysed qualitatively by means of the CAQDAS software Nvivo. For this, interventions will be coded in the following manner:

- An intervention that include communication and information exchange considerations will be coded as ‘communication based’
- An intervention that include socio-economic considerations will be coded as ‘socio-economic based’

The outcomes of this coding exercise are described in the following section.

2.3.5 Analysis

The analysis contained in this chapter will focus on the following areas. First, the occurrence of 'information based' and 'socio-economic based' interventions will be analysed. This includes a qualitative description and a summary of interventions that falls in these categories. Second and only if such information is available, a description of the type of collective agent having made the intervention will be provided.

Communication and information exchange

As regards interventions on the topic of communication and information exchange, which constitute the first proxy variable that mark a shift towards a 'knowledge and communication society', the following general interventions that would favour the Stockholm Convention adopting a dedicated mechanism to foster communication and the exchange of information have been identified:

> *"Many representatives noted the importance of developing and exchanging information on current uses of POPs, their impact, and alternatives to their use."*[12]

> *"Several other representatives said that arrangements should be made for the regional and subregional exchange of relevant information."*[13]

> *"One representative suggested that information exchange should be an obligation of the Parties to the future instrument and many representatives said that the article should include the broadest possible scope of information exchange on POPs."*[14]

Moreover, the Group of 77 and China noted that the "[e]xchange of information in a transparent and non-discriminatory manner will constitute an essential feature of the convention and should be suitably emphasized in a distinct article."[15] The European Union added in a statement that "[t]he exchange of and access to information on POPs between Governments and intergovernmental organizations and non-governmental organizations with relevant knowledge and experience will play an essential part in achieving the objectives of the convention."[16]

Still on the general principles of a communication and information exchange mechanism, several interventions were made on the topic of public access to information:

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[12] see paragraph 44 of document UNEP/POPS/INC.1/7

[13] see paragraph 45 of document UNEP/POPS/INC.1/7

[14] see paragraph 68 of document UNEP/POPS/INC.2/6

[15] see paragraph 5 of Annex V of document UNEP/POPS/INC.2/6

[16] see paragraph 9 of Annex VI of document UNEP/POPS/INC.2/6

"One representative advocated public access to information produced by any inventory activities developed through the Intergovernmental Negotiating Committee process and/or under the terms of an agreement on POPs." [17]

"Several representatives considered that an international legally binding instrument should include a provision on POPs inventory requirements, including public access to such information." [18]

"Several representatives stated that, regardless of the mechanism selected, all information must be made available to all countries on a free, fair, equal and easily accessible basis." [19]

"Several other representatives said that arrangements should be made for the regional and subregional exchange of relevant information." [20]

Furthermore, the European Union maintained that "[t]his convention is concerned with regional and global problems, but these problems can only be solved by action to control POPs at local, usually national level. Access to information by Governments and the public to increase awareness of the risks will play an essential part in solving these problems."[21] A representative from a non-governmental organization added that "[i]nformation should not be subject to confidentiality restrictions." [22] A contact group on implementation aspects established by the INC concluded that the "development of an outreach/information dissemination programme" "was a vital activity that would influence the success or failure of efforts in a number of activity areas already discussed. Efforts would have to be made to develop programmes within the context of specific national, subregional and regional circumstances."[23]

Interventions on the possible form of such a communication and information exchange mechanism under the Convention were made as well:

"Many representatives underscored the importance of specifying the mechanisms for information exchange at both national and international levels, which might take the form of national focal points or regional and subregional networks or a formal body,

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[17] see paragraph 49 of document UNEP/POPS/INC.1/7

[18] see paragraph 54 of document UNEP/POPS/INC.1/7

[19] see paragraph 70 of document UNEP/POPS/INC.2/6

[20] see paragraph 45 of document UNEP/POPS/INC.1/7

[21] see paragraph 2 of Annex VI of document UNEP/POPS/INC.2/6

[22] see paragraph 1 of Annex VIII of document UNEP/POPS/INC.2/6

[23] see paragraph 88 of document UNEP/POPS/INC.2/6

such as a centre of excellence, which could be the secretariat of the future instrument or a separate - but already existing - body."[24]

"Several representatives supported the creation of specific, national POPs focal points to facilitate the exchange of such information, including reporting progress made in the implementation obligations under the agreement."[25]

Finally, a smaller group of collective agents, mainly developing countries, also noted challenges that, if not addressed, would impede an effective and efficient communication and exchange of information:

"Many representatives expressed concern that, for developing countries, the capability to gather, exchange and utilize the information under discussion was itself dependent on the receipt of adequate financial and technical assistance."[26]

The Group of African Countries identified other obstacles to the effective management of POPs in the African region, which are an "[i]nadequate transfer of information from the developed world to the developing world and the necessary assistance in terms of technology and equipment, [a l]ack of public awareness of the hazards of the handling, use, storage, disposal and release of hazardous chemicals including POPs (often due to a high illiteracy rate) [and i]nadequate regional forum for information exchange."[27]

As a solution to address the costs of a communication and information exchange mechanism, several representatives stressed the importance of "tapping existing sources of technical information."[28] It was also proposed that "costs could also be held down by accessing information through the clearing-house mechanisms of other conventions and bodies, particularly those with ongoing activities of relevance to the POPs instrument."[29]

As is apparent from the evidence provided in the above interventions, the topic of communication and information exchange was an important feature of the negotiations of the Stockholm Convention. The interventions undertaken by basically all collective agents present at the meetings did not only stress the principle need of such a mechanism, but also provided a wealth of

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[24] see paragraph 69 of document UNEP/POPS/INC.2/6

[25] see paragraph 44 of document UNEP/POPS/INC.1/7

[26] see paragraph 71 of document UNEP/POPS/INC.2/7

[27] see paragraph 3 of Annex VII of document UNEP/POPS/INC.2/6

[28] see paragraph 45 of document UNEP/POPS/INC.1/7

[29] see paragraph 90 of document UNEP/POPS/INC.2/6

information on the question why and how communication and the exchange of information could be ensured in the most effective and efficient manner. Suggestions on how such a mechanism could be implemented in practice were also advanced.

A basic principle that has been stressed by many collective agents is the right of the broader public to access such information, which can be seen as reference to the United Nations Economic Commission for Europe (UNECE) Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (the so called Aarhus Convention, see Table 5) adopted in 1998. Arguably, this can be interpreted as an indication that collective agents negotiating the Stockholm Convention valued the right of the broader public to access to environmental information, to participate in environmental decision-making, and to review procedures to challenge public decisions on environmental matters. In doing so, some collective agents have sent a signal that also the broader public is to be included in decision-making processes concerning environmental protection. This can be seen been as a shift away from relying mainly on science to identify and assess environmental and human health risks.

Socio-economic considerations

Socio-economic factors played an important role in the negotiation of the Conventions. The report of the first INC stated that a focus on socio-economic factors during the negotiations was mandatory.[30] This was the case because Governing Council (GC) decision 19/13 C of UNEP[31], which provided the mandate of the development of an internationally binding legal instrument, decided, pursuant to paragraph 7 of that decision, that socio-economic factors should be addressed in developing and implementing international action. They were to include possible impacts on food production; possible impacts on human health (for example, for vector control agents); the need for capacity-building in countries and regions; financing concerns and opportunities; and possible trade impacts.

In addition, various collective agents made various interventions during the negotiation of the Convention citing the Principles contained in the Rio Declaration (UNCED 1992) and the concept of sustainable development (Brundtland 1987). The European Union stated that "[i]n accordance with the concept of sustainable development, it is the opinion of the European Union that the ultimate objective should be to phase out the production and use of POPs. Socio-economic considerations and the availability of alternatives have to be taken into account, both in

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[30] see paragraph 2 of document UNEP/POPS/INC.1/7

[31] see at http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=96&ArticleID=1470&l=en

the negotiations and the Criteria Expert Group." [32] The Group of Latin America and the Caribbean (GRULAC) maintained that the international legally binding instrument on POPs should "[e]nsure that all obligations, criteria and agreed procedures take into account the specific conditions of developing countries, with due regard for their environmental, climatic and socio-economic characteristics". [33] Also, indigenous or environmental non-governmental organizations stressed "the need to safeguard the human foetus and the nursing child from unacceptable contamination by POPs in women's bodies; the need to eliminate use of Dichlorodiphenyltrichloroethane (DDT) and the consequences of its bio-accumulation in the northern zone of the planet, not by means of an either-or approach to DDT that could expose large populations to fatal disease, but by adopting a flexible approach with greater use of alternative strategies and the provision of adequate technical and financial resources to developing countries; the need for the future instrument explicitly to state that its ultimate aim lay not in constant management, but in the elimination of identified POPs; the need to restrict the import and export of POPs, unless for the purposes of environmentally sound disposal; the need for the future instrument to address the public health implications of military contamination of lands, water and foods, particularly the traditional foods of indigenous peoples". [34] On the topic of financing, several representatives pointed out the "needs of developing countries for effective financial resources required an adequate financial mechanism that could mobilize resources, taking into account socio-economic considerations, and assist in effective implementation of the Convention." [35]

With regard to the Rio Principles and other ethical approaches to the sound management of chemicals, non-governmental organizations pointed "to the necessity of the provision of adequate financial and technical assistance" and "urged the application of the "polluter-pays principle"." [36] GRULAC also stated that the international legally binding instrument on POPs should "[r]espect the principles established by the 1992 Rio Declaration, especially the precautionary principle."

In this regard, the agreed text of the Convention[37] also noted "the respective capabilities of developed and developing countries, as well as the common but differentiated responsibilities of States as set forth in Principle 7 of the Rio Declaration on Environment and Development". It also reaffirmed "Principle 16 of the Rio Declaration on Environment and Development which states that

[32] see paragraph 3 of Annex VI of document UNEP/POPS/INC.2/6

[33] see paragraph 2 (e) and (f) of Annex IV of document UNEP/POPS/INC.1/7

[34] see paragraph 3 of Annex VI of document UNEP/POPS/INC.3/4

[35] see paragraph 104 of document UNEP/POPS/INC.7/28

[36] see paragraph 2 of Annex VI of document UNEP/POPS/INC.3/4

[37] see paragraph Appendix II of document UNEP/POPS/CONF/4

national authorities should endeavour to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment." Finally, the text noted that "[m]indful of the precautionary approach as set forth in Principle 15 of the Rio Declaration on Environment and Development, the objective of this Convention is to protect human health and the environment from persistent organic pollutants."

The evidence provided in the above interventions, citations of the agreed Convention text and the GC decision from 1997 that provided the mandate for the development of the instrument, shows that socio-economic considerations have been at the core of the negotiations of the Stockholm Convention.

2.3.6 Results

The findings above suggest that sufficient evidence has been provided indicating that collective agents clearly highlighted in their interventions the need to increase communication and information exchange for a successful implementation of the Convention. Furthermore, collective agents supported the argument that the negotiations in all spheres took into account socio-economic considerations. This is shown not only in their interventions, but also in other sources, such as the GC decisions and the agreed final text of the Convention.

It can be therefore concluded that the decision-making processes during the negotiation of the Stockholm Convention, in fact, did support the basic assumption of a cognitive society - that contemporary society would need to evolve from simple 'science society' towards a 'knowledge and communication society'.

As outlined above, the policy-science nexus requires the involvement of a broad range of different collective agents with their own unique knowledge bases. This is particularly important when risks emanating from the chemicals of concern in fact become collectively interpreted, defined and accepted.

The conclusion derived in this chapter should be further strengthened if collective agents, during the negotiations, proactively called for a participatory approach in support of a mediated discursive process to which the different collective agents, such as experts, states, industry associations or NGOs, make contributions from their own unique perspectives.

In several occasions, collective agents called for the inclusion of major stakeholders in the negotiation process. The European Union, for example, argued that "[s]tates have responsibility for the policy and regulatory environment, but in actual implementation the private sector and civil society will also be major stakeholders."[38] On a related matter, the INC called for the collection of a specific type of information "to enable other Governments, academic institutions, the industry sector and environmental groups to bring forward information on alternatives which meet the identified needs."[39] Moreover, "many representatives reported on activities within their countries relating to the work of the Committee and provisional implementation of the Stockholm Convention, including [...] stakeholder participation".[40]Particularly this last intervention shows that the Stockholm Convention strived for an inclusive and participatory approach not only during the meetings of the INC themselves, but also during the provisional implementation of the Stockholm Convention at the national level.

[38] see paragraph 5 of Annex VI of document UNEP/POPS/INC.2/6

[39] see paragraph 25 of Annex III of document UNEP/POPS/INC.3/4

[40] see paragraph 36 of document UNEP/POPS/INC.6/22

3 RECOMMENDATIONS FOR FUTURE RESEARCH AND CONCLUSIONS

3.1 Recommendations For Future Research

3.1.1 Chemical Industry and Trade (CLTS Subsystem 1)

Research article I on the review of implementation of Chemical Leasing in the past decade proposes types of further research suitable to address the identified gaps on both theoretical and practical aspects of Chemical Leasing. As regards the theoretical framework, future research needs to analyse the institutional settings and national circumstances that foster a shift from the traditional sale of chemicals to the implementation of chemical leasing business models. Here, Ohl and Moser (2007) have analysed two types of Chemical Leasing models to evaluate whether they support an effective management of environmental and public health risks of chemicals. While the first model foresaw a simple transfer of knowledge from the production to the user and differed the least from the traditional sales concept, the second model instead foresaw a more comprehensive shift of responsibility for the application of the chemicals to the producer and differed the most from the traditional sales concept. For both cases, Ohl and Moser have shown that both producer and user have an incentive to introduce Chemical Leasing. Further work is required to analyse Chemical Leasing models that either fall in the range between the two models analysed by Ohl and Moser, such as the model prevailing in practice as outlined by Jakl and Schwager, or that fall into the category of 'Grey Chemical Leasing' (see Moser et al. 2014a). This work would also need to further investigate the limitations of the functional aspects of the chemicals of concern and the sizes of all involved partners as stated by Lozano et al. (2013) and possible solutions of how to overcome these shortcomings.

Still at the theoretical level, the environmental impact of Chemical Leasing should be further assessed. Here, Moser et al. (2014a) have provided a first attempt to demonstrate to what extent Chemical Leasing is a means to contribute to the objectives of Sustainable Chemistry. Assessing the impact of Chemical Leasing is particularly important, simply because many approaches exist that aim at protecting the environment from the adverse effects of chemicals. Policy-makers should be provided with data that allows them to decide which approach achieves the largest environmental impact. Closely related to this, further research is required to better understand the role of environmental policy in terms of safeguarding the proliferation of Chemical Leasing. Here, it will be important to analyse what kind of policies at the national, regional and international level could support the up-take of Chemical Leasing. This important task can be supported by the development of tools like quality-assurance schemes or other instruments such as auditing or eco-labelling. Finally, it will be important to understand whether the concept of Chemical Leasing can easily be extended to other fields, such as energy consumption.

Regarding the practical aspects, Chemical Leasing is being implemented in all regions of the world. Nonetheless, information at the country or even local level may provide further insights on how this business model can be disseminated more widely. Related to that, research needs to explore whether the geographic location of Chemical Leasing partners plays a role. This is particularly important since potential partners could be located too far from each other, which may create a disincentive for its introduction. Moreover, a close cooperation and collaboration between the producer and the user is an important factor for the implementation of Chemical Leasing. The findings in literature confirm that Chemical Leasing has a vast potential to foster a more cooperative and collaborative environment for all involved partners. Notwithstanding these positive aspects, some authors have identified some problems that can arise with such a closer cooperation and collaboration. Lozano et al. (2014) for example has pointed out that increased collaboration may result in increased costs for coordination and information exchange or disputes over how economic gains are shared. More generally, Plas (2008) and Lozano et al. (2013) argue that a negative outcome of highly collaborative contractual arrangements can be that user and producer become overly dependent on each other. Lozano et al. (2013) pointed out that the user relinquishing control of key maintenance processes to the producer may result in increased vulnerability of the user and thus in increased costs to address these vulnerability issues. Since the above factors may be a barrier for the introduction of Chemical Leasing, further research is needed to identify and evaluate solutions that address these apparent shortcomings of a closer entanglement between the producer and the user.

From an economic standpoint, Lozano et al. (2013) argued that the function of the chemical is an important factor for the implementation of Chemical Leasing, and claim that Chemical Leasing may only be applicable to non-reactant chemicals that are indirectly used in processes and that do not become a part of the final product. The authors also came to the conclusion that size matters: an excessive bargaining power of larger chemical suppliers may discourage smaller user companies to introduce Chemical Leasing; on the other hand, a too small user may discourage the chemical supplier to introduce Chemical Leasing. There also has been a general agreement that the traditional units of consumption of auxiliary materials will be replaced with a unit-based price. It will be important to understand how the identification of measurements units as a basis for payment in Chemical Leasing can be streamlined and how the price should be set, so that both the user and supplier can achieve an adequate profit.

At the process level, research needs to address the question how the involved chemicals can be ecologically optimized in future. And since the working definition of 'Grey Chemical Leasing', as introduced in section 2, refers to the recovery rates of chemicals, it will also be important to better understand the recovery rates of chemicals in practice in the implementation of Chemical Leasing projects.

In article II on Chemical Leasing and Corporate Social Responsibility, it became evident that the analysis of two case studies for on a sub-set of two specific stakeholder groups has its limitations, since it cannot be excluded that other Chemical Leasing business models may not be suitable to be branded as a CSR initiative. While the analysis presented in this article is a first attempt to provide companies with a means to brand their Chemical Leasing activities also as a CSR initiative, further work in this field would need to analyse the impact that the implementation of Chemical Leasing has on further primary and secondary stakeholder groups. Increasing the availability of quantitative data from Chemical Leasing projects would strengthen the validity of further research in this field and may also allow analysing the general perception of, for example, consumers or local communities towards the environmental and social performance of the company introducing Chemical Leasing.

Research article III on Chemical Leasing in the context of Sustainable Chemistry proposed a methodology that includes a number of basic goals and sub-goals to assess the sustainability for eight different Chemical Leasing case studies implemented at the local and the national levels. The analysis of these case studies clearly showed that introducing Chemical Leasing business models could be a valid means to increase the sustainability of existing chemicals production and management systems. A positive impact of Chemical Leasing was demonstrated for the type of chemicals used before and after the introduction of Chemical Leasing; the quantity and efficiency in which resources are used in the production processes; the waste and waste water volumes; and the consumption of energy. For some case studies the suggested basic sustainability indicators have not been measured. The uncertainty of whether these case studies promote Sustainable Chemistry cannot be addressed ex post, it is assumed that with the closing of data gaps an increasing positive impact of introducing Chemical Leasing on the sustainability of chemicals' production and use could be demonstrated.

Future Chemical Leasing pilot studies are therefore encouraged to include measurements of the suggested sustainability criteria. This holds particularly true for broader studies that could focus on measuring the impact of Chemical Leasing on increasing sustainability in surrounding systems. As regards the refinement of the evaluation methodology, it is suggested that weighing factors may be introduced to compare the relative importance of various sustainability criteria. Also, further sustainability criteria, such as the impact of Chemical Leasing on policy-making and the implementation of existing chemicals' legislation, can be introduced for future work in this field.

3.1.2 University Education in Chemistry (CLTS Subsystem 2)

Research article IV on the critical review of environmental protection between chemical practice and applied ethics concludes that societies can benefit from a closer engagement of universities in the debates on managing the risks of chemicals. Universities, as the main provider of both research and higher education, are in fact uniquely positioned to facilitate the debates on contemporary ethical and methodological norms to assess the risks of chemicals (Dondi and Moser 2014). Universities therefore can support the shift of focus from regulating chemicals towards preventive measures. (Shrader-Frechette 2012) A particular important area for such an engagement of universities is preventing the exposure of vulnerable groups, such as children and women, to endocrine-disrupting chemicals in food and consumer products, as recently recommended by a white paper on developmental toxicity (Barouki et al. 2012).

In line with other scholars who note a general lack of the ethical principles in the natural science curricula of universities (Frank et al. 2011, Weber and Duderstadt 2012), this article encourages universities to feature ethical consideration more prominently in their curricula. This would enable them to arrive at objective conclusions and findings that modern societies need for progress and prosperity (Morin 1999, Shrader-Frechette 1994, Bok 2010).

Research article V proposes many practical approaches that can easily be put in practice by universities. On the one side, universities can develop courses that deal with the underlying ethical norms of risk assessment methods for chemicals. This could be instrumental for fostering a more widespread application of the precautionary principle in all fields of chemicals management (Strydom 2002, Frank et al. 2011, Dondi and Moser 2014).

On the other side, universities could engage their staff and students in the United Nations Sustainable Development Solutions Network (SDSN) or launch projects on Science Education for New Civic Engagements and Responsibilities (SENCER) (Middlecamp et al. 2006, SENCER 2014). This could provide universities with an opportunity to become more actively involved in the sustainable development agenda (Meadows et al. 1972, Brundtland 1987, Weber and Duderstadt 2012). In this way, universities can also help to build a bridge between science and civic engagement as recommended by Richard Ernst (Ernst 2003, 2007a and 2007b).

Further action can include the active participation in working groups, such as the Working Party on Ethics in Chemistry, which has been established in the framework of the European Association for Chemical and Molecular Sciences (EuCheMS) (EuCheMS 2014).

The analysis contained in this article on university and the risk society (article V) is far from exhaustive. Nevertheless, the findings can provide input for a more in-depth analysis of the nexus between ethics and science and provide a useful contribution to the debate on environmental risks. The following non-exhaustive list has been proposed as a concrete proposal of actionable items that universities at a global level can implement (Shrader-Frechette 2007):

1. Universities should promote transparency when carrying out studies of direct or indirect impact on public health.

2. Universities should avoid any potential conflict of interest, which is often the root cause of flawed science leading to flawed ethics (Shrader-Frechette 2007).
3. Universities should develop codes of conduct that govern consultant activities for external institutions (IM/NAS/NAE 2009).
4. Universities should make provisions for whistleblowing procedures in case the conduct of business of universities poses serious threats to human health and the environment. This should include a protection programme for employees that report possible violations. Universities should also promote whistleblowing functions for risk prevention and include the concept in their scientific programmes and curricula.
5. The European scientific institutions in chemistry should continue developing common codes of conduct to address the "dual nature" of science and technology (Tucker 2012, Santacesaria 2011). Likewise, universities should include the concept of the duality of science and technology as a key component of higher education in biological and chemical sciences.
6. Political institutions should promote a framework in which different collective agents of the risk society, such as academia, industry, states, environmental agencies or social movements, each work together to overcome the complex problems of the Risk Society (Beck 1992)

Universities should more actively engage students in the debate on the ethical aspects of scientific research, particularly during PhD programmes (Frank et al. 2011: paragraph 3, Pozzati and Palmeri 2007, IM/NAS/NAE 2009, Morin 1999).

3.1.3 International Governance of Chemical Substances (CLTS Subsystem 3)

It is evident that limiting the analysis to the Stockholm Convention is a first approach and will only showcase general trends. Further research in this area would need to look into other aspects of the Convention's processes that would deepen the understanding of which aspects of the setting are fostering a shift towards a cognitive society and which are not. This could include, for example, an analysis of question whether a plurality of different types of knowledge of the various collective agents - as called for in a cognitive society - observable at the various meetings and committees of the Stockholm Convention. Here the analysis could look into whether a broad range of stakeholders is included in the debates and decision-making processes.

This research question can be addressed both in a qualitative and quantitative manner. In a first step, the different collective agents present at the meetings and committees of the Stockholm Convention could be identified. For this, a similar methodology to that used in this thesis can be used in a second step to identify the number of interventions of the different stakeholder groups during the negotiation, governing and subsidiary body meetings of the Stockholm Convention. The interventions could be coded according to the group the collective agents belong. The ensuing analysis could then compare the number of interventions with the number of different collective agents present at the meetings, which can be derived from the list of participants of the respective meetings. Also, the trend within the negotiation meetings as well as within the meetings of the governing and subsidiary could be analysed. This could be followed by a comparison of the intervention undertaken by the different collective agents between the negotiation (i.e. the INCs) and the implementation phase (i.e. meetings of the COPs and POPRC) or between the political (COP) and the technical bodies (POPRC) of the Convention.

3.2 Conclusions

In this last chapter, the conclusions reached through the research undertaken in the different subsystems of the CLTS will be summarized and evaluated against the primary research question of this thesis:

> *To what extent did the activities undertaken in the three subsystems of the CLTS – chemical industry, university education and international governance of chemical substances – in the past decades take into account ethical approaches?*

As is evident from the outline of the results in the three specific CLTS subsystems provided in chapter 2 above, each of these subsystems did take into account ethical approaches. In fact, there are promising results in all subsystems with regard to their ability to reduce the risks of chemical substances.

In CLTS subsystem 1 on chemical industry, the introduction of Chemical Leasing as a new and innovative business model is one of the approaches that can be applied at the global scale for the production and use of chemical substances. This is promising in such that it allows the replication of activities through international organizations, such as UNIDO, in developing or transition economy countries, in manufacturing or supply chain companies of all sizes. Chemical Leasing business models could help achieve what R. Ernst described as a "responsible market economy [...] where the participant acts out of conviction that certain actions are needed for the sake of today's or tomorrow's society" (Ernst 2007b: 122).

Also CLTS subsystem 2 has shown promising results in mainstreaming ethics in university education by adopting a number of activities, for example the SENCER courses (SENCER 2014) that would allow students and researchers to better understand the underlying ethical principles of civic engagement and responsible conduct of research activities.

In CLTS subsystem 3 on the international governance of chemical substances, the development of international legally binding instruments like the Stockholm Convention are deeply rooted in the Rio Principles (UNCED 1992), like the precautionary principle, the principle of common but differentiated responsibilities or the polluter pays principle, and in the sustainable development agenda. It is therefore fair to assume that international chemical regulation has strong ethical foundations and supports the shift towards a cognitive society, as outlined in chapter 2.3 above.

All three subsystems of the CLTS take into account ethical considerations in a significant and detectable manner. A key finding of this thesis is that the different components of the CLTS interact with each other with a level of complexity that requires further attention. Indeed, internationally binding legislation developed in CLTS 3 will affect the conduct of business in CLTS 1 in chemical industry. Industry initiatives, at the same time, may influence the development of laws and regulation, both at the national and international levels. And most importantly CLTS 2 on university education represents a crucial juncture that will greatly influence the outcomes of the other CLTS subsystems 1 and 3. Universities play a critical role in educating future generations of scientists, decision-makers and persons employed by chemical industry. It is those future generations that will shape the world in the coming decades, who will conduct risk assessment studies, who will take decisions on the regulation of chemicals, and who will work on the synthesis of new substances in chemical industry. CLTS 2 on university education is arguably the most important field not only for its multiplier effect, but also to ensure that these important tasks are conducted with the highest levels of ethical standards. Therefore, work in the field of ethics in chemistry needs to focus on the education of future generations of researchers, scientists, plant chemists, and decision-makers to not make Michael Gorbachev's warning become a reality:

> *"When future generations judge those who came before them on environmental issues, they may conclude "they didn't know": let us not go down in history as the generations who knew, but didn't care" - Mikhail Gorbachev (2002).*

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Disclaimer

The views expressed in this doctoral thesis are not necessarily those of UNEP.

ANNEX

ARTICLE I

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RESEARCH ARTICLE

Chemical leasing—a review of implementation in the past decade

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Abstract In the past decade, research on innovative business models to manage the risk of chemical substances has sought to provide solutions to achieve the goals of the World Summit on Sustainable Development of 2002, which called for a renewal of the commitment to the sound management of chemicals and of hazardous wastes throughout their life cycle and set the ambitious goal, by 2020, to use and produce chemicals in ways that do not lead to significant adverse effects on human health and the environment. Chemical Leasing is an innovative business model that shows a great potential to become a global model for sustainable development within chemical management. This paper provides a review of the current standings of literature regarding the implementation of Chemical Leasing in the past decade. In doing so, the paper highlights the potential of this business model to serve as an approach for dematerializing production processes and managing the risks of chemicals at all levels. More in detail, it provides an outline of how Chemical Leasing has supported the alignment and implementation of the objectives of chemicals policy-makers and industry regarding the production and use of chemicals and analyses to what extent Chemical Leasing contributes to the implementation of a number of voluntary global initiatives, such as Cleaner Production, Sustainable Chemistry and Corporate Social Responsibility. This paper provides a systematic analysis of the gaps identified in literature regarding the implementation of Chemical Leasing business models. Based on this analysis, specific aspects in the field of Chemical Leasing are recommended to be further elaborated in order to increase the understanding and applicability of the business model.

Keywords Chemical Leasing · Chemical management · Sustainable Chemistry · Cleaner Production · Corporate Social Responsibility · Resource efficiency · Process optimization · Environmental protection

Introduction

Chemicals are ubiquitous and play an important role in modern society. A large number of new chemicals are developed and introduced in national and international markets, often through complex supply chains (McKinnon 2004) as quoted by (Mont et al. 2006). They are contained in products people use in their everyday life or used in the manufacture of products. Many industrial processes critically depend on chemicals performing a broad range of diverse functions, such as lubrication, cooling, solvation, cleaning or catalysis (Stoughton and Votta 2003).

Many chemicals, however, have a dual nature. Toxic chemicals, for example, can be used as chemical weapons or, peacefully, in the production of goods (Trapp 2008). Chemicals that are used as cooling agents are another example. These substances, such as polychlorinated biphenyls, have physical properties, such as inertia and low flammability, which make them the favourable choice in production processes or products in a controlled environment. However, when released into ecosystems, due to the same properties, these chemicals can cause adverse effects to human health and the environment (Letcher et al. 2010). The international community has addressed these risks through the negotiation of

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legally binding international treaties, like the Stockholm Convention on Persistent Organic Pollutants.

While the regulation of chemicals has been one approach to manage these risks, solutions have also been developed within the private sector. Landmark events, such as World Summit on Sustainable Development (WSSD) in 2002, called for a renewal of the commitment to the sound management of chemicals and of hazardous wastes throughout their life cycle and set the ambitious goal, by 2020, to use and produce chemicals in ways that do not lead to significant adverse effects on human health and the environment (WSSD 2002). These sustainability objectives gave impetus for the development of innovative business models to manage the risk of chemical substances.

Chemical Leasing is an innovative business model that shows a great potential to become "a worldwide perspective for sustainable development within chemicals management." (Jakl 2008b: 224) This review intends to outline the current standings of literature regarding the implementation of Chemical Leasing at the national and international levels. The following research questions have been addressed in recent literature on Chemical Leasing:

1. Can Chemical Leasing business models align the objectives of policy-makers and industry regarding the production and use of chemical substances?
2. What are the contributions of Chemical Leasing to other voluntary global initiatives on the management of chemical substances?

This paper seeks to review the responses of literature towards these research questions. In doing so, the paper systematically analyses the gaps identified in literature regarding the implementation of Chemical Leasing business models. Based on this analysis, the paper will highlight specific aspects in the field of Chemical Leasing that need to be further elaborated in order to increase the understanding and applicability of this business model.

After introducing Chemical Leasing business models and providing an overview of the current standing of its implementation in "Chemical Leasing business models as an innovative approach for managing the risks of chemicals" section, the paper is structured according to the above research questions. "Aligning the objectives of policy-makers and industry regarding the production and use of chemical substances" section refers to the first research question by describing how and to what extent Chemical Leasing has supported the implementation of the objectives of chemicals policy and industry regarding the production and use of chemicals. "Contributions of Chemical Leasing to other voluntary global initiatives on the management of chemical substances" section explores research question 2 and looks into the contributions of Chemical Leasing to other voluntary global initiatives on chemicals management, such as the implementation of the Sustainable Chemistry or Cleaner Production. The paper concludes with a summary of the limitations and inhibiting factors of introducing Chemical Leasing business models and an overview on the perspectives for future research in this field in "Conclusions and perspectives for future research" section.

It has to be noted that the complexity of this business model necessitates a more thorough discussion, including matters related to legal considerations or third-party certification, that goes beyond the scope of this paper. For those topics that could not be described in full detail in the main text, recommendations for future research are included in "Conclusions and perspectives for future research" section.

Chemical Leasing business models as an innovative approach for managing the risks of chemicals

This section introduces the origins of Chemical Leasing, its basic principles, and its relation to similar chemicals management approaches, thus setting the scene of the ensuing discussion of the two research questions in the following sections. The implications for the management of risks of chemicals are outlined, and a working definition for Chemical Leasing is proposed. This also includes a working definition of the so-called "Grey Chemical Leasing."

The origins of Chemical Leasing business models

With a view to reduce the risks that chemicals pose to humans and ecosystems, substance-specific policies and treaties have been adopted at the national, regional and global levels in the past decades. The European Union regulation on chemicals and their safe use (EC 1907/2006) on the ordinance on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) entered into force in June 2007 and is an example for regional chemicals regulatory framework. At the global level, the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992 (UNCED 1992), for example, was a landmark event that paved the way to the adoption of the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade and the Stockholm Convention on Persistent Organic Pollutants. The objective of policy-makers was to decrease the exposure of human beings and the environment to hazardous chemicals through reducing their use and turnover. This approach was in stark contrast to the objectives of chemicals' producers, which sought to maximize their profits through increasing the volumes of chemicals to its customers (Jakl 2008a). In order to align these antagonistic objectives, chemicals policy would need to pursue both an ecological as well as an economic objective in order to enable companies to succeed in global competition. Introducing resource efficiency within the standard “sell and buy”—paradigm means decrease in profit for the chemical industry. Policy-makers considered the introduction of innovative business models that would shift the paradigm by which chemicals are traditionally sold as a possible solution.

At the same time, intensifying the cooperation between the producer and the user of chemicals would increase the efficiency by which chemicals are used (Perthen-Palmisano and Jakl 2005). The traditional business models of selling volumes of chemicals, however, did not foster such cooperative approach. Here, companies are seen as self-sufficient entities rather than as collaborative agents. By applying the traditional sales concept, there was no incentive for companies to change their approach of selling chemicals, since any reduction of volumes sold to the user would necessarily reduce the revenues of the producer. In other words, the economic success of a chemicals producer in the traditional sale concept was directly linked to the overall volume of chemicals sold to the user. (Jakl 2008a: 3, Ohl and Moser 2007).

Any innovative business model that would mark this shift in paradigm, according to Jakl (2008b), would need to be implemented by the private sector. There has been a broad consensus in literature that focusing on markets, and therefore, corporations was a viable approach to implement environmental policies (Anderberg 1998; Hoffman 2001; Jakl 2008b). Many of the economic activities that adversely affect the environment and that policy-makers address through bans or restrictions occur within the boundaries of companies. Furthermore, corporations are considered as key drivers for achieving not only economic growth, but also ecological sustainable development. That is because they have the financial and technological means to put into practice sustainable practices for managing the materials used in the production of goods. (Schmidheiny 1992; Welford and Gouldson 1993; Shrivastava 1995). Since chemical policies usually address the most hazardous substances through bans or restrictions (Perthen-Palmisano and Jakl 2005), some authors suggested that it was necessary to support these government-led policies with voluntary initiatives of industry (Commoner 1990; Landy et al. 1990; Lee 1993). At the same time, such an innovative business model would need to be built on the principles of sustainable development, incorporating a more efficient management of material flows as well as the development of less material-intensive production and consumption patterns (Jakl et al. 2004: chapter 1, Stoughton and Votta 2003).

Decreasing the amount of materials used in production is a concept that is closely linked to the concept of dematerialization in functional economies. The following section contains a brief overview of those concept, which are relevant for the theoretical and practical understanding of Chemical Leasing.

The concept of dematerialization was founded on the seminal work of Meadows et al. (1972) on the *Limitations to growth* and the report of the Club of Rome. Other authors also called for an increase in efficiencies in the use of resources with a view to address the negative impact on the environment of industrial activities (Hinterberger et al. 1997; Schmidt-Bleek 1998; Von Weizsäcker et al. 1997). According to Mont et al. (2006), the dematerialization of production processes includes increasing recycling rates, closing material loops and increasing the efficiency of processes in which chemicals are applied. Mont, however, goes beyond the simple optimization of production processes by stating that such a dematerialization may involve companies selling services rather than products. Accordingly, producers of chemicals should consider their material products—in this case chemical substances—as vehicles for delivery of a function or a service.

Substituting material products with functions or services is a key feature of a so-called “functional economy”, which seeks to maximize the time and use value of material products while, at the same time, minimizing the consumption of resources and energy (Popov and DeSimone 1997; Stahel 1997; Mont 2002a). Product–service systems (PSS) play an important role in moving towards a functional economy (Mont 2000; Mont 2002b). The implementation of these systems foresees a substantial reduction of the overall environmental impact of consumption and production activities through replacing material products with increasingly dematerialized system solutions (Brezet et al. 2001; Halme et al. 2007; Mattes et al. 2013). The concept of Chemical Leasing builds upon the principles of a functional economy and constitutes a PSS (Stoughton and Votta 2003, Kurdve 2009). By introducing Chemical Leasing, the chemicals producer sells a service connected to the chemical instead of the chemical itself. This business model hence appears to be a valid response to the call for dematerializing production processes in the context of sustainable development and the management of risks of chemicals substances. In line with these findings, Chemical Leasing is considered as one of the elements of an effective raw materials strategy for European industry (European Parliament 2011).

In Europe, Chemical Leasing business models have been first introduced in the early 2000s in a range of pilot projects and studies commissioned by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW). Jakl et al. (2004) and Jakl (2008a) describe the outcomes of these initial activities in their work from 2004 to 2008, respectively.

Basic principles

Joas (2008) provides a succinct overview of the basic principles of Chemical Leasing business models. He starts his introduction by outlining the traditional sale concept of chemical substances. Here, the producer sells chemicals to the user, who uses them in its production processes to perform certain specific functions. The economic gains of the producer are linked to the overall volume of chemicals sold to the user. Joas, supported by Stoughton and Votta (2003), outlines that the traditional sales concepts, and with it the traditional supplier–user relationship, contains perverse incentives with regard to the volume of chemicals used in the production process. The producer has an incentive to increase its earnings through selling its chemicals at higher prices or in larger quantities. Joas (2008) adds that the intense global competition on the chemicals market may provide a price ceiling for certain chemicals, which, in turn, hampers the producer to increase its earnings through higher prices. The user, in turn, has the opposite incentive to decrease the volumes of chemicals to save costs. According to Ohl and Moser (2007, 2008), the user, however, may have neither the technological means nor the knowledge required to achieve this goal. That is because the chemicals' application is seldom part of the users' core competencies.

These conflicting objectives may persist for the following reasons. For the user, the costs of acquiring new technologies or to increasing the knowledge on the chemical and its application may be prohibitively high (Ohl and Moser 2007).

The producer, in turn, may need to focus on larger sales volumes in order to increase its revenues. This, in turn, raises concerns at the societal level, as augmenting the sales volume of chemicals likely results in increased releases of chemicals into the environment (Perthen-Palmisano and Jakl 2005:49) and hampers resource availability for future generations. Joas (2008) concludes that the continuous application of the traditional sales concept hence may not represent a sustainable solution neither for none of the involved stakeholders, i.e. chemicals' producers, users and society as a whole.

The impetus to introduce Chemical Leasing business models is due to their inversion of the incentive embodied in the traditional sales concept to increase the production and use of chemical substances. Joas (2008) continues by stating the core principle of Chemical Leasing: the payment of producer shifts from the volume of chemicals sold to a service provided to the user. The producer, now being a service provider, has a clear incentive to avoid any unnecessary consumption of chemicals in the processes, since this would decrease its revenues. Chemical Leasing thus turns resource efficiency into an economic asset—even for the chemicals' provider. According Ohl and Moser (2007, 2008) the producer has a vast knowledge of the chemicals it produces, which enables it to use its know-how for the optimization of processes in which the chemical is applied. Joas (2008) further argues that the optimization of processes leads not only to reduced amounts of chemicals required in the process, but also in additional cost savings, thanks to reduced energy consumption.

The current literature also describes the collaborative aspects of Chemical Leasing. Here, Lozano et al. (2013, 2014) maintain that collaboration is an integral aspect of Chemical Leasing. By introducing the Japanese philosophy of Kyosei as a strategy to foster cooperation and collaboration between companies, the authors argue that with the introduction of Chemical Leasing, companies are able to reap the benefits of collaboration. This includes the sharing of information and knowledge between the producer and user of the chemical (see also Ohl and Moser 2007), the creation of win–win situations and strengthening of their environmental performance. Chemical Leasing, according to Lozano et al. (2013), also addresses the problem of free riding.

Joas (2008) maintains that with the application of Chemical Leasing models, both producer and user share a common interest to reduce the consumption of chemicals. On the one hand, the producer has an incentive to reduce the chemicals' use. That is because by selling a service linked to the chemical, any overconsumption of chemicals would now decrease its revenues. The user, irrespective of the business model it applies, has an incentive to reduce the amount of chemicals used, since this decreases its costs. Chemical Leasing generates an added value mainly by reducing the chemicals consumption. The resulting cost savings are shared between producer and user (Beyer 2008a; Schott 2008). Perthen-Palmisano and Jakl (2005) add that Chemical Leasing, in turn, increases both the environmental as well as economic competitiveness through the introduction of best available technologies and best environmental practices. Lozano et al. (2013) add that a successful implementation of Chemical Leasing might benefit from the use of a facilitator. By introducing an example of a project that was implemented with support of a UNIDO National Cleaner Production Centre (NCPC)[1], the authors were able to show the benefits of using a facilitator. In their example, the facilitator played a key role in promoting Chemical Leasing, which was important for identifying and attracting potential partners. During the implementation of the Chemical Leasing project, the facilitator also assisted in monitoring, evaluation and reporting activities. Other specific activities included calculating potential savings and the analysis of baseline scenarios.

As is evident from this analysis, Chemical Leasing fosters a closer collaboration between producer and user, since both partners have a clear incentive to increase the efficiency of the application of chemicals. In some cases, the implementation of Chemical Leasing may benefit from using a facilitator, such as NCPCs, who could also take over tasks such as third-party quality assurance. This may be particularly relevant if the Chemical Leasing project is implemented in developing countries or countries with economies in transition.

[1] See http://www.unido.org/ncpc.html

Table 1 provides an overview of some typical Chemical Leasing business models that vary as a function of integration in and responsibility of the producer in the processes of the user.

Another important aspect for the introduction of the basic principles of Chemical Leasing is the relation to other service-oriented approaches for the management and application of chemicals. The conceptual framework of Chemical Management Services (CMS) is such a service-oriented approach. In recent literature on Chemical Leasing, the concept of CMS is mentioned frequently in publications on Chemical Leasing and vice versa. A clear understanding of the concepts of Chemical Leasing and CMS, and the possible overlaps and differences between the two, is therefore important for this review and the ensuing discussion.

CMS, according to Stoughton and Votta (2003), is a services-oriented business model, in which a manufacturer of goods uses an outside chemical supplier—the service provider—for the application of chemicals in its production processes. The current findings in the literature suggest that the development of CMS is driven by stringent chemicals policy. The provision of serviced solutions is a prominent feature of CMS. According to Mont and Lindhqvist (2003), CMS thus can be seen as a PSS (see also White et al. 1999 and Reiskin et al. 1999).

Stoughton and Votta (2003) define CMS as follows:

> CMS is a business model in which a customer engages with a service provider in a strategic, long-term contract to supply and manage the customer's chemicals and related services.

The United States Environmental Protection Agency (US EPA 2014) defines CMS as follows:

> Chemical Management Services (CMS) is a business model in which a customer purchases chemical services rather than just chemicals. These services can encompass all aspects of the chemical management life cycle including the following: procurement, delivery/distribution, inventory, use (including chemical substitute research), collection, monitoring/reporting, training, treatment, disposal, information technology and even process efficiency improvements; each of which poses its own costs and risks. Under CMS, the service provider is compensated based on the quality and quantity of services provided that reduce chemical life cycle costs, risks and environmental impacts, not on the volume of chemical sold. Therefore, the service provider has the same objective as the customer: to reduce chemical use and cost. Both participants achieve bottom line benefits through reduced chemical use, cost and waste. This model is now widely used in the automotive, aerospace, and microelectronics sectors where environmental benefits observed include reduced chemical use, reduced emissions, and reduced waste generation, as well as substantial cost savings. A total average cost reduction of 30 % has been achieved in the first 5 years.
> Different to Chemical Leasing where process optimization is given central attention, CMS "might" encompass process efficiency improvement; in most cases, however, there is little transfer of know-how between chemicals supplier and chemicals user.

With the application of CMS, the service provider is directly involved or is responsible for the handing and use of the chemical in the production processes. According to Mont et al. (2006: 282), this can include for the purchase of chemicals, their identification, sourcing and procurement. For the preparation of inventories, this can include receiving, inspection and verification, testing, labelling and warehousing. For the application of the chemical itself, it can include the movement to the application area and its use.

Table 1 Classification of Chemical Leasing business models

Producer of chemicals responsible for			Name of model	Responsibility of producer
supply of chemicals	*application of chemicals*	*management of wastes*		
✗	✗	✗	'Traditional sales' model	
✗	✗	☑	Responsible Care' model	
☑	✗	✗	'Supplier service' model	
☑	✗	☑	'Client Operation' model	
☑	☑	✗	'Supplier cooperation' model	
☑	☑	☑	'Total care' model	

Source: Jakl et al. (2004), Perthen-Palmisano and Jakl (2005)

For data management, it can include the order tracking, material safety data sheet (MSDS) management and chemical use tracking. For disposal activities, it can include the handling, collection and actual treatment of waste. For the Environmental Health and Safety services, it can include the provision of data for reporting, safety procedures, emergency preparedness and response planning. As a value added, CMS can also include process changes to improve efficiency, chemical management advice and training services.

The profits of the service provider are a direct result of the cost savings realized by decreasing the unit production costs with the application of CMS. Some authors see the potential of realizing these cost savings in the "hidden costs" of managing chemicals, which arise from the expenses that occur at different stages of the life cycle of the chemical, such as storage, transport, handling or disposal (Oldham and Votta 2003; Reiskin et al. 1999; Bierma and Waterstraat 1999).

With regard to the interlinkages with Chemical Leasing, there is no clear conclusion in literature about the relationships between these two concepts. Some authors use the terms Chemical Leasing and CMS synonymously to the extent that they describe Chemical Leasing as a CMS initiative designed to promote CMS-type principles, such as the increase of eco-efficiency and sufficiency of chemicals use; an increased focus on services instead of material products; delinking economic success from the quantity of chemicals sold; fostering integrated approached by changing the traditional customer–supplier relationship; and transfer of responsibility from the user to the chemical supplier for the application, handling, storage or disposal of the chemicals (Mont et al. 2006; Geldermann et al. 2009; Anttonen 2010). Other authors conclude that CMS and Chemical Leasing, while sharing many common features, differ in some characteristics. Stoughton and Votta (2003: 841), for example, describe Chemical Leasing as a subset of CMS and note that there is clear delineation between these two concepts. They argue that while Chemical Leasing can be a feature of a broader CMS programme, the terms CMS and Chemical Leasing should not be confused.

For Stoughton and Votta, the "term 'leasing' implies a transfer of liability from manufacturer to supplier that is often not possible in the US regulatory context". It is evident that some of these differences in the specifics of these concepts stem from the fact that Chemical Leasing and CMS have been initially developed in different locations: CMS in the USA and Chemical Leasing in Europe. Nevertheless, there is consensus in literature that both concepts support a shift to a service-based economy, long-term cooperation between the suppliers and users, and an extended responsibility of the supplier that spans over the entire life cycle of the chemical (Stoughton and Votta 2003; Lozano et al. 2013).

The fact that there is no unique definition of CMS makes it difficult to pinpoint the major differences between these two approaches. A key difference can certainly be seen in the scope of the services. Chemical Leasing focuses predominately on the processes by which the chemicals are applied, whereas CMS has a much larger scope and includes other services such as supply, handling and storage as well. Moreover, the switch to the services delivered by the chemicals as the basis of payment is specific for Chemical Leasing. In the context of CMS, the company that offers such services may not supply the chemicals themselves, which is instead a key feature of Chemical Leasing.[2]

Definition of Chemical Leasing

Based on the finding of implementing Chemical Leasing in the past decades, several scholars have provided definitions that outline the scope and limitations of this business model. This subsection introduces these different attempts.

The United Nations Industrial Development Organization (UNIDO) has played an important role in the introduction and promotion of this business model at the global level in the past decade. UNIDO (2011) has developed a definition of Chemical Leasing as follows.

> Chemical Leasing is a service-oriented business model that shifts the focus from increasing sales volume of chemicals, towards a value-added approach. The producer mainly sells the functions performed by the chemical, and functional units are the main basis for payment.[3] Within chemical leasing business models, the responsibility of the producer and service provider is extended and may include the management of the entire life cycle. Chemical Leasing strives for a win–win situation. It aims to increase the efficient use of chemicals while reducing the risks of chemicals and protecting human health. It improves the economic and environmental performance of participating companies and enhances their access to new markets. Key elements of successful chemical leasing business models are proper benefit sharing, high-quality standards and mutual trust between participating companies.

Other authors provide definitions of Chemical Leasing and related approaches. Lozano et al. (2014:59), based on the findings of their research, suggest the following definition of Chemical Leasing:

> Chemical Leasing is a business model based on collaborative approaches between two or more industrial partners, where one uses the chemical and the other provides

[2] See also: http://www.chemicalleasing.com/sub/faq.htm# or http://www.epa.gov/osw/hazard/wastemin/minimize/cms.htm

[3] Functions performed by a chemical might include the following: number of pieces cleaned, amount of area coated, etc.

their service, so that environmental impacts and use of hazardous chemical are reduced. As a principle of leasing, it involves unlimited access to chemicals from the user. The types of chemicals that are covered by the concept are non-reactant products that are easy to recovery and have a high recovery rate (more than 75 %), for example, solvents and catalysts, and that are not part of the final product. Good candidates include chemicals that are high risk for human health or the environment and have high value.

Moser et al. (2014a) further describe the term Grey Chemical Leasing and suggest that Chemical Leasing business models are called "grey" if one or more than one of the following aspects are not fulfilled. First, Chemical Leasing necessitates no change of ownership of the chemical. This means that the user should not purchase the chemical, which needs to remain property of the provider. Second, Chemical Leasing requires a change to use-related payment. And third, the sustainability criteria of a Chemical Leasing project, as suggested by the authors, need to be fulfilled completely.

All aspects proposed by the above authors are important for a proper definition of Chemical Leasing. We hence propose a working definition of both Chemical Leasing and Grey Chemical Leasing that takes into account all aspects of these specific definitions. Table 2 below provides a synthesis of these working definitions.

Chemical Leasing and managing the risks of chemicals

There is consensus in literature that chemicals potentially lead to negative environmental and health impacts practically at all stages of their life cycle. A particular problem identified in literature is emissions that occur during the application of certain chemicals in industrial processes that have a potential to negatively impact human health and the environment. This also includes emissions of chemicals when they are disposed of at their end-of-life cycle (RCEP 2003; Perthen-Palmisano and Jakl 2005; Mont et al. 2006). Ohl and Moser (2007, 2008) added that such emissions in particular occur as a function of the knowledge on the properties or the efficient application of the chemical of concern. They further argue that particularly small and medium enterprises (SMEs) are prone to lack such knowledge, since the use of chemicals, in most cases, may not part of their core competencies. The costs of undertaking research on the risks and efficient application of the chemicals may be prohibitively high for those companies.

The producer, instead, has such knowledge. Ohl and Moser maintain that if a user would like to seek information on the chemical it applies, the producer is a likely source of information. Increasing the efficiency of the chemicals' application and, in turn, reducing the risks emanating from emissions in the use and end-of-life phases may critically depend on a transfer of specific knowledge from the producer to the user of a chemical. They further claim that there are no incentives under the traditional concept of selling chemicals to transfer such knowledge, since a more efficient application, and the resulting decrease in quantities of chemicals used in the processes of the user, would directly decrease the revenues of the producer.

Ohl and Moser (2007) introduce two types of Chemical Leasing models to evaluate whether they support an effective management of environmental and public health risks of chemicals: the first model foresees a simple transfer of knowledge from the production to the user and differs the least from the traditional sales concept (see Table 1: "Supplier service" or "Responsible care" models). The second model foresees a more comprehensive shift of responsibility for the application of the chemicals to the producer and differs significantly from the traditional sales concept (see Table 1: "Total care" model). The first step of their evaluation included an analysis of the costs of handing chemical substances for the producer and the user as well the recycling potential of the chemicals of concern (2007:1001). In a second step, they analyzed under which conditions would the producer be willing to offer a Chemical Leasing model and the user be willing to accept the Chemical Leasing model (2007: 1003-6).

Ohl and Moser argue that both Chemical Leasing models—differing most and least from the traditional sales concept—will be applied in praxis if the following circumstances are met. First, service charges under Chemical Leasing should not depend on the volume of applied or disposed of chemicals. And, second, the producer must have detailed knowledge on the properties and efficient use of the chemicals. The producer will be able to realize gains from switching from traditional sales contracts to Chemical Leasing business models, if the efficiency of the chemicals application can be increased by either using the knowledge or transferring it to the user. Moreover, this transfer should allow the producer to decrease its own costs of applying, disposing or recycling the chemical. And, finally, this cost reduction outweighs gains achieved by an overconsumption of chemicals by the user under the traditional sales concept. The authors conclude that Chemical Leasing business models can be a valid means to improve the effective risk management of chemical substances, either by coping with undesired information asymmetries by transferring knowledge to the user or by shifting responsibility for applying and disposing of the chemical to the producer.

Legal aspects of Chemical Leasing business models

A detailed summary and discussion of the legal aspects of Chemical Leasing business models can be found in the contributions of Wittmann (2008), who provides a comprehensive evaluation of Chemical Leasing based on the Austrian legal

Table 2 Working definitions of "Chemical Leasing" and "Grey Chemical Leasing"

Organizational dimension	Economic dimension	Environmental dimension	Technical dimension	A Chemical Leasing business model is called Grey Chemical Leasing if
Chemical Leasing: - Is a service-oriented business model - Is based on collaborative approaches between two or more industrial partners: at the minimum a user of the chemical and a provider[b] of a service[c] - Allows selling the functions performed by the chemical Extends the responsibility of the producer and/or service provider and may include the management of the entire life cycle - Requires high-quality standards and mutual trust between the industrial partners - Requires unlimited access to the chemical by the user	Chemical Leasing: - Shifts the focus from increasing sales volume of chemicals towards a value-added approach - Uses functional units and the main basis for payments[d] - Enhances the access to new markets of all involved partners - Requires proper benefit sharing between all involved partners - Improves the economic and environmental performance of all involved partners, thus striving for a win–win situation	Chemical Leasing: - Aims to increase the efficient use of chemicals while reducing the risks of chemicals and protecting human health - Reduces the environmental impacts of hazardous chemicals - Reduces the consumption of hazardous chemicals - Improves the environmental performance of all involved partners	Chemical Leasing: - Focuses on non-reactant chemicals that are easy to recovery[e] and that are not part of the final product - Focuses on chemicals that are high risk for human health or the environment - Focuses on chemicals that have a high value	- The ownership of the chemical changes to the user (purchase of the chemical) - Functional units are not the main basis for payments - Sustainability criteria for Chemical Leasing are not or incompletely fulfilled[a] - The chemicals of concern are reactant chemicals that are difficult to recover or that become a part of the final product

Source: adapted from UNIDO (2011), Lozano et al. (2014), Moser, Karavezyris, and Blum (2014a)

[a] See Moser, Karavezyris and Blum (2014a)

[b] The service provider can be the producer of the chemical

[c] The service is usually connected to a function performed by the chemical

[d] Functions performed by a chemical might include the following: number of pieces cleaned, amount of area coated, etc

[e] For example, solvents and catalysts

system, and Leismann et al. (2013), who provide a more general discussion of incentives for and legal certainty of ownership substitution services (Wittmann 2008; Leismann et al. 2013). Nagel and Schaff (2008) outline how observing specific legal requirements for the implementation of Chemical Leasing can be supported by third-party quality assurance and certification.

Leismann et al. analyze the enabling factors for the introduction of "use rather than own" concepts. The authors claim that an important task of policy-makers is increase legal clarity and transparency by closing gaps in legislation regarding standard warranty and liability rules. These measures should be supported through the development of standard or model contracts and by providing assistance, for example, in insurance-related issues. Wittmann, instead, has identified key legal aspects in the fields of private and administrative law (2008: 123–127).

To address the prevention of misuse and fraud during the implementation of Chemical Leasing, Nagel and Schaff (2008) provide a comprehensive overview of quality management strategies through an impartial third-party certification entity. According the authors, quality assurance can ensure that specific legal requirements are observed, thus enabling all involved partners in Chemical Leasing to fully realize the benefits of this business model. By applying third-party quality assurance, it is possible to certify whether Chemical Leasing meets relevant quality criteria in terms of environmental and occupational health and safety management. Nagel and Schaff outline that for this purpose, a "Certified Chemical Leasing" standard was developed by the TÜV SÜD Management Service.

While a detailed description of the legal aspects of this business model is beyond the scope of this paper, "Conclusions and perspectives for future research" section includes a list of recommendations on how this topic could be further elaborated.

Current standing of the implementation of Chemical Leasing business models

This subsection will provide an overview on the activities that various stakeholders have taken to implement Chemical Leasing and which measures have been taken to promote its introduction at all levels. The intention of this section is to provide the reader with a snapshot on the worldwide coverage of Chemical Leasing and which industrial sectors are covered.

As outlined in "Basic principles" section above, Chemical Leasing business models have been first introduced in Europe in the early 2000s in a range of pilot projects and studies commissioned by the Austrian BMFLUW. The outcomes of an initial study showed that in Austria, about 4000 companies could benefit from the implementation of Chemical Leasing. For companies applying Chemical Leasing, the annual use of 150,000 t of chemicals was expected to be decreased by one third, with projected cost savings of about 15 % (Jakl 2008a; Schott 2008). Perthen-Palmisano and Jakl (2005:52) outline that these possible reduction potentials have been based on input amounts, which can be attributed to the following groups of chemicals application: 33 % catalysts, 15 % oils/emulsions, 13 % acids/bases and 9 % hydrocarbons. Taking into account the instruments and tools developed in the studies, the BMLFUW subsequently commissioned several pilot projects in the fields of metal degreasing, the recycling of heat transfer oils, and paint stripping processes. The project also included a more methodical analysis of possible application fields in medium-sized enterprises. The outcomes of this pilot phase in Austria are outlined in chapter 4 of the *Chemical leasing goes global* and involve the findings on how to enhancing the acceptance of Chemical Leasing (Plas 2008), a report by an Austrian company on a "best practice" example of Chemical Leasing in metal cleaning in the automotive industry (Erbel 2008) and a report on the application of Chemical Leasing in the field of paint stripping (Beyer 2008b).

In 2006, the German Federal Environment Agency has launched a Chemical Leasing initiative for Germany. The initiative foresaw the establishment of a German Chemical Leasing national working group and the conceptualization and subsequent implementation of several Chemical Leasing pilot projects. The projects focused on a broad range of manufacturing sectors, such as cleaning pipes and containers in the food and pharmaceutical industries; use of PVC for automotive under-body coating; the production, further processing and use of catalysts; cleaning, pre-treatment and coating of metal surfaces; use of abrasives in the metal industry; glass bonding using sealant tape; coating aluminium sheet for beverage can lids; or the use of pesticides in agriculture in agriculture. The projects also addressed the topic of substitution of chemical substances and sought to provide solutions for the introduction of new and innovative technologies. The preliminary outcomes of the implementation of the pilot studies are contained in the report of the German Federal Environment Agency on *Chemical Leasing as a model for sustainable development with test procedures and quality criteria on the basis of pilot projects in Germany* (FKZ 3707 67 407) (UBA 2010). The outcomes of the case studies are also expected to inform the development of sustainability criteria for Chemical Leasing business models (Moser et al. 2014a).

At the international level, in 2005 UNIDO launched several Chemical Leasing pilot projects, starting with projects in Egypt, Mexico and Russia (Schwager and Moser 2006). UNIDO's aim was to demonstrate whether the Chemical Leasing concept could be applied, as part of its Cleaner Production Programme, in selected chemical industries in developing and transition economy countries. These pilot studies were limited to show the potential of Chemical

Leasing in cleaning processes. The outcomes of these international pilot projects are outlined in chapter 5 of the book *Chemical leasing goes global* and involve the findings on the application of Chemical Leasing in Egypt in the fields of electrostatic powder coating (Sena et al. 2008a), cleaning equipment with hydrocarbon solvent (Sena et al. 2008b) and hot dip galvanizing (Sena et al. 2008c); in Mexico in the fields of sugar mills (Valerio et al. 2008a) and electroplating (Valerio et al. 2008b); and in Russia in the field of water purification (Startsev and Schott 2008). In 2008, UNIDO launched further pilot projects in Sri Lanka, Serbia and Colombia. Ongoing projects are coordinated by UNIDO in Serbia, Sri Lanka, Colombia, Brazil, Croatia, Mexico, Nicaragua, Russia (Kazan/Volga Region), Ukraine and Uganda (UNIDO 2011).

Table 3 provides a concise overview of Chemical Leasing pilot projects implemented in the past years, including possible awards that those projects have obtained[4].

Activities to promote the introduction of Chemical Leasing

Information on Chemical Leasing is mainly disseminated to a broader audience through a website[5] and a dedicated award programme. The Global Chemical Leasing Award was launched by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW) and UNIDO in September 2009[6] (Jakl 2011).

The award is open to organizations, companies and individuals worldwide and comprises four categories: case studies, scientific publications, consulting services and public relation activities. Various impact factors are taken into consideration such as innovation, technical applicability and sustainability, which also includes the aspects of resource efficiency, precaution in terms choice of hazardous substances, effective chemicals management and social implications.

The first award ceremony took place on March 1, 2010, in Prague within the frame of the International Conference on International Chemical Control Legislation & Trade Aspects[7]. The award in 2012 was jointly organized by UNIDO, BMLFUW and the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). The award ceremony took place in June 2012 within the World Exhibition Congress on Chemical Engineering, Environmental Protection and Biotechnology in Frankfurt, Germany[8]. A third Global Chemical Leasing Award is planned for December 2014 to further enhance the global visibility of Chemical Leasing, acknowledge best practices and inspire companies and individuals around the globe to apply the Chemical Leasing service-based business concept. The award 2014 is sponsored and supported by UNIDO, BMLFUW, BMUB, the Swiss State Secretariat for Economic Affairs and the Swiss Federal Office for the Environment.

Aligning the objectives of policy-makers and industry regarding the production and use of chemical substances

This section summarizes the findings of literature regarding the key objectives of different stakeholders in the production and use of chemical substances and whether the objectives of the chemicals' user and producer are aligned with Chemical Leasing. It then discusses the findings of literature regarding the first research question: "Can Chemical Leasing business models align the objectives of policy-makers and industry regarding the production and use of chemical substances?"

Key objectives of policy-makers regarding the production and use of chemicals

Recent literature has cited a number of policy approaches that were instrumental for triggering the introduction of Chemical Leasing. Two main types of policies have been cited. First, integrated policies focusing on products and resource efficiency in general and, second, environmental policies specifically targeting the risks of chemicals over their entire life cycle.

Regarding product-related policy approaches, several authors described the European Union's (EU) Integrated Product Policy (IPP) as a driving force for the introduction of sustainable products along their life cycles and for targeting consumption patterns. Policy measures such as IPPs are seen as a support to the development of long-lived products, which are produced with lower resource demand and emissions of hazardous chemicals. IPPs thus constitute a useful means to stimulate environmental innovation or optimization of life cycle environmental impacts. However, literature remains doubtful that IPPs and other national sustainability strategies alone would be sufficient to address the international dimension of sustainable production and consumption. Here, new market-based approaches like Chemical Leasing can provide a solution since they are implemented by industry on a voluntary basis (Jakl et al. 2004; Steinhäuser et al. 2004; Mont and Bleischwitz 2007).

Jakl et al. (2004: chapter 1) add that IPPs, and with them service-oriented business models such as Chemical Leasing, can play an important role in the context of the implementation of the European Sustainability Strategy (EU SDS 2009) or other initiatives aiming at enhancing eco-efficiency, such as the "Factor 10" (Bolund and Johansson 1998) or "Factor 4"

[4] Based on the draft database of Chemical Leasing projects (http://www.chemicalleasing.com/docs/database.pdf)
[5] See http://www.chemicalleasing.com/
[6] See http://www.chemicalleasing.com/sub/Award/award.htm
[7] See http://chemcon.net/europe/chemcon_2010/chemcon_2010 cz.shtml
[8] See http://www.achema.de/en.html

Table 3 Overview of Chemical Leasing projects by country, sector and process

Country	Sector	Process	Companies involved	Unit of payment	Resource savings	Economic savings	Comments	Awards
Austria	Metal working industry	Metal cleaning	User: Automobiltechnik Blau; equipment supplier: PERO; chemicals supplier: Safechem	Euro per number of cleaned parts	Energy consumption reduced by 50 %, use of spare parts reduced by 66 %, solvents reduced by 71 % per year		Car parts, military industry, multiplied in France, one of the oldest cases in Chemical Leasing, still ongoing	
Austria	Metal working industry	Paint stripping	User: Mepla-Alfit; supplier: Tiefenbacher				Case not continued	
Colombia	Construction/ceramic industry	Wastewater treatment	User: Corona-Colceramica; supplier: Transform Ecoskandia	Columbian pesos per cubic metre of re-circulated water used in the process	Potential for water savings of 30,000 m^3/year (potential for drinking water); 0.15/year of total suspended solids; 1.9 t/year of BOD	Potential financial savings by US$5000 per year	Manufacture of ceramic tiles; elimination of wastewater discharges (zero chemicals); new case, concrete data not yet available	
Colombia	Galvanic sector	Wastewater treatment	User: Grival; supplier: Dindep	Colombian pesos per cubic metre of treated water and quality or raw material incorporated	Potential saving in chemicals by 40 %; 50 % reduction of sludge; water recirculation 100 %	Potential savings up to US$3000/month	New case, data not yet available	
Colombia	Metal working industry	Galvanization and degreasing	User: Armalco; supplier: Dismongo	Colombian pesos per kilogram of carbonated wire	Reduction in water consumption by 80 %=5500 m^3 of HCl per year			
Colombia	Metal working industry	Wastewater treatment	User: Grival; supplier: Tecca	US$ per cubic metre of treated water	50 % reduction in use of chemicals		New case, data not yet available	
Colombia	Oil industry	Wastewater treatment	User: Ecopetrol; supplier: Nalco	US$ per kilo barrel of fluid	80 % reduction of total costs, 20 % reduction in chemicals consumption in 10 months	Total savings in 10 months: US$2.2 million		Gold in the Global Chemical Leasing Award in 2010
Egypt	Automotive industry	Cleaning of equipment with hydrocarbon solvents	User: GM; supplier: Dr. Badawi	Egyptian pound per vehicle produced	Saving of raw material through recycling, reduction of solvent consumption from 1.5 L/vehicle to 0.85–1 L/vehicle which leads to significant reduction in VOCs; total savings of hydrocarbon solvents by recycling is around 20 t per year (20,000 L)	Total savings: E£ 220,000 (US$37,000 per year)		Silver in the Global Chemical Leasing Award 2012
Egypt	Metal working industry	Electrostatic powder coating	User: ABB; supplier: Akzo Nobel	Egyptian pound per coated square metre of final product	Reduction in powder loss by 7 %, cost reduction in coating process per square metre from 3.8/m^2 to 3.2/m^2 (16 %); less energy consumption, less maintenance costs	US$68,000 per year, less energy consumption, less maintenance costs		
Egypt	Metal working industry	Hot dip galvanization	User: El Sewed Company; supplier: Zibc Misc Company	Egyptian pound per galvanized tonne of final product	Significant reduction in zinc consumption	US$200,000 per year		

Table 3 (continued)

Country	Sector	Process	Companies involved	Unit of payment	Resource savings	Economic savings	Comments	Awards
Germany	Health service	Disinfection in hospitals	User: Hospital; supplier: Schülke & Mayr GmbH	Euro per hygiene level achieved	Potential reduction in surface disinfectants by 15 % and in sanitary disinfectants by 30 %			
Germany	Metal working industry	Cleaning and degreasing	Distributor: Jaecklechemie; user: DHD Technology GmbH, supported by Safechem via distributor	Euro per hours of operation of the respective equipment		Extend the life cycle of the chemicals in use, electricity savings	Other benefits: mitigating the risk of accidents and uncontrolled, exposure to high-risk chemicals	
Germany	Metal working industry	Metal cleaning	User: STAI; supplier: Safechem	Time-based set-up: annual consumption of solvent, waste take back, service products, consultancy and training were calculated based on the customer's specific production data and charged per month	Reduction in solvent consumption by 8–10 % per year		Within Chemical Leasing, direct involvement of local distribution partners and cooperation with leading Original Equipment Manufacturers (OEMs); global promotion of Chemical Leasing	Gold in the Global Chemical Leasing Award 2012
India	Textile industry	Dying	User: IKEA (three factories); supplier: Huntsman	US$ per kilogram of dyed textile	75,000 m^3 of water per year, energy savings: 2 m kWh, 78 t of dyes per year			Special award in 2010
Mexico	Agriculture	Fertilization	User: Biosoluciones Palmer; supplier: agricultural company	US$ per treated hectare			New case, data not yet available	
Mexico	Food processing	Lubrication of equipment	User: Fideicomiso Ingenio San Cristobal; supplier: Chemical Mac Oil S.A.	US$ per sugar cane milled (grease applied in mill area)			Case not continued	
Mexico	Metal working industry	Electroplating	User: Cromadora Delgado, S.A. de C.V. (CRODEL); supplier: MARDI	US$0.14/10 Ah	Reduction of nickel consumption by 22 % in 1 year	US$10,000 per year	Case not continued	
Russia	Water supply	Wastewater treatment	User: ERG; supplier: Henkel ERA	Rouble per cubic metre of treated water	More than 50 % decrease in chemicals consumption	More than 50 % decrease in wastewater purification costs	Case not continued	
Russia, St. Petersburg	Water supply	Disinfection	User: Vodokanal; supplier: Aquatechservice Ltd.	Rouble per cubic metre of disinfected water	33 % reduction of water disinfection costs			
Russia, St. Petersburg	Water supply	Water disinfection	User: SUE Vodokanal St. Petersburg, supplier: KEMIRA	Rouble per cubic metre of treated water	32 % reduction in chemicals consumption per 1000 m^3			
Serbia	Food processing	Bonding of boxes	User: Bambi; supplier: Henkel	Euro per number of bonded boxes	Reduction in chemicals between 30 and 40 %	Total cost reduction: 18,000 €		Gold in the Global Chemical Leasing Award 2012
Serbia	Food and beverage	Lubrication of packaging line and washing of bottles	User: Coca-Cola, supplier: Ecolab	Euro per number of packed product units			Contract signed end of 2012; subject of the contract is the lubrication of conveyors for packaging of PET bottles, cleaning of external surfaces of equipment and additives for bottles washing	

Table 3 (continued)

Country	Sector	Process	Companies involved	Unit of payment	Resource savings	Economic savings	Comments	Awards
Serbia	Food processing	Lubrication of equipment	User: Knjaz Milos; supplier: Ecolab	Euro per number of working hours of conveyor	Water consumption: 6500 m^3 per year, consumption of chemicals reduced by 7.4 t; hazardous chemical substituted	Total savings 9500 €	Chemical Leasing model was first applied for one packaging line, then it was extended to 3 lines, and it is planned to soon cover all packaging lines	Silver in 2010 and Gold in the Global Chemical Leasing Award 2012
Serbia	Metal working industry	Metal cleaning	User: FKL; supplier: Safechem	Time based set- up: annual consumption of solvent, waste take-back, service products, consultancy and training were calculated based on the customer's specific production data and charged per month	Consumption of perchloroethylene reduced by 83 %; waste reduced by more than 25,000 kg/year; solvent reduction >25,000 kg per year		Within Chemical Leasing, direct involvement of local distribution partners and cooperation with leading OEMs, global promotion of Chemical Leasing	Gold in the Global Chemical Leasing Award in 2012
Slovenia	Metal working industry	Dye casting of aluminium	User: MLM; supplier: ABC Maziva	Euro per tonne of moulded aluminium	Reduction in releasing agents consumption by 50 %; reduction in fresh water consumption by 13 % per year	100,000 € per year		
Slovenia	Paper industry	Lubrication	User: VIPAP; supplier: ABC Maziva	Euro per tonne of paper produced	Reduction of lubricants consumption by 20 t per year; waste reduction by 15 t in 1 year	70,000 € per year		
Sri Lanka	Agriculture	Plant cultivation	User: Nanayakkara Farm; supplier: Kandurata Agr.	LKR (Rs) per kilogram of harvest per season	40 % less chemicals in 6 months	Over US$150/ha added value in 6 months	Cleaner Production Centre is investigating potential of Chemical Leasing in the plantation sector (tea, coconut); potato cultivation	Bronze in the Global Chemical Leasing Award in 2012
Sri Lanka	Paint industry	Building painting—binder and paint handling processes	User: Madushika Paints, Chemicasl Pvt Ltd. supplier: Sri Lanka Broadcasting Corporation	30.34 Rs per square feet (US$~0.6) for smooth finishing painting and 25.27 Rs per square feet (US$~0.5) for rough finishing	Totals savings: coverage increased by 10 %, considerable reduction of water consumption, reduction of packaging waste in 6 months		Chemical Leasing contract signed by the partners in March 2012 for a period of 6 months; ongoing negotiations with the supplier to expand Chemical Leasing applications with other users	
Sri Lanka	Printing industry	Printing of newspapers	User: Wijeya Newspaper Ltd.; supplier: Kumar Namasivayam	Rs per printed square meter of newspaper	Ink consumption reduced by 7 %, i.e. 40 t per year	Total savings US$30,000		
Sri Lanka	Printing industry	Printing process	User: St. Regis Printing and Packaging Ltd.; supplier: General Ink; Chemical Leasing Promoter: Holcim Lanka	0.80 Rs per printed cement bag	Potential for reduction of ink consumption by 10 % and of ink evaporation up to 70 %	Potential financial savings of about 32,000 (US$~600)		
UK	Metal working industry	Metal cleaning	User: Henton; supplier: Safechem	Time based set-up: annual consumption of solvent, waste take-back, service products, consultancy and training were calculated based on the customer's	Reduction in solvent consumption by 10 % per year, reduction of trichloroethylene solvent		Within Chemical Leasing, direct involvement of local distribution partners and cooperation with leading OEMs	

Table 3 (continued)

Country	Sector	Process	Companies involved	Unit of payment	Resource savings	Economic savings	Comments	Awards
				specific production data and charged per month				
UK	Oil Industry	Oil drilling	User: different oil companies like Statoil, Exxon Mobil and Total; supplier: Cabot Specialty Fluids	US$ per number of days the chemical is used in the field			Replacement of the hazardous zinc bromide brine by the caesium formate brine	Bronze in the Global Chemical Leasing Award 2010
Ukraine	Agriculture	Plant cultivation	User: Interagro Skvira; supplier: Enzim	US$ per hectare of arable land		Potential reduction of costs by about US$40,000 per year	Chemical fertilizers are partially substituted by organic fertilizers	

Source: "Draft Database of Chemical Leasing Projects" http://www.chemicalleasing.com/docs/database.pdf (accessed on 14 May 2014])

(Von Weizsäcker et al. 1997) concepts. Both concepts state in principle that societies need to significantly reduce the use of natural resources and increase the efficiency of their use in order to ensure resource availability for future generations.

Scholars also outline the apparent overlaps of these two policy fields. Environmental policies, on the one side, are important for fostering corporate activities that aim at improving the environmental performance of their products. IPPs, on the other side, can reward innovative and sustainable product solutions, often as a voluntary measure. They thus are a valid means to complement the more prescriptive chemical policy strategies (Mont and Lindhqvist 2003; Steinhäuser et al. 2004).

An important factor for the introduction of service-oriented business models at the national level was the Austrian chemicals policy. The so-called "Best Practice Diffusion" concept was not only instrumental for facilitating a know-how transfer as a key ingredient for fostering the introduction of more environmentally friendly alternatives in the product and technology field, but also to create enabling conditions for companies that adopters such alternatives at an early stage. The dissemination of best practices is also outlined in the "Global Plan of Action" of the Strategic Approach to International Chemicals Management (SAICM), which provides the international policy framework for chemicals' management in the twenty-first century (Jakl et al. 2004; Jakl 2008a).

At the European level, the EU's 6th Action Programme for the Environment (EU 2002) has played an important role for the development of the EU chemicals policy and hence influenced the introduction of Chemical Leasing business models. Jakl et al. (2004:13) describes the key aspects of the programme. First, "[c]hemicals that are dangerous should be replaced by safer chemicals or safer alternative technologies not entailing the use of chemicals, with the aim of reducing risks to man and the environment." Second, the programme demands to place "the responsibility on manufacturers, importers and downstream users for generating knowledge about all chemicals (duty of care) and assessing risks of their use, including in products, as well as recovery and disposal." Third, the programme commits the EU to aim at achieving "within one generation (2020) that chemicals are only produced and used in ways that do not lead to a significant negative impact on health and the environment […]". The programme also paved the way for the adoption of the European Union regulation on chemicals and their safe use (EC 2007), which entered into force in 2007. The ordinance on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) seeks to improve the protection of human health and the environment through the better and earlier identification of the properties of chemical substances. Accordingly, REACH incorporates the principle of documentation, evaluation and minimization of risks resulting from chemicals. Since industry will be responsible for implementing these measures, REACH requires a rethinking of the traditional provider–user relationship. It also calls for a more intense communication along the supply chain (Jakl et al. 2004; Ohl and Moser 2008; Lozano et al. 2013).

These different policy approaches reported in literature led to the following list of key objectives of a modern environmental policy:

1. Awareness raising objective: the intrinsic risks of producing and using chemicals are known.
2. Risk management objective: the risks of the produced and used chemicals are being minimized risks at every stage of the chemicals' life cycle.
3. Process optimization objective: the quality of practices used in the application of chemicals is increased.
4. Communication objective: communication regarding the risks of chemical substance is intensified along the supply chains.
5. Ownership objective: industry itself is responsible for the documentation, evaluation and minimization of risks resulting from chemicals.

Aligning the objectives of the chemicals' user and producer with Chemical Leasing

Joas (2008) maintains that the key objective of the producer is to maximize its economic gains to ensure economic growth and retain or increase competitiveness in global markets. Stoughton and Votta (2003) claim that the producer can increase its earnings by selling its chemicals either at higher prices or in larger quantities. At the same time, the producer can increase its gains by reducing the costs of production of the chemical. For Schott (2008) and Ohl and Moser (2007), these costs comprise expenses for the safe handling and working environment, transport, research and development, and the acquisition of raw materials for the production of the chemical and general production costs. Most importantly, the producer has an incentive to increase its revenues by increasing the quantity of chemicals sold to the user.

Stoughton and Votta (2003) maintain that users that apply chemicals in its production processes usually have the objective to maximize their throughput and accelerate the time to market of their products. The users will also generally seek to reduce costs of its chemical management system. According to Schott (2008) and Ohl and Moser (2007), the costs for the user mainly arise from ensuring a safe application, handling and disposal or recycling of the chemicals. This can include, for example, costs for maintaining a safe working environment or safety training for workers. For the user, the total costs for using a specific chemical in its processes is the sum of the above safety-related costs, the costs for buying the chemical, and the costs for its application. Critically, the user has an incentive to reduce its costs by reducing the quantity of chemicals used.

As regard the objectives of the producer and the user in producing and using chemical substances, there is broad consensus in the current literature that introducing Chemical Leasing has a vast potential to increase the revenues of both producer and user. That is because both partners now share a common interest to reduce the consumption of chemicals and thus can share the resulting added value (Beyer 2008a; Schott 2008). Introducing Chemical Leasing can be a reasonable economic choice for both the producer and the user.

Discussion

As is evident from the literature presented in this section, Chemical Leasing has a vast potential to increase the effective risk management of chemical substances. This is done either by resolving undesired information asymmetries by transferring knowledge to the user or by shifting responsibility for applying and disposing of the chemical to the producer. Any unnecessary consumption of chemicals in production processes can be avoided, as this would now decrease the revenues of the producer. Chemical Leasing also helps to reduce the amounts of chemicals required in the application, thanks to the optimization of processes. It thus saves costs, also thanks to reduced energy consumption. Communication between the producer and user can be strengthened, since both partners now have a clear incentive to increase the efficiency of the application of chemicals. Chemical Leasing also fosters cooperation between the user and the producer, since the producer has increased responsibility for the processes in which the chemicals are applied. Finally, it increases the environmental performance and the economic competitiveness through the introduction of best available technologies and best environmental practices. Chemical Leasing also creates a positive business environment, in which companies can grow in competitive global markets. At the same time, companies are able to reduce the overall amounts of chemicals applied in their production processes (Schwager and Moser 2006; Joas 2008; Lozano et al. 2013).

Recalling the key objectives of a modern environmental policy, as outlined above, the implementation of Chemical Leasing convincingly contributes to the achievement of all five chemical policy objectives. The following two specific examples of policy approaches for the sound management of chemicals at the regional and at global levels provide further evidence that the implementation of Chemical Leasing is a convincing response to achieve an alignment of the objectives of policy-makers and industry regarding the production and use of chemical substances.

Example 1: Chemical Leasing and REACH

There is broad consensus in literature that Chemical Leasing is a convincing means to implement REACH. A key component of the REACH regulatory framework will be the reversal of the "burden of proof", which, in turn, bolsters a "no data–no market" approach. As a precondition for market access, producers or importers of substances are obliged under REACH to deliver documentation regarding properties of chemicals. This is to include information on possible risks during their applications. Jakl (2008b: 214) states that this implies a "real shift of paradigm: Although the current legislation also was based to a certain extent on the producers' responsibility, the actual burden of proving a certain risk and of demanding risk-appropriate management measures however was with the authorities."

Jakl (2008b) maintains that the implementation of REACH requires intensified cooperation, networking and communication based on documentation, evaluation and minimization of hazards. Chemical Leasing fosters an intensified dialogue as well as cooperation and collaboration between the supplier and user of chemical substances and can therefore serve as a basis for the implementation of REACH. Lozano et al. (2013) also share this view, stating that the relationship is built between the provider and the user of a chemical, thanks to Chemical Leasing which fosters knowledge sharing among these actors. They further argue that this would constitute a prerequisite for REACH and REACH-like regulatory frameworks.

REACH also requires chemicals to be handled with care. This implies that chemicals and their applications are not only monitored but also managed with maximum accuracy. Jakl (2008b: 217) outlines that REACH and Chemical Leasing share the same philosophy: "REACH represents the regulatory driver for this attitude aiming at protecting human health and the environment […] whereas Chemical Leasing is additionally driving it from the economic point of view since resource efficiency simply increases profit." Moreover, Chemical Leasing, according to Jakl (2008a, b:217), "is the ideal business environment to identify and apply the use and exposure category concept in particular within the Chemical Safety Report—jointly by suppliers and users." Jakl (2008b: 218) concludes that "Chemical Leasing is making use of REACH structures and is turning them into economic advantages while at the same time catalyzing REACH compliance".

In particular within the "Authorization" regime REACH is establishing for substances of very high concern, applicants might document their commitment towards safe handling and accurate monitoring by basing their applications on the Chemical Leasing concept. Tracing chemicals involved throughout all stages of application while at the same time optimizing the resource efficiency are specific characteristics of Chemical Leasing aiming at risk mitigation, a prerequisite for authorizations to be granted. On the other hand, it is a central aim of authorization to ensure substitution of authorized chemicals as soon as benign alternatives are available. Authorization under REACH and Chemical Leasing thus are mutually supportive instruments.

Similarly, Ohl and Moser (2007, 2008) demonstrate that the implementation of Chemical Leasing models supports a transfer of knowledge from the producer to the user or transfers the responsibility for applying and disposing of the chemical to the supplier. The authors conclude that the implementation of Chemical Leasing is in line with the objectives of REACH, since these business models address these undesired information asymmetries between the user and the supplier of chemicals.

Also, a recent report of the European Commission has shown that REACH discouraged chemical suppliers to continue competing in the markets of certain chemicals. The report showed that this market concentration and the resulting increased prices could positively influence the development of business models, such as Chemical Leasing. It can be expected that this trend may increase the safety of using and producing chemical substances (European Commission 2013).

Example 2: Chemical Leasing and the SAICM

The International Conference on Chemicals Management (ICCM) adopted in 2006 the Strategic Approach to International Chemicals Management (SAICM) as a policy framework to foster the sound management of chemicals. SAICM, according to Jakl (2008a), constitutes a framework of measures that seeks to increase the eco-efficiency of chemicals and, with that, the minimization of their releases into the environment. Chemical Leasing, according to Jakl (2008a), complies with the new paradigm of environmental policy and of chemicals policy in particular as set out in the SAICM, as it addresses not only the characteristics of chemicals but also the optimization of the processes in which chemicals are applied. The author confirms that it is therefore evident that Chemical Leasing can support the implementation of the SAICM and could be disseminated as a "best practices" as called for in SAICM's "Global Plan of Action". He concluded by stating that Chemical Leasing shall become a central element of that instrument and its implementing processes. Chemical Leasing was prominently featured at the ICCM in an event in which the Austrian Federal Minister for the Environment and the UNIDO Director General committed themselves to Chemical Leasing as their common political priority.

Joas (2008) also agreed that the concept of Chemical Leasing is in line with the policy framework set out by the SAICM. That is because Chemical Leasing adopts a life cycle approach for the sound management of chemicals in industrial processes and fosters a responsible use of chemicals that ultimately lead to the minimization of adverse effects on human health and the environment. Chemical Leasing also supports the transfer technologies from developed to developing countries and hence is a suitable vehicle to implement the objectives of the SAICM to strengthen the capacity of developing countries for the sound management of chemicals.

The evidence provided in this section supports the argument that Chemical Leasing business models are able to align the objectives of users and producers of chemicals. However, the analysis of further examples is needed to evaluate whether the implementation of Chemical Leasing, particularly at the national level, is aligned with chemical policy objectives also in other regions of the world.

Contributions of Chemical Leasing to other voluntary global initiatives on the management of chemical substances

This section looks into the possible impact that Chemical Leasing has on the implementation of other global initiatives that are implemented by industry on a voluntary basis and aim at protecting the environment from the adverse effects of chemicals and related waste. This section focuses on three specific fields. The first example is taken from the field of Cleaner Production, which is an industry-centred initiative that seeks to strengthen industrial processes and sustainable production patterns as well as to minimize the generation of wastes. The second example focuses on Sustainable Chemistry, which is specific field of the sustainable development agenda. The third example is taken from the field of Corporate Social Responsibility.

Chemical Leasing and Cleaner Production

The link between Chemical Leasing and other similar cooperative models has been described in literature from the late 1990s on. Bierma and Waterstraat (1999), in this regard, introduced the concept of *Shared Savings*, which takes into account that the traditional relationship between a chemical supplier and the user is wasteful and leads to the degradation of the overall environmental performance of the involved companies. With the application of Shared Savings, the waste could have turned into profit, which in turn was shared between the chemical supplier and the chemical user. The supplier is much more closely involved in the processes of the user, which resulted in a continuing reduction of chemical use, related wastes and costs. Applying the Shared Savings concept was instrumental for enhancing environmental performance of the companies by improving production processes and product quality. For the supplier, it meant increased competitiveness in the chemical supply industry. Bierma and Waterstraat (1999) concluded that the Shared Savings concept hence promotes Cleaner Production.

More specifically on the concept of Chemical Leasing, Perthen-Palmisano and Jakl (2005) first introduced the notion of Cleaner Production in 2005 when describing the outcomes the implementation of case studies and pilot project in Austria. They maintained that the experiences gained in these national pilot projects could serve as a framework for the wider application of Chemical Leasing at the regional and international levels. They outlined that the UNIDO NCPCs have showed clear interest to implement Chemical Leasing as a part of their Cleaner Production Programmes.

Schwager and Moser (2006) reported that UNIDO launched three Chemical Leasing pilot projects in Egypt, Mexico and Russia in 2005 with a view to demonstrate whether the Chemical Leasing concept could be applied in selected chemical industries in developing and transition economy countries as well. They described the main elements of the projects focusing on national capacity building in the identified industry sectors. A key feature of the projects was their implementation in close cooperation with the NCPCs in Egypt, Mexico and Russia. Using the UNIDO's NCPC, network proved beneficial since the involved centres are well connected within the respective national chemical industry sectors and are a familiar with problems associated to sustainable industrial development.

Schwager (2008a) outlined that experience gained in the past years clearly demonstrated that the concept of Chemical Leasing is closely linked with the principle of Cleaner Production. It therefore constitutes an important part of UNIDO's Green Industry strategy. That is because Chemical Leasing promotes process optimization, thanks to increased cooperation between suppliers and users, development and transfer of environmentally sound technologies, greening of the supply chain and capacity building. It is convincing solution to sustainable chemicals management and to curb releases to the environment. Schwager, supported by Geldermann et al. (2009), concludes that combining Chemical Leasing and Cleaner Production also responds to the advancements of international chemical policy and will also support the implementation of the objectives of the SAICM. In order to systematically support the implementation of Chemical Leasing business models at the factory level, Schwager (2008b) reported that UNIDO has developed a Chemical Leasing Toolkit in close cooperation with the national and international experts involved in the UNIDO Chemical Leasing activities.

Lozano et al. (2013) further describe a Chemical Leasing case study in Serbia that was implemented with a view to foster green chemistry through the application of collaborative business models. As outlined in "Definition of Chemical Leasing" section above, Lozano et al. have described the role NCPC in Serbia as a facilitator, which was an important factor for the successful implementation of project.

These promising findings of the recent literature have largely been confirmed in praxis by UNIDO's global Chemical Leasing programme, which has been launched in 2005. The programme is implemented at the national level in close cooperation with UNIDO's NCPCs. These centres are partners of the Resource Efficient and Cleaner Production (RECP) network of the United Nations Environment Programme (UNEP) and UNIDO, which presently includes nearly 50 NCPCs and programmes globally (UNIDO 2011).

Chemical Leasing and Sustainable Chemistry

A first attempt to link Chemical Leasing with the concept of Sustainable Chemistry has been undertaken by Steinhäuser et al. (2004) in the context of the discussion of IPPs serving as a main element for a strategy for sustainability of chemistry.

Such a strategy requires, among other things, a framework for sustainable products. That is because a Sustainable Chemistry approach should favour products that exhibit a prolonged use phase, that can be produced and used with a minimum of resources, that minimize releases of hazardous substances and that can be reused and recycled. Chemical Leasing has been listed as one option to achieve these objectives (UBA 2010). Lozano et al. (2013, 2014) argue that Chemical Leasing business models are based on Green Chemistry. However, Chemicals Leasing focuses less on the scientific or technological spheres and more on the business relationships between used and supplier of chemicals. He concludes that Chemical Leasing nevertheless can complement the objectives of Green and Sustainable Chemistry to reduce and ultimately eliminate the use of hazardous chemicals and to optimize production processes through a more environmentally sound design of chemical reactions.

The contribution of Moser et al. (2014a) is a first attempt to address the question to what extent Chemical Leasing business models can complement the implementation of Sustainable Chemistry in a more methodological manner. For this, they analyzed a series of pilot studies in order to respond to two distinct research questions. The first question that they have addressed was to understand whether the application of Chemical Leasing, in principle, can promote sustainability in comparison to an existing chemicals production and management system. The second question was to see which Chemical Leasing project type is the most promising in terms of sustainability. The authors have developed a methodology and criteria to evaluate the potential of Chemical Leasing to contribute to four basic goals of Sustainable Chemistry: optimization of resource efficiency; reduction of adverse effects on health and environment; increasing economic value and optimization of chemicals management; and safeguarding the overall sustainability taking into account the economic, ecologic and social dimensions. In this context, the authors conclude that five case studies contribute to Sustainable Chemistry with certainty. For three case studies, it was not possible to arrive at conclusions. This was mainly due to the lack of data on the impact of Chemical Leasing on the overall resource efficiency or the substitution of hazardous chemicals with lower risk chemicals. We concur with the authors that future projects need to address the assessment of sustainability criteria and whether the respective project is able improve sustainability after the introduction of Chemical Leasing.

Chemical Leasing and Corporate Social Responsibility

In a first attempt to understand which aspects of Corporate Social Responsibility (CSR) are implied in the implementation of Chemical Leasing, Moser et al. (2014b) analyzed two Chemical Leasing-related case studies with a view to identify key criteria that would allow understanding whether Chemical Leasing business models can be branded as a CSR initiative. The analysis was founded on a stakeholder-centric CSR theory, which defines stakeholders as a group of persons that have a legitimate interest in the activities of a company (Evan and Freeman 1988; Donaldson and Preston 1995; Freeman and Philips 2002).

This choice was founded on the understanding that chemical substances, on the one hand, have a vast potential to polarize such stakeholder groups of a company, such as workers or nearby communities. On the other hand, chemicals often constitute a significant cost factor (Schott 2008) and can potentially damage a company's reputation, if used inefficiently or released through accidents.

The authors come to the conclusion that, with the introduction of Chemical Leasing, the companies' occupational health and safety standards and the ability to protect human health and the environment from the adverse effects of the used chemicals could be improved. They argue that both Chemical Leasing case studies could be branded as a CSR initiative and that this would have a positive impact on stakeholders of the companies, such as workers or nearby communities.

Discussion

It is evident from these three specific examples that introduction of Chemical Leasing, in principle, contributes to the objectives of Cleaner Production, Sustainable Chemistry and CSR. Evidence from the two examples on Sustainable Chemistry and CSR is based on case studies spanning several sectors and countries and, in the case of the work on CSR, a smaller subset of two studies, one from an open and one from a closed-site application of chemicals. In this latter example, Moser et al. (2014b) concluded that a critical study of additional Chemical Leasing projects is necessary to arrive at more conclusive findings on the potential of Chemical Leasing to generate impact, for example, on working conditions. For this, the authors conclude that further work in this field would need to analyze the impact that the implementation of Chemical Leasing has on further primary and secondary stakeholder groups. Increasing the availability of quantitative data from Chemical Leasing projects would further increase the validity of further research in this field and may also allow analyzing the general perception of, for example, consumers or local communities towards the environmental and social performance of the company introducing Chemical Leasing.

As regard the work on Sustainable Chemistry, the analysis of a number of case studies by Moser et al. (2014a) clearly showed that introducing Chemical Leasing business models could be a valid means to increase the sustainability of existing chemicals production and management systems. A positive impact of Chemical Leasing was demonstrated for the type of chemicals used before and after the introduction of Chemical Leasing, the quantity and efficiency in which resources are used in the production processes, the waste and waste water volumes and the consumption of energy. The authors, however, noted that for some case studies, the suggested basic sustainability indicators have not been measured. While the authors claim that the uncertainty of whether these case studies promote Sustainable Chemistry cannot be addressed ex post, they assume that with the closing of data gaps, an increasing positive impact of introducing Chemical Leasing on the sustainability of chemicals' production and use could be demonstrated. They hence encourage future Chemical Leasing pilot studies to include measurements of the suggested sustainability criteria. This holds particularly true for broader studies that could focus on measuring the impact of Chemical Leasing on increasing sustainability in surrounding systems. As regard the refinement of the evaluation methodology, the authors suggest that weighing factors may be introduced to compare the relative importance of various sustainability criteria. Also, further sustainability criteria, such as the impact of Chemical Leasing on policy-making and the implementation of existing chemicals' legislation, can be introduced for future work in this field.

While the choice of the studies and their scope so far have been relevant, it must be noted that further work would need to be undertaken to validate these initial findings. This holds particularly true for the work on Chemical Leasing and CSR. With regard to the work on Cleaner Production, this work is based on the activities of UNIDO in this field in the past decades. The scope of these activities is global and has generated a sufficiently large information base and robust evidence to support the conclusions reached by the authors of these studies.

Conclusions and perspectives for future research

This review concludes with an analysis of the gaps in the current literature on Chemical Leasing that need attention in order to increase the understanding and applicability of this business model. Conclusions and recommendations for further research in the field of Chemical Leasing are based on the findings of this gaps analysis.

Gaps in the theoretical and practical understanding of Chemical Leasing business models

Literature in the past decade has provide convincing evidence of the economic and environmental benefits of implementing Chemical Leasing in various fields, such as environmental policy, Sustainable Chemistry or Cleaner Production. However, there are still certain gaps in the understanding on specific aspects of Chemical Leasing in theory and in praxis that have not been looked in detail so far.

A first identified gap is the lack of a more detailed analysis of the inhibiting factors to the successful implementation of Chemical Leasing. Joas and Schott (Jakl et al. 2004: chapter

4), Lozano et al. (2013, 2014), Plas (2008) and Beyer (2008b) provided an overview of such inhibiting factors. For example, existing trade structures often do not facilitate direct relationship between the manufacturer and the user of the chemicals. Also, the establishment of communication chains between the potential partners, investments in logistics and training activities, financial security in the case of economically weak partners, or use-specific liability aspects may incur in additional costs and thus discourage the implementation of Chemical Leasing. For the user, implementing Chemical Leasing may result in dependency owing to a closer contractual relationship with the supplier. Related to that, an increased dependency may also result in a reduced flexibility in case other suitable solutions become available from competing manufacturers. Also, the user may be fear intellectual property theft and industrial espionage due to the closer involvement of Chemical Leasing partner in its production. While these insights are useful, case studies on Chemical Leasing, at the practical level, often fall short of providing conclusions if at all and how these inhibiting factors can be addressed. At the theoretical level, there is a general lack of empirical evidence in the literature. For example, a more thorough understanding whether Chemical Leasing is only applicable to non-reactant chemicals that are indirectly used in processes would provide a solid foundation for the implementation of this model in the future. In this regard, there has been an attempt to define Grey Chemical Leasing for such cases. However, a more thorough empirical application of this is still pending. Gaps also exist in the understanding of the legal and regulatory frameworks of countries. Wittmann (2008) highlighted the Austrian situation, but a thorough analysis of the legal frameworks of other countries is yet to be done.

To summarize this analysis, we concur with Joas (2008) that gaps in the following four main areas still exist. First, the question of what are the right partners for Chemical Leasing and how these partners can be identified. Second, how to ensure confidence between all involved partners. Third, how to implement quality assurance measures in a cost-efficient and cost-effective manner. And, fourth, how to develop fair contracts that meet expectations of partners.

Although we still need to know much more about the theoretical and practical aspects of Chemical Leasing, this is not preventing the model from being successful. The following section highlights recommendations in key areas to fill the gaps identified in this subsection.

Recommendations for future research

In this section, further research to address these gaps, on both theoretical and practical aspects of Chemical Leasing, is proposed.

As regard the theoretical framework, future research needs to analyze the institutional settings and national circumstances that foster a shift from the traditional sale of chemicals to the implementation of Chemical Leasing business models.

Here, Ohl and Moser (2007) have analyzed two types of Chemical Leasing models to evaluate whether they support an effective management of environmental and public health risks of chemicals. While the first model foresaw a simple transfer of knowledge from the production to the user and differed the least from the traditional sales concept, the second model, instead, foresaw a more comprehensive shift of responsibility for the application of the chemicals to the producer and differed the most from the traditional sales concept. For both cases, Ohl and Moser have shown that both producer and user have an incentive to introduce Chemical Leasing. Further work is required to analyze Chemical Leasing models that either fall in the range between the two models analyzed by Ohl and Moser, which can be, for example, the Chemical Leasing model prevailing in practice as outlined by Jakl and Schwager, or that fall into the category of Grey Chemical Leasing (see Moser et al. 2014a). This work would also need to further investigate the limitations of the functional aspects of the chemicals of concern and the sizes of all involved partners as stated by Lozano et al. (2013) and possible solutions of how to overcome these shortcomings.

Still at the theoretical level, the environmental impact of Chemical Leasing should be further assessed. Here, Moser et al. (2014a) have provided a first attempt to demonstrate to what extent Chemical Leasing is a means to contribute to the objectives of Sustainable Chemistry. Assessing the impact of Chemical Leasing is particularly important, simply because many approaches exist that aim at protecting the environment from the adverse effects of chemicals. Policy-makers should be provided with data that allows them to decide which approach achieves the largest environmental impact. Closely related to this, further research is required to better understand the role of environmental policy in terms of safeguarding the proliferation of Chemical Leasing. Here, it will be important to analyze what kind of policies at the national, regional and international level could support the uptake of Chemical Leasing. This important task can be supported by the development of tools like quality assurance schemes or other instruments such as auditing or eco-labelling. Finally, it will be important to understand whether the concept of Chemical Leasing can easily be extended to other fields, such as energy consumption.

Regarding the practical aspects, Chemical Leasing is being implemented in all regions of the world, as shown in Table 3. Nonetheless, information at the country or even local level may provide further insights on how this business model can be disseminated more widely. Related to that, research needs to explore whether the geographic location of Chemical Leasing partners plays a role. This is particularly important since potential partners could be located too far from each other, which may create a disincentive for the introduction of Chemical Leasing. Moreover, a close cooperation and collaboration between the producer and the user is an important factor for the implementation of Chemical Leasing. The findings in literature confirm that Chemical Leasing has a vast potential to foster a more cooperative and collaborative environment for all involved partners. Notwithstanding these positive aspects, some authors have identified some problems that can arise with such a closer cooperation and collaboration. Lozano et al. (2014), for example, have pointed out that increased collaboration may, in turn, result in increased costs for coordination and information exchange or disputes over how economic gains are shared. More generally, Plas (2008) and Lozano et al. (2013) argue that a negative outcome of highly collaborative contractual arrangements can be that user and producer become overly dependent on each other. Lozano et al. (2013) pointed out that the user relinquishing control of key maintenance processes to the producer may result in increased vulnerability of the user and thus in increased costs to address these vulnerability issues. Since the above factors may be a barrier for the introduction of Chemical Leasing, further research is needed to identify and evaluate solutions that address these apparent shortcomings of a closer entanglement between the producer and the user.

From an economic standpoint, Lozano et al. (2013) argued that the function of the chemical is an important factor for the implementation of Chemical Leasing and claim that Chemical Leasing may only be applicable to non-reactant chemicals that are indirectly used in processes and that do not become a part of the final product. The authors also came to the conclusion that size matters: an excessive bargaining power of larger chemical suppliers may discourage smaller user companies to introduce Chemical Leasing; on the other hand, a too small user may, in turn, discourage the chemical supplier to introduce Chemical Leasing. There also has been a general agreement that the traditional units of consumption of auxiliary materials will be replaced with a unit-based price. It will be important to understand how the identification of measurements units as a basis for payment in Chemical Leasing can be streamlined and how the price should be set, so that both the user and supplier can achieve an adequate profit.

At the process level, research needs to address the question how the involved chemicals can be ecologically optimized in future. And since the working definition of Grey Chemical Leasing, as introduced in "Chemical Leasing business models as an innovative approach for managing the risks of chemicals" section, refers to the recovery rates of chemicals, it will also be important to better understand the recovery rates of chemicals in practice in the implementation of Chemical Leasing projects.

Conclusions

The introduction of Chemical Leasing business models in the past decade started in the beginning of the 2000s with some studies and pilot activities undertaken in Austria and Germany as well as through the Cleaner Production Programme of UNIDO at the international level. The findings of this first phase were reported in peer-reviewed journals, on dedicated websites or through international award programmes. This paper showed that the experiences gained in the first decade of work demonstrate that Chemical Leasing business models are a convincing alternative to the traditional concept of selling chemicals. The outcomes of this work, as analyzed in this paper, revealed that Chemical Leasing business models can, in fact, align the objectives of policy-makers and industry regarding the production and use of chemical substances. The findings in literature show that Chemical Leasing has a vast potential to increase the effective risk management of chemical substances by resolving undesired information asymmetries, shifting responsibility for applying and disposing of the chemical to the producer, and by fostering collaboration and cooperation among the provide and the user of chemicals. This, in turn, leads to an optimization of production processes and, accordingly, to a reduction in the consumption of chemicals and energy in such processes. Chemical Leasing also increases the environmental performance and the economic competitiveness through the introduction of best available technologies and best environmental practices. It thus creates a positive business environment in which companies can grow in competitive global markets. Recalling the key objectives of a modern environmental policy, it can be concluded that the implementation of Chemical Leasing convincingly contributes to the achievement of chemical policy objectives.

Second, Chemical Leasing business models can provide a significant contribution to the implementation of regional and global initiatives on the sound management of chemicals, such as the implementation of REACH, Cleaner Production or Sustainable Chemistry. While the choice and scope of the studies provided in the literature support such conclusion, further work needs to be undertaken to validate these initial findings at a broader geographic level. Such studies would also need to cover a wider range of industry sectors. This holds particularly true for the work on Chemical Leasing and CSR and the interrelation with the ongoing efforts to promote Sustainable Chemistry. For the latter, further case studies would need to measure additional sustainability criteria at a more aggregated level, with a particular view on those focusing on increasing sustainability at the national and regional levels.

Despite the limitations of Chemical Leasing presented in this paper, it is evident that these business models can provide a significant contribution to the plan of implementation of the WSSD, which aims to achieve, by 2020, that chemicals are used and produced in ways that lead to the minimization of significant adverse effects on human health and the environment, using transparent science-based risk assessment procedures and science-based risk management procedures, and taking into account the precautionary approach, as set out in principle 15 of the Rio Declaration on Environment and Development (WSSD 2002). Two planned research activities will provide results that allow a deeper understanding of the potential of benefits of introducing Chemical Leasing for the environmental and socio-economic spheres. First, the Organisation for Economic Co-operation and Development (OECD), in collaboration with the consultant company BIPRO and supported by the Austrian BMFLUW, is undertaking a study that focuses on key inhibiting factors for the implementation of Chemical Leasing business models. As an outcome, this study is expected to identify strategies to overcome those factors. Second, UNIDO is currently implementing a pilot study to evaluate and assess the global environmental benefits of Chemical Leasing business models. This study particularly focuses on the quantities of chemicals that could have been reduced with the implementation of Chemical Leasing so far and is the first comprehensive global study of this kind. These two studies, together with future applied and theoretical research, will shed additional light on the benefits of introducing Chemical Leasing business models.

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ARTICLE II

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RESEARCH ARTICLE

Chemical Leasing business models and corporate social responsibility

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Abstract Chemical Leasing is a service-oriented business model that shifts the focus from increasing sales volume of chemicals towards a value-added approach. Recent pilot projects have shown the economic benefits of introducing Chemical Leasing business models in a broad range of sectors. A decade after its introduction, the promotion of Chemical Leasing is still predominantly done by the public sector and international organizations. We show in this paper that awareness-raising activities to disseminate information on this innovative business model mainly focus on the economic benefits. We argue that selling Chemical Leasing business models solely on the grounds of economic and ecological considerations falls short of branding it as a corporate social responsibility initiative, which, for this paper, is defined as a stakeholder-oriented concept that extends beyond the organization's boundaries and is driven by an ethical understanding of the organization's responsibility for the impact of its business activities. For the analysis of Chemical Leasing business models, we introduce two case studies from the water purification and metal degreasing fields, focusing on employees and local communities as two specific stakeholder groups of the company introducing Chemical Leasing. The paper seeks to demonstrate that Chemical Leasing business models can be branded as a corporate social responsibility initiative by outlining the vast potential of Chemical Leasing to improve occupational health and safety and to strengthen the ability of companies to protect the environment from the adverse effects of the chemicals they apply.

Keywords Chemical Leasing · Chemical management · Corporate social responsibility · Resource efficiency · Process optimization · Working conditions · Environmental protection

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Introduction

With an ever-growing number of chemicals entering the global market each year, chemical policy in the European Union is focusing on reducing the exposure of human beings and the environment to hazardous chemicals.

Chemical Leasing is a service-oriented business model that helps to achieve the objectives of policy makers to reduce the risks emanating from the production and use of chemical substances. Chemical Leasing has been applied in various cases at the national and global levels and has proven to be both an economically and ecologically viable alternative to the traditional concept of selling chemicals.

In this paper, we will outline the different arguments used to promote the introduction of Chemical Leasing and show that those arguments focus predominantly on the economic and environmental aspects of this business model. We will also show that after a decade, it is still mainly the public sector and international organizations that promote the introduction of Chemical Leasing.

We argue in this paper that selling Chemical Leasing business models solely on the grounds of economic and environmental considerations falls short of branding it as a corporate social responsibility (CSR) initiative. We also argue that in order to introduce this business more widely, it is necessary to bolster its promotion by the manufacturing industry itself.

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The paper is structured as follows. "The evolution of risk management of chemicals—the example of Chemical Leasing as a new and innovative market-based approach" section describes the evolution and the limits of policy approaches for managing the risks of chemicals at the national, regional and international levels, which is followed by a description of Chemicals Leasing business models, a market-based approach to manage the risks of chemicals, in the section "Market-based approaches to manage the risks of chemicals". The section "Promoting the introduction of Chemical Leasing" outlines strategies for promoting and branding these business models. The section "Chemical Leasing and corporate social responsibility" puts Chemical Leasing in the context of CSR. This section includes two case studies on CSR and Chemical Leasing, which will be analyzed in the section "Analysis of the case studies" with a view to demonstrate that branding Chemical Leasing as a CSR initiative is justified and will provide companies in the chemical industry with a competitive advantage in the global marketplace. We conclude in the section "Conclusions and outlook" with a summary of the findings of the analysis of the case studies and an outlook for further work in this field.

The evolution of risk management of chemicals—the example of Chemical Leasing as a new and innovative market-based approach

To achieve the policy goal of producing and using chemicals in an environmentally sound manner, policy makers in the past decade adopted substance-specific legislation and treaties to address specific environmental problems at the regional and international levels, in particular to reduce the risks that regulated chemicals pose to human health and the environment.

At the regional level, the European Union Regulation on Chemicals and their Safe Use (EC 1907/2006) entered into force in June 2007. The ordinance on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) is the most important legislation for chemicals in Europe and of particular importance to this publication. REACH proposes a new way and intensity of communication along the supply chain and seeks to improve the protection of human health and the environment through the better and earlier identification of the properties of chemical substances.

At the international level, the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992 (UNCED 1992), for example, gave impetus for the adoption of two international treaties: the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade and the Stockholm Convention on Persistent Organic Pollutants, both of which entered into force in 2004. The main objective of the Stockholm Convention, for example, is to eliminate or restrict the production and use of a group of 22 particularly dangerous chemical substances (Stockholm 2013).

While the enforcement of the above legislation and international treaties foresaw a reduction of production and use of regulated chemicals or, in other cases, their elimination, the predominant business model used by the chemical industry in the past decades has been what can be referred to as a traditional sales concept, in which the economic success of a chemical producer was linked to the overall volume of chemicals sold to the user (Jakl et al. 2004, p. 3). Since an inefficient use of the chemical is directly increasing the revenues of the producer, there was no incentive to change this model (Ohl and Moser 2007).

The aim of policy makers to reduce the exposure of human beings and the environment to hazardous chemicals negatively affected the traditional sales concept of chemical industry in such that it sought to reduce the use of chemicals as well as their turnover (Jakl 2008). As is apparent, the objectives of chemical policy and chemical industry, particularly in quantitative terms relating to the reduction of the production and use of chemicals, were all but aligned.

Market-based approaches to manage the risks of chemicals

With a view to better align the objectives of chemical policy and industry, governments in the past decade promoted the introduction of market-based approaches building on the principles of sustainable development.

This approach was founded on the understanding that chemical policy has to pursue both an ecological as well as an economic objective in order to enable companies to succeed in global competition (Jakl 2008).

Focusing on the corporate level stemmed from a growing awareness of decision-makers in the public sector of the important role that companies play in ecologically sustainable development. While governments issue regulations and policies to address economic activities that adversely affect the environment, many of these activities still occur within the boundaries of companies. Shrivastava (1995) suggested that companies should complement such government-led approaches with voluntary activities, since they are not only the key actors to achieve economic growth but also have the financial and technological means to put into practice sustainable practices for managing the materials used in the production of goods (Schmidheiny 1992; Welford and Gouldson 1993).

Chemicals, according to Stoughton and Votta (2003), are ubiquitous in the processes of companies that manufacture products. They can be directly used in production process, which means that they become an integral part of the later product. Chemicals can also be indirectly used in production processes to perform functions such as lubrication, cooling, catalysis, solvation, or cleaning. Many chemicals possess characteristics, such as toxicity, flammability and acidity, which necessitate the implementation of appropriate management systems (Stoughton and Votta 2003). Accordingly, companies need to take measures to properly monitor, track, report, transport, store, handle and dispose the chemicals and related waste they use in order to comply with local, national or international legislation. Chemical Leasing business models are a promising market-based approach to address these management needs and, at the same time, to align the objectives at chemical policy and corporate levels.

The introduction of Chemical Leasing business models can be of particular interest for companies that use chemicals in their manufacturing processes indirectly, which implies that the application of chemicals may not be part of their core competency. Ohl and Moser (2007) stated that under these circumstances, the costs of collecting the necessary information on the chemicals used in the manufacturing process could be prohibitively high. Chemical suppliers, in turn, generally have more knowledge on the specific characteristics of the chemical they sell to their customers, which may also extend to the efficient application of the chemical in manufacturing processes.

With the introduction of Chemical Leasing, the company offers a service related to the chemical, instead of the chemical itself. The service can include, for example, a knowledge transfer of characteristics of the chemical or information of its efficient use. The traditional concept of selling chemicals, in turn, provides no incentive for such a knowledge transfer, since an overconsumption due to inefficient use of the chemical directly increases the revenues of the producer.

Since Chemical Leasing results in a general closer cooperation between producers and users of chemicals (Ohl and Moser 2007, 2008), it has a vast potential to optimize material flows and overcome the ineffective use and overconsumption of chemicals (Schwager and Moser 2006).

These promising findings of the recent literature have largely been confirmed in praxis by global Chemical Leasing programme of United Nations Industrial Development Organization (UNIDO), which has been launched in 2005. The programme is implemented at the national level in close cooperation with UNIDO's National Cleaner Production Centres (NCPCs). These centres are partners of the Resource Efficient and Cleaner Production (RECP) network of the United Nations Environment Programme (UNEP) and UNIDO, which presently includes nearly 50 NCPCs and programmes globally (UNIDO 2011). Chemical Leasing business models have also been included in policy planning documents and strategic plans of countries (Colombia 2011).

With the introduction of Chemical Leasing, the economic success of the producer no longer depends on the volume of chemicals sold to the user but on a service that is connected with the application of the chemical.

The UNIDO is one of the key players in the implementation of Chemical Leasing. UNIDO's definition of Chemical Leasing as outlined below provides a useful basis for our subsequent analysis of these business models in the context of CSR.

Definition of Chemical Leasing

> "Chemical Leasing is a service-oriented business model that shifts the focus from increasing sales volume of chemicals, toward a value-added approach. The producer mainly sells the functions performed by the chemical, and functional units are the main basis for payment.[1] Within chemical leasing business models, the responsibility of the producer and service provider is extended and may include the management of the entire life cycle. Chemical leasing strives for a win-win situation. It aims to increase the efficient use of chemicals while reducing the risks of chemicals, and protecting human health. It improves the economic and environmental performance of participating companies, and enhances their access to new markets. Key elements of successful chemical leasing business models are proper benefit sharing, high-quality standards and mutual trust between participating companies (UNIDO 2011)".

Since Chemical Leasing business models target a closer collaboration between suppliers and users of chemicals, it also can be seen as an effective and efficient contribution to the implementation of REACH (Ohl and Moser 2007). At the same time, the ongoing implementation of REACH itself is an important driver for the introduction of Chemical Leasing business models in the European Union. REACH requires authorization for certain substances of very high concern, and the authorization dossier prepared by an applicant needs to prove a safe use of the chemical. Suppliers increasingly see Chemical Leasing as a means to demonstrate a commitment towards such a safe use of chemicals. As a consequence, such suppliers sell certain critical substances as a package deal, which hinges on the application of Chemical Leasing.

Promoting the introduction of Chemical Leasing

The exposure to globalized markets forces companies selling chemicals to continuously innovate and increase the efficiency and sustainability of their operations (Joas 2008).

Chemical Leasing business models are being introduced in this highly competitive global chemical market and are a convincing approach to achieve the objective of sustainable

[1] Functions performed by a chemical might include: number of pieces cleaned; amount of area coated, etc.

material management. At the same time, they represent an innovative and competitive alternative to the traditional business model of selling chemicals (Jakl2008).

Key actors for the introduction of Chemical Leasing have been the Austrian government (Jakl et al. 2004; Perthen-Palmisano and Jakl 2005) and UNIDO through their cleaner production programme (Schwager 2008).

With the aim to disseminate information on Chemical Leasing business models more widely, a series of outreach activities have been undertaken. This included the creation of dedicated websites[2] and activities such as awards[3] and capacity building programmes.

The implementation of Chemical Leasing projects in the past years have caused reflections on how this business model could be even spread further and on how knowledge about Chemical Leasing applications already existing on a global scale can be acquired and disseminated to a broader audience. For this purpose, the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW) and UNIDO launched in September 2009 the Global Chemical Leasing Award. This award, which is the first of its kind, seeks to contribute to the "greening" of industry and promote safer chemical management. The first award ceremony took place on March 1, 2010 in Prague within the frame of the International Conference on International Chemical Control Legislation and Trade Aspects.[4] The award in 2012 was jointly organized by UNIDO, BMLFUW and the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). The award ceremony took place in June 2012 within the World Exhibition Congress on Chemical Engineering, Environmental Protection and Biotechnology in Frankfurt, Germany.[5] A third Global Chemical Leasing Award is planned for 2014, which intends to further enhance the global visibility of Chemical Leasing, acknowledges best practices and inspires companies and individuals around the globe to apply the Chemical Leasing service-based business concept. The Award 2014 is sponsored and supported by UNIDO, BMLFUW, BMUB, the Swiss State Secretariat for Economic Affairs and the Swiss Federal Office for the Environment. It will take place from 11 to 13 November in Basel, Switzerland, during the International Conference and Exhibition on Sustainable Chemistry and Engineering.[6]

Further dissemination activities comprise training of multipliers, for example, through the RECP programme of the UNEP and UNIDO. The training activities also focused directly at companies involved in the production and use of chemicals. The main target group for the training comprised distributors acting as intermediate between manufacturer and user.[7]

While the promotion and branding of this business model has been predominantly undertaken by those key actors, there are few examples in which companies that have introduced Chemical Leasing business models more actively promote their introduction.

The Dow Chemical Company, for example, is one of the few private sector companies that brand the introduction of Chemical Leasing as a shift of paradigm from selling a volume of a chemical to the volume of cleaned metal. Chemical Leasing is described as "an innovative system…whereby performance rather than chemicals and service are sold can result in massive savings and increased efficiencies". It also "creates a situation in which the chemical supplier and its customers share the same objective: maximizing the efficiency of the cleaning process and reducing the solvent expenditure" (Dow Chemical Company 2013). The company Akzo Nobel, in its 2007 sustainability report, describes a Chemical Leasing project in the field of powder coating undertaken in Egypt (UNIDO 2011) as a "win-win situation for Akzo Nobel, customer and environment" (Akzo Nobel 2007).

We conclude that currently the introduction of Chemical Leasing is mainly promoted by the public sector and international organizations and argue that this group of key actors for the promotion of Chemical Leasing could be expanded to include the private sector in a more active manner, as it is the case now.

Beyer (2008) claims that companies in chemical industry first and foremost look at the economic considerations when taking decision on aligning their business models to the changing global environment in which they operate. In-line with this assumption, companies that more actively promote the introduction of Chemical Leasing, such as Akzo Nobel (2007) and Dow Chemical Company (2013), predominantly highlight the potential to save costs and apply resources more efficiently.

Crone (1986) claims that companies selling or applying chemicals often face criticism from various groups in society, such as consumers, local communities, non-governmental organizations (NGOs) or employees, which originates from a general negative sentiment that the broader public has towards chemicals. It may therefore often be difficult for

[2] See http://www.chemicalleasing.com

[3] The award is open to organizations, companies and individuals worldwide and comprises four categories (case studies, scientific publications, consulting services and public relation activities). Various impact factors are taken into consideration such as innovation, technical applicability and sustainability, which also includes the aspects of resource efficiency, precaution in terms choice of hazardous substances, effective chemical management as well as social implications. For more information see http://www.unido.org/what-we-do/environment/resource-efficient-and-low-carbon-industrial-production/cp/awards/global-chemical-leasing-award.html

[4] http://chemcon.net/europe/chemcon_2010/chemcon_2010 cz.shtml

[5] http://www.achema.de/en.html

[6] http://ecochemex.com/2014-conference/

[7] http://www.unep.fr/scp/cp/unep_unido_prog.htm

companies to successfully market either their business of selling chemicals or products in which chemicals are applied, since much energy may be needed to overcome the general scepticism of society towards chemical substances.

This supports the above findings that companies themselves promote the introduction of Chemical Leasing only sporadically and, if so, predominantly on grounds of cost-saving and resource efficiency considerations. We argue that branding Chemical Leasing as a CSR initiative will support companies in their marketing activities and provide them with a means to increase acceptance by the broader public of the legitimacy of the company.

We will demonstrate in the following section that the introduction Chemical Leasing encompasses a variety of CSR-related measures and, therefore, render benefits beyond the economic sphere.

Chemical Leasing and corporate social responsibility

To understand which aspects of CSR are implied in the implementation of Chemical Leasing, we will first define CSR in broader terms and outline criteria used in literature that would highlight a successful implementation of CSR in companies. Two Chemical Leasing-related case studies will be subsequently analyzed to identify to what extent those criteria are met.

The field of CSR encompasses a broad array of different theories and approaches. The concept evolved from a perception that a company's main objective is to provide services and goods to society (Chamberlain 1973; Friedman 1968; Friedman 1970) towards the perception that a company is to contributing to the general welfare of society (Carrol 1979; Steiner and Steiner 1997; Wood 1991). This view was further amplified by the changing public perception towards the social responsibility of companies, which were to go beyond the economic interests of the company and its legal obligations. This, together with the occurrence of social movements and NGOs (Doh and Guay 2006), were the reasons why some scholars began to see a company's relationship with society, in the essence, as a relationship with its stakeholders (Clarkson 1995; Smith 2003; Maignan and Ferrell 2004; Ingenbleek et al. 2007). Freeman in 1984 even went as far as stating that "managers bear a fiduciary relationship to stakeholders" as opposed to its shareholders, which was a well-accepted view in that time (Freeman 1984, xx).

This view of a company's responsibility towards society was coined as "stakeholder theory" (Evan and Freeman 1988; Bowie 1991; Donaldson and Preston 1995; Freeman and Philips 2002). It defined stakeholders as a group of persons that have a legitimate interest in the activities of a company, including suppliers, customers, employees or the local community. According to this "normative" CSR approach, companies are to take into account the views of all their stakeholders. This was seen as beneficial, since the views of all stakeholders are considered to have an intrinsic value, each of which should be considered individually and not because of their potential impact on shareholders (Donaldson and Preston 1995).

We believe that this stakeholder-centric approach is a CSR theory that merits attention in the context of this paper for the following reasons. First, the implementation of Chemical Leasing involves chemical substances, which are either non-toxic but perceived with a negative connotation or are actually hazardous. In other words, chemical substances have a vast potential to polarize various stakeholders of companies producing or applying them. And, second, the negative impact of inefficient use or accidents of chemicals on the stakeholders of the company can often be costly and damaging to the company's reputation. In such a demanding and risk-prone environment, a CSR approach that seeks to foster relationships and takes into account the views of all its stakeholders seems to us particularly suitable fundament for the further analysis of Chemical Leasing business models.

For this paper, we define CSR accordingly "as a stakeholder-oriented concept that extends beyond the organization's boundaries and is driven by an ethical understanding of the organization's responsibility for the impact of its business activities, thus, seeking in return society's acceptance of the legitimacy of the organization" (Maon et al. 2008, p. 72).

Stakeholders, according to Clarkson (1995, p. 106), are defined as "persons or groups that have, or claim, ownership, rights, or interests in a corporation and its activities, past, present, or future. Such claimed rights or interests are the result of transactions with, or actions taken by, the corporation and may be legal or moral, individual or collective". Clarkson further distinguishes between primary and secondary stakeholder groups. The former represents a group of stakeholders that is of crucial importance for the survival of the company and typically includes employees, customers, suppliers and the broader public such as the government or communities that provide infrastructures and markets. The latter represents a group that is not essential for the survival of the company but nevertheless is able to either influence or affect or be influenced or affected themselves by the company (Clarkson 1995).

In the subsequent analysis of Chemical Leasing business models, we will focus on a specific subset of stakeholder groups of the company introducing Chemical Leasing: employees, representing a primary stakeholder group, and local communities, representing a secondary stakeholder group.

Employees, on one side, handle the chemicals that the company applies and therefore are potentially at risk if exposed to such chemicals. An integral aspect of the field of occupational health and safety is the protection of workers from workplace-related risks (Erikson 1996; Reese 2003; Montero et al. 2009).

We assume in the context of this analysis that applying chemicals poses a certain risk to workers and that this risk is positively correlated with the acute and long-term adverse effects of the involved chemicals to human health. A reduction of the exposure of employees to these chemicals will therefore decrease workplace-related risks.

In-line with the stakeholder theory, we further assume that the employees of the company introducing Chemical Leasing value an increase of the occupational health and safety standards at their workplace.

The criterion we will use in the ensuing analysis is the level of the occupational health and safety within the company. We will measure the extent that this criterion is met by evaluating exposure rates of workers to chemicals of concern before and after the introduction of Chemical Leasing.

Local communities in the geographical vicinity of the company, on the other side, are a group of stakeholders that are immediately affected by the inefficient use of chemicals or chemical-related accidents.

We assume in the context of this analysis that applying chemicals poses a certain risk that those chemicals are released into the environment and that this risk is positively correlated with the acute and long-term effects of the involved chemicals to human health and the environment. A reduction of the releases of these chemicals into the environment will therefore decrease risks to the health of local communities as well as the degradation of ecosystems. In-line with the stakeholder theory, we further assume that the local communities will value measures to protect human health and the environment from the adverse effects of chemicals.

The criterion we will use in the ensuing analysis is the ability of the company to protect the environment from the adverse effects of the chemicals it applies. We will measure the extent that this criterion is met by evaluating the level of releases of involved chemicals into the environment before and after the introduction of Chemical Leasing.

The following two case studies outlining the introduction of Chemical Leasing in two different sectors: The oil and gas as well as the surface cleaning sector will provide the basis for the subsequent analysis.

Case study 1: water purification and oil dehydration in the oil and gas sectors

Oil dehydration and water treatment processes involve many variables regarding the quantity, quality and efficiency of the chemicals used which also represent an important part of the operation costs of a company (UNIDO 2011). Proper monitoring is essential to avoid negative environmental impact and accidents caused by the waste water.

Usually, the following parameters are measured to define the efficiency of the process: water content in oil—if too high, customers may not accept the oil; oil content in wastewater and suspended solids in waste water—if too high, environmental authorities may impose fines or even close the oil field.

Colombia has seen an increase in oil production in recent years after a period of steady decline. The Colombian government has created a series of regulatory reforms to attract foreign investors. In 2009, the country produced an estimated 680,000 barrels per day of oil up from 600,000 barrels per day in 2008. With oil consumption reaching an estimated 282,000 barrels per day in 2008, Colombia exports about half of its oil production, with much of it going to the USA.

Since 2006, a Columbian oil company, Ecopetrol S.A.,[8] was looking for new strategies to not only lower costs but also consider the total economic balance of its crude oil drilling and water treatment operations. Acknowledging the potential environmental and economic benefits of implementing best practices in the chemical process, in 2008, Ecopetrol recognized the Chemical Leasing business model as the most suitable strategy. The Chemical Leasing project was developed together with a supplier of Ecopetrol S.A., Nalco de Colombia Ltda.,[9] and implemented at the Castilla oil field in Colombia, with the assistance of UNIDO's NCPC in Colombia.

Involved chemicals

The involved chemicals include emulsion breakers, antifoam agents, inverse breakers and water clarifiers.

Situation before the introduction of Chemical Leasing

The processes to dehydrate the oil and to treat the respective wastewater by means of the involved chemicals were planned and implemented by Ecopetrol before the introduction of Chemical Leasing. This included the on-site storage of all concerned chemicals, their on-site transport from the storage to the cleaning area and their application in the water treatment process.

The efficiency of the processes of Ecopetrol to dehydrate the oil and to treat the respective wastewater was generally low which resulted in a high consumption of the involved chemicals. The low efficiency also resulted in the increased risks of workers on-site at the cleaning area to be exposed to the chemicals through improper handling at any of these steps in the water treatment process. This also included an increased

[8] Ecopetrol S.A. is the main producer of petrol in Colombia. It ranks among the top 40 oil companies in the world and among the five largest oil companies in Latin America. Ecopetrol exploits hydrocarbon extraction fields throughout Colombia and operates two refineries and a pipeline network of 8,500 km (http://www.ecopetrol.com.co/especiales/Reporte%20de%20Sostenibilidad%20inges %202010/b_responsabilidad_en_la_cadena_01.html).

[9] Nalco de Colombia Ltda. (chemical supplier), is a company involved in water treatment and process improvement applications, providing services, chemicals and equipment to industrial and institutional customers.

risk of environmental contaminations due to spillages through improper handling, on-site storage and on-site transport. This included also risks for population living in the vicinity of the facility, since the treated water is reintroduced in water systems, which are used as a source for drinking water.

There was no incentive for the supplier—Nalco—to introduce measures that would result in an increase in efficiency of the processes to avoid environmental contamination or reduction of the consumption of chemicals, as this would have directly affected its earnings. Moreover, Ecopetrol faced high storage and transport costs for all involved chemicals. The total energy consumption per year amounted to approximately 3.400 MWh, of which approximately 50 MWh resulted from direct electricity consumption and approximately 3.350 MWh indirectly from the production of chemicals. The basis for payment between Ecopetrol and Nalco was US dollar per gallons or kilograms of chemicals purchased.

Situation after the introduction of Chemical Leasing

With the introduction of Chemical Leasing, the unit of payment changed from US dollar per gallons or kilograms of chemicals purchased to US dollar per kilo barrels of oil of specified quality. With the implementation of Chemical Leasing, Nalco continued to supply the chemicals but now worked with Ecopetrol to optimize the processes in dehydrating the oil and to treat the respective wastewater on-site at the cleaning area. Given the unit price being kilo barrels of oil of specified quality, Nalco had a clear incentive to make all efforts to reduce the amount of chemicals used in the processes and lost in spillages and improper handling. Nalco made use of his core competence and information on the properties of the chemicals and their efficient application in the optimization of the processes. This resulted in a decreased mass flow of all concerned chemicals. With a general optimization of processes, the amount of oil and grease used in the cooling towers could be decreased. Since, Nalco was closely involved in the operations to dehydrate the oil and to treat the respective wastewater with the chemicals, which included on-site storage and transport as well as the actual application of the chemicals in the process. Through the implementation of this cooperative business model, Ecopetrol was able to reduce the risk of workers' exposure to chemicals on-site at the cleaning area as well as the risk of environmental contaminations through improper handling, storage and transport. In addition, more oil could be recovered in the stabilization pools. The above measures resulted in lower maintenance costs for pools and cooling towers. Costs of the treatment process could be reduced by almost 20 %. Moreover, the amount of drums used for the transport and storage of the chemicals could be reduced from 4,900 to 3,500.

Figure 1 outlines the quantification of benefits of introducing Chemical Leasing in terms of consumption of involved chemicals. As is apparent from the diagram, the consumption of emulsion breaker, antifoam agents, the inverse breaker and water clarifier could be reduced by approximately 120 t per year with the introduction of Chemical Leasing.

The total financial savings for Nalco amounted to US$164,630 in 2008 and US$249,418 in 2009. Financial savings for Ecopetrol amounted to US$1,800,000 in 2008–2009.

As outlined in Fig. 1, the direct environmental benefits included a reduction in polymer consumption and fewer polymer residues in the stabilization pools and treated water. Overall, under Chemical Leasing, more oil and water could be treated while the consumption of involved chemicals was reduced and less solid waste generated.

As per the energy consumption, the direct energy consumption of approximately 50 MWh remained the same with the introduction of Chemical Leasing. However, the indirect energy consumption of 500 MWh for producing 120 t of chemicals, which now are not required anymore under Chemical Leasing, could be saved. This resulted in a reduction of energy consumption by 15 %.

At the same time, the introduction of Chemical Leasing reduced the environmental impact of treated water and resulted in an increased quality of drinking water for the population nearby the facility (see Fig. 1). In addition, there are fewer subproducts in the chemical production process due to a new methodology used by Nalco.

The social benefits included the creation of five new jobs in laboratories and a general reduction of risks through an increased efficiency of the processes. The long-term commercial relationship between Ecopetrol and Nalco further encouraged continuous improvement of the processes.

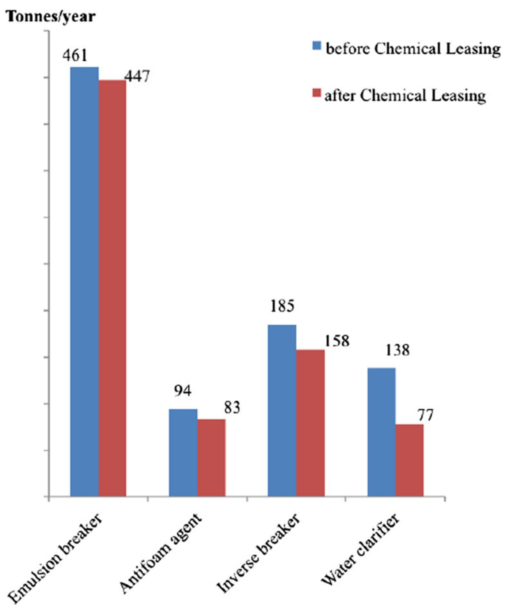

Fig. 1 Quantification of benefits of introducing Chemical Leasing—reduction of chemical consumption (tonnes per year)

Case study 2: industrial degreasing processes with chlorinated organic solvents

The second case study involves solutions for industrial surface cleaning with organic solvents (Erbel 2008; Jakl 2011). The surfaces to be cleaned in the context of this study are metal parts, produced by the company Automobiltechnik Blau, a daughter company of MAGNA STEYR, whose main clients are car manufacturers at the global level. The core competence of Automobiltechnik Blau is the forming of metal parts. Its main products are filling systems, like caps of fuel and oil tanks that once formed, need to be degreased before the next step in the production process.

The involved partners for this Chemical Leasing case study include the company SAFECHEM Europe GmbH, a global business unit of The Dow Chemical Company. SAFECHEM since its foundation has been focusing on providing sustainable solutions for industrial surface cleaning with solvents, following the cradle to cradle philosophy.

The other partner involved in this study is the company PERO AG Königsbrunn and its daughter company Pero Innovative Services, a manufacturer of high-performance equipment for solvent-cleaning processes. For the case study, Pero provided the Chemical Leasing service, including the cleaning machine as well as peripheral devices necessary for the supply, reconditioning, recovery of chemicals and maintenance of the equipment. The equipment was engineered specifically for this case study based on the principle of cost reduction with regard to chemical consumption, supply of spare parts and service. The solvent and stabilizers were adapted to the specific cleaning needs of Automobiltechnik Blau. The implementation of these measures ensured an optimal adaptation to the desired cleaning process and the minimization of costs during the complete life cycle of the equipment.

Involved chemicals

The involved chemicals included chlorinated organic solvents and stabilizers.

Situation before the introduction of Chemical Leasing

Before the introduction of Chemical Leasing, Automobiltechnik Blau was entirely responsible for degreasing its metal parts. Since the degreasing process is not part of the core competency of the company and given that the degreasing part is one of many steps in the overall production process, optimizing the use of solvent and installing better-performing equipment was not considered an economically viable solution for the company. The degreasing process before the implementation of Chemical Leasing was undertaken in a semi-open process (second generation of degreasing machinery) with non-up-to-date equipment, which resulted in a considerable risk of worker to be exposed to the solvents. The chemical solvent provider, on the other side, was interested in a high turnover of solvents, as this was directly correlated with an increase of its revenues. There was no incentive to foster recycling of solvents, which would have meant a lower turnover of solvents.

Situation after the introduction of Chemical Leasing

With the introduction of Chemical Leasing, the unit of payment changed from euros per litre of solvent purchased to euros per cleaned metal part.

The specific model set-up for this case study included leasing of latest technology equipment and process operation. SAFECHEM is acting as the chemical product and know-how supplier providing the cleaning solvent in the closed loop system, technology and know-how to monitor and readjust the solvent quality, training of partners and clients and provisions on safe waste take-back and waste management. The use of a closed loop system from the fifth generation of degreasing machines considerably reduced the risks of works being exposed to the chemicals of concern by a factor of over 10. Pero provided the latest technology cleaning machine and the know-how to run the equipment in an optimum way. Pero Innovative Services finally is running the cleaning process for the client, based on the combined know-how of SAFECHEM and Pero. Pricing unit is the number of parts cleaned with different unit prices for different parts according to their cleaning complexity.

Within 4 years, in which the case study has been running, besides the environmental benefits, it has demonstrated to be able to generate the cost savings needed to be economically beneficial for all participants. Solvent emission reduction is well over 90 %, the solvent consumption was reduced by 72 % and the need for stabilizers by over 55 %. In addition to that, a reduction in energy consumption of 50 % could be achieved, which contributed to a major part of the cost savings realized during the implantation of this case study Fig. 2.

These high reduction rates were possible because latest technology equipment is provided to the lessee, and the process is fully run by a lessor partner. For cases, where the equipment leasing or process operation is not part of the Chemical Leasing model, lower solvent consumption savings (>50 %) are projected.

Beside these short-term benefits, a long-term benefit, judged very important by SAFECHEM, is to make solvents sustainable and to assure their long-term availability. This not only benefits clients by giving them assurance to achieve the quality required for the continuous improvement of their products. It also benefits the chemical producer and supplier by allowing him to achieve a high value with his products, although they are used in minimized quantities.

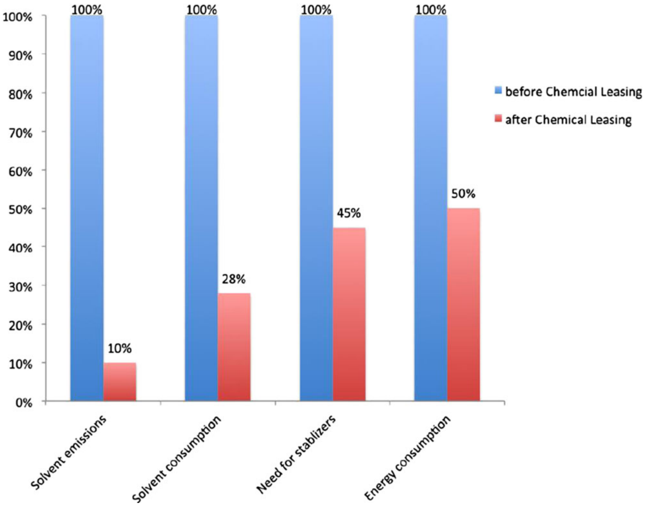

Fig. 2 Quantification of benefits of introducing Chemical Leasing—reduction of chemical and energy consumption (percent over 4 years)

Analysis of the case studies

With the subsequent analysis of the two case studies, we seek to demonstrate that branding Chemical Leasing as a CSR initiative is justified and will provide companies in chemicals industry with a competitive advantage.

Our assessment of the extent to which the two case studies have met the criteria will guide the conclusion as to whether it is justified that companies introducing Chemical Leasing business model brand this business approach as a CSR initiative.

As outlined above, we will use in the ensuing analysis as the first criterion the level of the occupational health and safety within the company. The extent that this criterion is met will be measured by evaluating exposure rates of workers to chemicals of concern before and after the introduction of Chemical Leasing. The second criterion we will use is the ability of the company to protect the environment from the adverse effects of the chemicals it applies. The extent that this criterion is met will be measured by evaluating the level of releases of involved chemicals into the environment before and after the introduction of Chemical Leasing.

While it is evident that focusing on a subset of two specific stakeholder groups has certain limitations, we contend that our choice to cover one primary and one secondary stakeholder group allows us to arrive at valid conclusions. On one side, our analysis is the first step to demonstrate that Chemical Leasing business models can, in principle, be branded as CSR initiative. On the other side, we assume that a positive effect of the introduction of Chemical Leasing on these two stakeholder groups will, in the worst case, have no negative and, in the best case, positive effects on other stakeholder groups not covered by this analysis.

Analysis of case study 1: water purification and oil dehydration in the oil and gas sectors

With regard to the first case study, the involved chemicals include emulsion breaker, antifoam agents, inverse breaker and water clarifier. All applied chemicals show low toxicity levels, both for humans and ecosystems. Most of these chemicals have surface-active properties. Since they partition to oil or gas rather than in water, they normally can be recovered during the production process (Scholten et al. 2000). However, their overconsumption, as it has been the case before the introduction of Chemical Leasing, resulted in elevated levels of these chemicals in produced water. This water has been as per the regular process released into the environment. Releasing such produced water into nearby water systems resulted in a potential impact of traces of such substances on ecosystems and local communities. The potential impact on the latter was of particular relevance, as produced water is being released into waters systems serving as a source of drinking water for nearby communities.

With the introduction of Chemical Leasing, the consumption of chemicals could be reduced by a total 120 t per year, through the optimization of the processes in which the chemicals are applied to purify the water. Although the involved chemicals show low levels of human and ecotoxicity, we argue that the introduced measures are suitable to decrease the health risks of workers. The chemicals in the purification process were applied to the produced water, which typically consists of dissolved and dispersed oil compounds; dissolved formation minerals; production chemical compounds; production solids, including formation solids, corrosion and scale products, bacteria, waxes and asphaltenes; and dissolved gases. Produced water is usually treated as a waste product from oil field operations and either be disposed of or treated for reuse and recycling (Fakhru'l-Razi et al. 2009).

For this case study, the produced water is treated with chemicals for reuse and recycling. Before Chemical Leasing, the chemicals in the water purification process were applied directly on-site by employees of Ecopetrol. The workers were also responsible for on-site transport, storage and application. With the introduction of Chemical Leasing, the amount of chemicals used and stored on-site could be decreased thanks to a closer involvement of Nalco, the chemicals' supplier, in the processes. The optimized processes, in turn, gave rise to a reduced exposure of workers to those chemicals in storage sites, during on-site transport and during the application of the chemicals. As a result, we conclude that workers are less exposed to chemicals used in the water purification process with the introduction of Chemical Leasing.

Through the reduced consumption, the overall release of chemicals into the environment, which were discharged into water systems, could also be reduced. This, at the same time, reduced the risks of environmental degradation of nearby ecosystems as well as the health risks of local communities, as a release reduction is suggested to positively impact drinking water quality. The reduction of indirect energy consumption of 500 MWh for producing 120 t of chemicals constitutes another positive environmental impact of introducing Chemical Leasing.

Based on the findings of the case study, we argue that the introduction of Chemical Leasing improved occupational health and safety standards through a reduced exposure of workers to the chemicals used in the processes to purify water. It also strengthened the ability of the company to protect human health and the environment from the adverse effects of the chemicals it applies through a significant reduction of the amount of chemicals released into the environment thus improving the quality of drinking water for nearby communities.

Analysis of case study 2: industrial degreasing processes with chlorinated organic solvents

With regard to the second case study, the use of chlorinated organic solvent in degreasing process poses certain risks to employees handling the machines and overseeing the clearing process.

Although the carcinogenicity and toxicity of these substances have been controversially discussed in literature, the exposure to these substances is likely causing adverse health effects to the central nervous and reproductive systems, liver, and kidneys (Ramlow 1995; Norman and Boggs 1996; Wartenberg and Scott 2002; 2001a; 2001b; Wartenberg and Scott 2002; Norman 2005; Sass et al. 2005; Boffetta et al. 2005; Ruder 2006).

With the introduction of Chemical Leasing, the machinery to degrease the metal parts has been changed from a semi-open system of the second generation to a closed-loop system of the fifth generation. As a result, workplace-related emissions of chlorinated organic solvents could be reduced by over 90 %. This could have been achieved by introducing state-of-the-art equipment and optimized processes for the degreasing of metal parts, which were tailored to the needs of the metal-producing company. The emission reduction, in turn, resulted in a significantly reduction of the exposure of workers to chlorinated organic components during the degreasing process. Given the high toxicity and carcinogenicity of the involved chemicals, we argue that the introduction of Chemical Leasing positively affected the level of the occupational health and safety within the company. Moreover, the overall solvent consumption was reduced with the introduction of Chemical Leasing by 72 %. Since releases of such substances to the environment are also suggested to negatively impact groundwater sources (Jackson and Dwarakanath 1999), we argue that the introduction of Chemical Leasing strengthened the ability of the company to protect the environment through a reduction of the releases of chemicals, which it applies in the degreasing processes, into the environment.

Conclusions and outlook

The results of both case studies showed that the introduction of Chemical Leasing improved occupational health and safety standards in the two companies in which the chemical substances are being applied and strengthened their ability to protect human health and the environment from the adverse effects of the used chemicals through the optimization of processes. In the water purification case, the involved chemicals were less toxic in their nature. Nevertheless, we argue that the potential of Chemical Leasing to largely reduce the use of chemicals of 120 t per year shows a similar level of significance as the degreasing example, in which the involved chemicals have a much higher carcinogenicity and toxicity and hence pose a higher level of risk to human health and the environment. We conclude that both case studies successfully meet the established criteria. We hence argue that it is justified to brand both Chemical Leasing case studies as a CSR initiative that would help the companies to foster relationships with their key stakeholders.

As outlined above, it is evident that the analysis of two case studies for on a subset of two specific stakeholder groups has its limitations, since we cannot exclude that other Chemical Leasing business models may not be suitable to be branded as a CSR initiative.

Nevertheless, the analysis presented in this paper is a first attempt to provide companies with a means to brand their Chemical Leasing activities also as a CSR initiative. We believe that our choice of a qualitative description is suitable for this first approach to discuss whether Chemical Leasing business model can be promoted as CSR initiative.

In order to come to more general conclusions, a critical study of further examples of Chemical Leasing projects is necessary. Further work in this field would need to focus on the effects of Chemical Leasing activities on a broader range of primary and secondary stakeholder groups. The availability of quantitative data, for example, to measure the exposure of workers and the environment to the chemicals of concern before and after the introduction of Chemical Leasing, would also increase the validity of further studies in this field.

UNIDO's activities in this field may provide a useful basis for such further work (UNIDO 2011). Enlarging the scope of the research may also provide opportunities to introduce other criteria, such as the perception of consumers towards the introduction of Chemical Leasing. The measurement of the perception of this stakeholder group could be of particular relevance for the second example of water purification, since the changes of drinking water quality before and after the introduction of Chemical may critically influence the perception of a broader stakeholder group of the environmental and social performance of the company introducing Chemical Leasing.

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ARTICLE III

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RESEARCH ARTICLE

Chemical leasing in the context of sustainable chemistry

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Abstract Chemical leasing is a new and innovative approach of selling chemicals. It aims at reducing the risks emanating from hazardous substances and ensuring long-term economic success within a global system of producing and using chemicals. This paper explores how, through chemical leasing, the consumption of chemicals, energy, resources and the generation of related wastes can be reduced. It also analyses the substitution of hazardous chemicals as a tool to protect environmental, health and safety and hence ensure compliance with sustainability criteria. For this, we are proposing an evaluation methodology that seeks to provide an answer to the following research questions: (1) Does the application of chemical leasing promote sustainability in comparison to an existing chemicals production and management system? 2. If various chemical leasing project types are envisaged, which is the most promising in terms of sustainability? The proposed methodology includes a number of basic goals and sub-goals to assess the sustainability for eight different chemical leasing case studies that have been implemented both at the local and the national levels. The assessment is limited to the relative assessment of specific case studies and allows the comparisons of different projects in terms of their relative contribution to sustainable chemistry. The findings of our assessment demonstrate that chemical leasing can be regarded as promoting sustainable chemistry in five case studies with certainty. However, on the grounds of our assessment, we cannot conclude with certainty that chemical leasing has equivalent contribution to sustainable chemistry in respect of three further case studies.

Keywords Chemical leasing · Sustainable chemistry · Sustainability · Resource efficiency · Substitution of hazardous chemicals · Chemicals management

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Introduction

Production, use and management of chemicals is subject to a real-world system consisting of different actors, such as globally distributed enterprises, supply chains or installation, equipment providers, industrial users and consumers. An integral part of this system is the production, use and trade of chemicals, with a global chemicals turnover of €3,127 billion in 2012. The economic success of chemicals industry is based, among other things, on base chemicals, such as petrochemicals and their derivatives, and basic inorganics; specialty chemicals like auxiliaries for industry, paints and inks, crop protection, dyes and pigments; and consumer chemicals like soaps and detergents, perfumes or cosmetics (CEFIC 2013).

While the functioning of modern societies largely depends on the use chemicals in a broad variety of different sectors ranging from industrial processes to households, many of them pose serious threats to human health and the environment. The predominant response of policy-makers to such threats since the early 1980s has comprised adopting legislation and treaties to address specific environmental problems associated with the production and use of chemicals. At the

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regional level, this included, for example, the Convention on Long-Range Transboundary Air Pollution, which entered into force in 1983, or the European Union Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals or REACH (EC 2006). At the international level, the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade and the Stockholm Convention on Persistent Organic Pollutants have been adopted in 1998 and 2001, respectively. The overarching objective of these regulatory measures and agreements was to reduce the risks that certain chemicals pose to human health and the environment, a goal which was reached through reducing the use of chemicals and their turnover (Jakl and Schwager 2008). This regulatory approach was in stark contrast to the traditional sales concept of chemicals industry in the past, as the economic success of a chemicals producer was generally linked to the overall volume of chemicals a producer would sell in the markets. At the same time, there was no incentive to change the traditional sales concept, since any reduction of use or turnover of chemicals would result in a decrease of revenues for the producer (Jakl et al. 2004: p. 3).

To overcome this apparent misalignment of the objectives of policy makers and chemicals industry, there was a growing understanding that chemicals policy would need to pursue both an ecological as well as an economic objective to enable companies to succeed in global competition (Jakl and Schwager 2008). As a response to this apparent misalignment, chemical leasing business models have been introduced as a new and innovative approach of using chemicals for industrial applications. Chemical leasing aims at reducing the risks emanating from hazardous substances (Ohl and Moser 2007) and, at the same time, ensuring long-term economic success within this global system of producing and using chemicals.

In this paper, we will explore how the introduction of chemical leasing business models is a viable means to reduce the consumption of chemicals, energy and resources as well as the generation of related wastes. We will also analyse the substitution of hazardous chemicals through applications of chemical leasing as a tool to protect environmental, health and safety and hence are in compliance with the sustainability criteria as outlined below.

The paper is structured as follows. The second section, introduces "Key concepts" relating to chemical leasing, sustainability and sustainable chemistry. In the third section, "Chemical leasing: a concept to promote sustainable chemistry," the key research question is introduced, which is to what extent can chemical leasing be seen as a concept to promote sustainable chemistry. This section also introduces the methodology with which we seek to answer our research question. The next section, "Empirical analysis of selected chemical leasing projects in the context of policy making," outlines a number of selected chemical leasing case studies at the national and global levels. This will serve as the basis of the subsequent discussion of the results of the case studies with regard to our research question in the next section, "Assessment of the contribution of chemical leasing case studies to sustainable chemistry." We conclude with an outlook for further work on chemical leasing in the field of sustainable chemistry in section "Outlook for further work on chemical leasing and sustainable chemistry and conclusions."

Key concepts

For the purpose of this paper, i.e. to show that chemical leasing is a business model contributing to sustainable chemistry, it is necessary, on one side, to provide a definition of sustainable chemistry and chemical leasing and, on the other side, to establish a distinction between conventional chemistry and Sustainable chemistry.

Chemical leasing and related concepts

Chemical leasing belongs to a category of business models that are applied in the chemicals industry and are service-oriented. This category includes models such as Chemical Management Services, Pay-On-Production, Single-Source-Supply and Cost-Per Unit that will be presented below. Individual companies in various forms have used such models for many years. However, chemical leasing as a defined concept was not established in a systematic approach in industry. Moreover, it has neither been received broad publicity nor been the subject of intense scientific discourse.

At the World Summit of Sustainable Development in Johannesburg in 2002, the concept of chemical leasing was mentioned as a non-regulatory instrument to reach sustainability goals (WSSD 2002). Parallel, Austria communicated the concept of the business model in the chemical sector as well as launched and promoted the first pilot projects. The United Nations Industrial Development Organization (UNIDO) has been adopting the chemical leasing concept since 2004 and starting the first international demonstration projects in 2005 (UNIDO 2011). Since 2006, the German Federal Environment Agency operates a chemical leasing initiative for Germany. Within this program, a German chemical leasing national working group has been mounted, and several pilot projects have been initiated by the German Federal Environmental Agency.

As a consequence of these developments and activities the term, chemical leasing was established as a brand name in the context of policy-making and voluntary instruments on chemicals management. The definition of Chemical Leasing by UNIDO (2011) states:

> Chemical Leasing is a service-oriented business model that shifts the focus from increasing sales volume of chemicals, toward a value-added approach. The producer mainly sells the functions performed by the chemical, and functional units are the main basis for payment. Within Chemical Leasing business models, the responsibility of the producer and service provider is extended and may include the management of the entire life cycle. Chemical Leasing strives for a win–win situation. It aims to increase the efficient use of chemicals while reducing the risks of chemicals, and protecting human health. It improves the economic and environmental performance of participating companies, and enhances their access to new markets. Key elements of successful Chemical Leasing business models are proper benefit sharing, high-quality standards and mutual trust between participating companies.

Service-oriented business models each have several characteristics, as shown below, and chemical leasing is a special type of leasing enriched and modified by additional features:

- In typical leasing types like financing, leasing a transfer of duties and obligations like maintenance costs and object risks occurs from the owner to the lessee. In contrast, with chemical leasing, the range of responsibility of the lessor is extended to include new tasks like recycling of residual or materials, training of customer personnel or additional supply chain management. Unlike typical leasing, chemical leasing includes process optimisation or more intensive cooperation between the partners. Through this intensification of the cooperation, chemical leasing offers the possibility for longer-term business relationships and the opening of additional opportunities for customer acquisition.
- Chemical management services (CMS) is characterised by a long-term strategic business relationship between a provider of management services (not necessarily the producer of chemicals) and the user of these chemicals. This includes the intention to reduce environmental impacts as well as life-cycle costs and risks (Oldham and Votta 2003). CMS focuses on the management of chemicals in areas like purchase, delivery, storage, recycling, disposal, monitoring of emissions, risk management and quality measurements. Additionally, by disconnecting the amount of chemical sold and the profitability, CMS is aiming at breaking up volume-oriented sales incentives (Reiskin et al. 2000). These characteristics demonstrate parallels to chemical leasing and the common interest of the chemicals provider and user towards a 'less is more' approach. Still, unlike chemical leasing, CMS does not necessarily involve the more efficient use of chemicals and process optimisation (Oldham and Votta 2003).
- Outsourcing describes the transfer from uneconomical in-house operations and subsidiaries to external services of a third party (Köhler-Frost 1995). This focus on core competence is a component, which also applies to chemical leasing. However, the focus on a physical product differentiates outsourcing from chemical leasing and other chemical management services which concentrate on a service-based, functionality-oriented partnership (Reiskin et al. 2000). With outsourcing, the production is usually relocated, whereas chemical leasing usually takes place at the original production site. In contrast to chemical leasing process, optimisation is not aspired as a result of more intensive cooperation between the producer of chemicals and the user.
- With the Pay-on-Production business model, the plant manufacturer finances, plans, builds, operates and maintains the plant at the user's factory site. Similar to chemical leasing process, optimisation can be achieved via an exchange of expertise. However, plant and machinery stay property of the plant manufacturer, and the producer of chemicals is not necessarily involved in this business model. Additionally, the payment is based on the output of the production plant whereas, with chemical leasing, the payment is based on the function of the chemical.
- The contracting business model is mostly used in the facility management sector and connects the operator of plant and equipment with the user. The operator provides the deliverables (e.g. heating, power, steam, etc.) operates the relevant plant and equipment over a fixed period and benefits from long-term supply contracts. The user avoids high investment costs, which may be incurred in order to establish new technologies (Reisz 2002). Analogies to chemical leasing lay in the shared distribution of financial savings from reduced costs between the operator and the user as well as on the focus on process optimisation.
- The business model Single-Source-Supply model is characterised by a change of ownership. The operator purchases the product (e.g. a metal part) and processes this with chemicals (e.g. paint) before selling it back to the user (Niebling 2006). This is in contrast to chemical leasing, where the user always maintains the ownership of the product. Still, both business models focus on process optimization.
- Cost-per-Unit business models are very similar to chemical leasing in terms of the billing category. However, they usually do not offer additional services whereas chemical leasing intends to stimulate side-effects of more intensive cooperation like customer personnel training and management of waste and recycling.

A model similar to the typical chemical leasing as defined by UNIDO should also be mentioned here. The so-called grey chemical leasing can include various chemical services models. The difference in the grey to typical chemical leasing is often not evident in individual cases. We talk of typical chemical leasing, when the following aspects are fulfilled:

- No change of ownership of the chemical (no purchase, the chemical remains property of the provider).
- Change to use-related payment (dimension of allocation, e.g. Euros per square meter cleaned surface). This may greatly reduce the chances of environmental burdens predominantly by reduction of chemical consumption.
- Complete fulfillment of the sustainability criteria for chemical leasing

Grey chemical leasing is substantially different to typical chemical leasing. We talk about grey chemical leasing when all of these aspects, or only some, are not fulfilled.

Among these chemical service models presented here, chemical leasing may be the most powerful, because it combines ambitious environmental and health protection goals with economic incentives.

Sustainability

Whereas the notion of sustainability as well as related activities in the chemical industry are shown to be largely subject to stakeholders' views and evaluation (Johnson 2012), we prefer to deal with it in the context of policy-making with reference to the report of the United Nations World Commission on Environment and Development (UN 1987) and subsequent works. In that context, sustainability is regarded as an interaction of three pillars, i.e. ecologic, economic and social that does not compromise the ability of future actors (society, enterprises, individuals) to meet their own needs.

In the context of policies on international chemicals management, emphasis is put on the ecologic and social pillar of sustainability, since reduction of risks for environment and health is the prevailing imperative.[1] In the past, concerns of potential dangers focused mainly on hazard and safety aspects: In terms of environmental hazards caused by the emission of substances and products into the environment, ecotoxicology and plant safety were regarded as central issues.

For the social aspect of workers' and users' protection, the physical–chemical properties of substances and products was—and still is, at least in developing countries—of great importance. Additionally, safety and introduction of best available techniques of an industrial plant is key for both protection of humans and environment. Although, higher protection standards are realised comprehensively in industrialised countries in the field of human safety, in developing countries those are only scarcely established. This shows that, in the social field, rather, a local shift of concerns on a global scale than the introduction of new aspects is the driving force for the necessary improvements.

The picture is more complex in respect of the environmental pillar. First, regarding emission of hazardous substances into the environment and safety of industrial plants, there is a local shift of concerns on a global scale, as it is seen in the social field. Second, this pillar is shaped by life-cycle assessment, recycling and eco-balancing as well as cradle-to-grave and cradle-to-cradle approaches. Last but not least, new approaches like supply chain responsibility, use of renewable resources, green house gas emissions and long-range transport of hazardous substances streamed into the environmental assessment of the chemical sector.

Today, the traditional aspects together with the new emerging aspects form together the requirements and opportunities of sound chemicals management. And this comprises the idea of sustainable chemistry in our understanding.

The normative context of sustainable chemistry

From an analytical point of view, the use of the term 'sustainable' before chemistry implies a particular reasoning for specification or, otherwise, differentiation of the conventional chemistry. In other words, chemistry—be it a scientific discipline, a set of industrial activities or a relevant issue for policy-making and administration tasks—is considered to be the umbrella term or somehow distinct notion than sustainable chemistry. Since sustainable chemistry includes many aspects—as we have shown above—that have not played central roles in chemistry in the past, it can be regarded as complementary to the chemistry system. To elaborate on this point, we first distinguish between a structural and a normative context of chemistry by use of a systems engineering approach.[2]

In a structural context, we view chemistry as a real-world system consisting of globally distributed enterprises,

[1] "Renew the commitment, as advanced in Agenda 21, to sound management of chemicals throughout their life cycle and of hazardous wastes for sustainable development as well as for the protection of human health and the environment, inter alia, aiming to achieve, by 2020, that chemicals are used and produced in ways that lead to the minimization of significant adverse effects on human health and the environment, using transparent science-based risk assessment procedures and science-based risk management procedures, taking into account the precautionary approach, as set out in principle 15 of the Rio Declaration on Environment and Development, and support developing countries in strengthening their capacity for the sound management of chemicals and hazardous wastes by providing technical and financial assistance." In the context of the United Nations, this paragraph has been coined by to contribute to meeting the 2020 goal on the sound management of chemicals throughout their lifecycle.

[2] Systems engineering is a discipline that deals with analysis, evaluation and design of complex systems. For further reference to systems engineering and systems thinking, see Haberfellner et al. (1997).

installations, equipment, market actors, management and labour, chemicals and various products. These entities are penetrated by various material, energy and information relations between them. The relations, in turn, function on the grounds of physical–chemical properties and processes for production of products that cover various societal needs.

A more elaborate analysis of a chemistry system that claims to go beyond the structural context has to focus on the normative context. Shifting the conceptualization of sustainable chemistry from the structural context to a normative one means moving from *analysis* to *evaluation* of chemistry in the context of sustainability.

In order to evaluate sustainability in respect of a given chemistry system, one has to consider the various concepts on which basis the action of stakeholders in the field of sustainability might be explained. The notion of sustainability, generally accepted to be founded in the Brundtland report (UN 1987), may apply as a useful normative framework to evaluate the structure, processes and performances of a chemistry system. Taking a chemical installation for surface treatment as an example, the design, management, control and optimization of such a chemistry system may focus on its structure and processes or its interactions with the natural environment or both. Evaluation may then be focussed, among other things, on:

- Minimization of accidents of the whole plant/installation.
- Minimization of the use of hazardous substances in the process.
- Minimization of risk exposure of the personnel within the installation.
- Minimization of wastes or emissions from chemical installations to the surrounding area.
- Reduction of water consumption needed for the batch processes.
- Reduction of energy demand.

Considering local shifts of concerns on a global scale, it becomes evident that more aspects of the normative context will be relevant for evaluation of a chemistry system with respect to sustainability. This can include, for example:

- Increase in employment, poverty eradication.
- Added value and responsibility within the local value chain.
- Possible innovation in cooperation with buyer or other stakeholders, in case of good economic performance and growing market demand.

However, the picture of sustainability is frequently obscured because many trade-offs (e.g. wastes vs. emissions) or conflicts with surrounding systems (e.g. labour displacement in other sectors, unbalanced distribution of high added value, etc.) may occur. In this paper, we focus on two normative approaches with different underlying concepts for identification of the overall sustainability goal:

1. Sustainable chemistry is an integral part of the chemistry system.
2. Sustainable chemistry is a new paradigm that has to replace or substitute for parts of an existing chemistry system.

Whereas normative approaches (1) and (2) have different underlying concepts (complementarity vs. imperative necessity of sustainable chemistry), in practice, they overlap at the point that an existing chemistry system has to be changed—partially or as a whole. Taking prevailing definitions concepts of sustainable chemistry into account, we find that one or all of the normative approaches and underlying evaluations aforementioned may be reflected. In our view, in the chemical sector, most conceptual strategies and even more practice underlying concepts are frequently tacit or mixed. In this paper, we show that chemical leasing is a business model for the chemical sector that contributes to the normative approach (1): The application of chemical leasing replaces or substitutes parts of an existing chemistry system in a sustainable manner.

In this context, we propose an approach for definition of sustainable chemistry as follows: sustainable chemistry is achieved by reaching four basic goals:

Goal 1 Optimisation of resource efficiency
Goal 2 Reduction of adverse effects on health and environment
Goal 3 Increase in economic value and optimisation of chemicals management
Goal 4 Safeguarding of overall sustainability (economic, ecologic and social dimension)

Whereas goals 1 to 3 refer to a system of chemical production in itself, goal 4 addresses the implications of this system to other surrounding systems.

Chemical leasing: a concept to promote sustainable chemistry

Chemical leasing business models have been promoted as a market-oriented approach to overcome this misalignment between the regulatory and industry spheres, with the aim to provide companies with a comparative advantage in global markets.

With the introduction of chemical leasing, the economic success of the producer no longer depends on the volume of chemicals sold to the user but on a service that is connected with the application of the chemical. The producer mainly sells the functions performed by the chemical, with functional units being the main basis for payment.

The economic and ecological viability has been demonstrated in praxis by UNIDO's global chemical leasing programme, which has been launched in 2004. The experience gained in the implementation of this innovative business approach has shown promising results regarding the minimization of the risks emanating from chemicals and related wastes, including a reduced consumption of raw materials and energy in the processes chemicals are used (UNIDO 2011).

Chemical leasing combines reduction of chemicals used and environmental pollution with economic advantages for the involved partners. To accomplish these benefits to environment and stakeholders, sustainability criteria for chemical leasing were developed jointly by the German Federal Environment Agency and UNIDO in 2009–2010 (UBA 2010; UNIDO et al. 2011). Besides expert monitoring of the case studies, the experiences of existing and initiated case studies fed into the development of the sustainability criteria for chemical leasing.

The following five sustainability criteria help to establish a high standard for chemical leasing and play an important role for the efficient and effective functioning of the business model:

a. *Reduction of adverse impacts* for environment, health, energy and resource consumption caused by chemicals and their application and production processes.

   This criterion aims at the transition of reduced chemicals consumption into improvements for environment, health and safety. A reduction in the amount of chemicals used leads to less waste, wastewater and emissions and therefore to a decrease in chemicals exposure as well as reduced resource consumption. Reductions in energy consumption are achieved mainly through a decrease in material flows. The basic idea of close cooperation between the partners through chemical leasing helps to optimise the use of chemicals and to reach the objective of this criterion.

b. *Improved handling and storage of chemicals to prevent and minimise risks*.

   This criterion helps to reduce or avoid potential risk impacts. In addition, this is also important for the economic component of potential changes of liabilities between the participants under chemical leasing.

c. *No substitution of chemicals by substances with a higher risk*.

   This criterion assures that workers and environment are not exposed to higher risks through the introduction of chemical leasing in a process. At the same time, it stresses the importance to increase the efficiency of the used chemicals and the process. Thereby, conflicts with the sustainability objectives are avoided.

d. *Generation of economic and social benefits*.

   A contract should contain the objective of continuous improvements and should enable a fair and transparent sharing of the benefits between the partners. This criterion is very important for a long-ranging partnership and successful application of the business model.

e. *Monitoring of the improvements* needs to be possible.

   This criterion is necessary to identify and document the improvement, potentials and deficits of the process parameters in a chemical leasing application. Monitoring is a core part for a potential adjustment of the agreement between the partners in dynamic contractual chemical leasing relationships.

The sustainability criteria were tested in several countries and applied to different cases studies (UBA 2010). They have proven to be very helpful in the start-up phase as well as for evaluating chemical leasing projects. Today, the sustainability criteria for chemical leasing are implemented in UNIDO, Austrian and German chemical leasing programs.

It is assumed that chemical leasing business models result in an extension of the responsibility of the producer and service provider, which may include the management of the entire life cycle (UNIDO 2011). Literature supports this finding by showing chemical leasing business models target a closer collaboration between suppliers and users of chemicals and can hence be seen as an effective and efficient contribution to the implementation of REACH (Ohl and Moser 2007).

Chemical leasing also aims to increase the efficient use of chemicals while reducing the risks of chemicals, and protecting human health (UNIDO 2011). With the implementation of chemical leasing, material flows can be optimised and the ineffective use and overconsumption of chemicals decreased.

Chemical leasing also promotes a transfer of knowledge from the producer to the user (Schwager and Moser 2006; Ohl and Moser 2007, 2008). Other work in this field focused on the potential of chemical leasing to improve occupational health and safety standards in the context of Corporate Social Responsibility (Moser et al. 2014).

We argue that application of chemical leasing have a vast potential to contribute the objectives of sustainable chemistry. Under this light, we seek to explore the concept of chemical leasing business models in the context of the different dimensions of sustainable development. We will subsequently elaborate on a broad evaluation approach in terms of sustainability on the basis of selected case studies. Finally, we will discuss the factors that are shared among chemical leasing and sustainable chemistry to improve certain chemistry systems as may be indicated by evaluation of selected studies.

Conceptual framework to evaluate the sustainability of chemical leasing business models

The evaluation of the sustainability of target systems using different indicators has been extensively discussed in literature (Singh et al. 2009).

For the selection of the conceptual framework and indicators relevant for this paper, we follow a top-down approach as suggested by Lundin (2003) taking into account the Bellagio Sustainability Assessment and Measurement Principles (Pintér et al. 2012).

We have selected a number of basic goals and sub-goals to assess the sustainability within a given chemical leasing system. The following table outlines the conceptual framework and indicates what aspects or domain of sustainability the indicator measures (Table 1).

The conceptual framework we propose serves to answer two subsequent questions relevant for decision-makers:

1. Does the application of chemical leasing actually promote sustainability in comparison to an existing chemicals production and management system?
2. If various chemical leasing project types are envisaged, which is the most promising in terms of sustainability?

In the interest of transparency, the data sources for all case studies are made available to the readers and are included in the description of the case study as reference.

Assessment methodology

We use an assessment methodology that has been developed in order to ensure comparability of the different case studies. The benchmark for measuring the impact of a chemical leasing project will be a 'business as usual scenario' in which chemical leasing is not applied.

Sustainability indicator to assess chemical leasing projects

In order to assess whether a chemical leasing project promotes sustainability or not, we propose the following assessment methodology.

A nominally scaled variable with a score of $\{1, 0, -1\}$ is assigned to each sub-goal g_{ij}. A score of $\{1\}$ indicates that the implementation of a chemical leasing project has achieved the respective sub-goal. A score of $\{0\}$ indicates that a sub-goal is either not relevant for the implementation of the chemical leasing project or no data are available. A score of $\{-1\}$ indicates that the implementation of a chemical leasing project has not achieved the respective sub-goal.

To arrive at these scores, the different sections of the case studies are coded. For this, qualitative information provided in the case study is screened to decide, in a first step, whether any of the sub-goals g_{ij} are not relevant for the case study. All non-relevant sub-goals are given a score of $\{0\}$, which is then recorded in a specific table (see Table 2 below). In a second step, the case study is screened to decide whether it provides data for each relevant sub-goal. All sub-goals that the case study fails to provide data on are given a score of $\{0\}$, and the score, again, is recorded in the table. In a third step, the remaining relevant sub-goals are screened to decide whether the implementation of a chemical leasing project has or has not achieved the respective sub-goal. The respective scores of $\{1\}$ or $\{-1\}$ are transferred into the table. In a last step, the scores for each sub-goal g_{ij} are summed to obtain a value for the 'Total Score', which is defined as follows:

$$\text{Total Score} = \sum_{i=1}^{4} \sum_{j=1}^{n} g_{ij} \quad (1)$$

This value, which is also recorded in the table, represents the indicator we propose for assessing the sustainability of a project.

Scope of the methodology

The scope of the proposed methodology is limited to the comparison of different chemical leasing projects in terms of their relative contribution to sustainable chemistry. It hence allows a relative assessment of specific case studies among each other. We also assume that all sub-goals and goals have equal weights.[3]

The 'Total Score', as defined above, is a single, qualitative indicator that shows a possible increase in sustainability after the introduction of chemical leasing.

Subject to certain conditions, this methodology allows to conclude 'with certainty' that introducing chemical leasing has increased sustainability. For this, any basic goal must positively contribute to sustainability. This means that the aggregated scores $\sum_{j=1}^{n} g_{ij}$ for each basic goal g_i must be larger than zero. This is set out in Eqs. 2, 3, 4 and 5:

$$\sum_{j=1}^{4} g_{1j} > 0 \quad (2)$$

$$\sum_{j=1}^{6} g_{2j} > 0 \quad (3)$$

$$\sum_{j=1}^{6} g_{3j} > 0 \quad (4)$$

$$\sum_{j=1}^{10} g_{4j} > 0 \quad (5)$$

[3] The calculation of the scores for each sub-goal will not be adjusted through weighting factors.

Table 1 Conceptual framework outlining basic goals and related sub-goals for promoting sustainable chemistry through chemical leasing

Basic goals (g_i)	Sub-goals (g_{ij})
g_1 Increase overall resource efficiency	$g_{1,1}$ Use less energy
	$g_{1,2}$ Use less raw and auxiliary materials
	$g_{1,3}$ Use less water
	$g_{1,4}$ Produce less waste/wastewater
g_2 Reduce adverse effects on health and environment of the chemicals of concern	$g_{2,1}$ Reduce impacts on labour health
	$g_{2,2}$ Substitution of carcinogenic, mutagenic and toxic for reproduction (CMR) chemicals
	$g_{2,3}$ Substitution of persistent, bioaccumulative and toxic (PBT) chemicals
	$g_{2,4}$ Reduce impacts on water
	$g_{2,5}$ Reduce impacts on air
	$g_{2,6}$ Reduce impacts on soil
g_3 Increase economic value and strengthen chemicals management	$g_{3,1}$ Increase output with desired properties
	$g_{3,2}$ Optimise handling/storage/logistics
	$g_{3,3}$ Increase economic gain: increase revenue for supplier
	$g_{3,4}$ Increase economic gain: increase revenue for user
	$g_{3,5}$ Increase competiveness for supplier
	$g_{3,6}$ Increase competiveness for user
g_4 Increase sustainability in surrounding systems	$g_{4,1}$ Use less fossil resources
	$g_{4,2}$ Reduce impacts on health of consumers
	$g_{4,3}$ Promote recycling/use in cascades
	$g_{4,4}$ Increase economic gains in the region/country: increase revenue for trade
	$g_{4,5}$ Increase economic gains in the region/country: increase revenue for other stakeholders in the supply chain
	$g_{4,6}$ Reduce poverty in the region
	$g_{4,7}$ Increase employment in the region
	$g_{4,8}$ Reduce impacts on water in the region
	$g_{4,9}$ Reduce impacts on air, including reduction of greenhouse gases
	$g_{4,10}$ Reduce impacts on ecosystems/biodiversity

Accordingly, we argue that an increase in overall sustainability is 'uncertain' if the above conditions are not fulfilled. In this case, the respective value of the 'Total Score' shall have no further relevance.

In addition, we assume that case studies may not be suitable to contribute to sustainable chemistry if the following two conditions are met. First, the aggregated score for a specific basic goal g_i is zero, and second, no sub-goal g_{ij} of that specific basic goal has achieved the sustainability criteria, i.e. a score of {1}. This can be the case if either data for the respective sub-goals are not available at all or such data are not relevant.[4] Case studies that fall under these conditions will not be considered by this methodology.

Limitations of the methodology

As regards its limitations, the methodology will not reveal to what extent a chemical leasing project has achieved or not achieved the respective sub-goals. Also, our conceptual framework will not allow deriving conclusions whether chemical leasing business models are sustainable per se, or to what extent chemical leasing promotes sustainable chemistry. The assessment rather seeks to identify either the limitations of typical chemical leasing systems to sustainable chemistry or whether such systems can be used as a benchmark.

Practical considerations

We characterised case studies according to their size, number of sectors covered and their geographic scope to facilitate the interpretation comparability of the different case studies. We have established following categories.

Smaller case studies that are implemented as a single standing project at a local level in one specific sector fall in category A. Instead, larger case studies that are implemented in several sectors or at the national, regional or sub-regional levels fall in category B.

The impact of case studies on surrounding systems (basic goal 4) may differ between these two categories. It is evident

[4] Or any other combination of 'no data are available'- and 'sub-goal not relevant'-entries.

Table 2 Evaluation of the potential of chemical leasing to promote sustainable chemistry

Promoting sustainable chemistry through chemical leasing		Case study 1		Case study 2		Case study 3		Case study 4		Case study 5		Case study 6		Case study 7		Case study 8	
Basic goals	Sub-goals	Achievement	Score	Achievement	Score	Achievement	Score	Achievement	Score	Achievement	Score	Achievement	Score	Achievement	Score	Achievement	Score
1 Increase overall resource efficiency	1.1. Use less energy	–	0	–	0	–	0	–	0	yes	1	yes	1	yes	1	yes	1
	1.2. Use less raw and auxiliary materials	Yes	1	–	0	–	0	Yes	1	Yes	1	Yes	1	Yes	1	Yes	1
	1.3. Use less water	–	0	–	0	Yes	1	–	0	–	0	–	0	–	0	–	0
	1.4. Produce less waste/waste water	Yes	1	–	0	Yes	1	Yes	1	Yes	1	Yes	1	Yes	1	Yes	1
	Sub-total basic goal 1		2		0		2		2		3		3		3		3
2 Reduce adverse effects on health and environment of the chemicals of concern	2.1. Reduce impacts on labour health	–	0	Yes	1	Yes	1	Yes	1	Yes	1	Yes	1	Yes	1	Yes	1
	2.2. Substitution of CMR chemicals	n.r.	0	n.r.	0	n.r.	0	no	−1	n.r.	0	n.r.	0	Yes	1	n.r.	0
	2.3. Substitution of PBT chemicals	Yes	1	Yes	1	Yes	1	no	−1	n.r.	0	n.r.	0	n.r.	0	n.r.	0
	2.4. Reduce impacts on water	–	0	–	0	Yes	1	–	0	Yes	1	–	0	–	0	–	0
	2.5. Reduce impacts on air	–	0	–	0	Yes	1	–	0	n.r.	0	Yes	1	Yes	1	–	0
	2.6. Reduce impacts on soil	n.r.	0	–	0	n.r.	0	–	0	–	0	–	0	–	0	–	0
	Sub-total basic goal 2		1		2		4		−1		2		2		3		1
3 Increase economic value and strengthen chemicals management	3.1. Increase output with desired properties	–	0	–	0	–	0	–	0	Yes	1	Yes	1	Yes	1	Yes	1
	3.2. Optimise handling/storage/logistics/processes	Yes	1	Yes	1	Yes	1	Yes	1	Yes	1	Yes	1	Yes	1	Yes	1
	3.3. Increase economic	–	0	–	0	–	0	Yes	1	Yes	1	Yes	1	Yes	1	Yes	1

Table 2 (continued)

Promoting sustainable chemistry through chemical leasing		Case study 1		Case study 2		Case study 3		Case study 4		Case study 5		Case study 6		Case study 7		Case study 8	
	gain: increase revenue for supplier																
	3.4. Increase economic gain: increase revenue for user	Yes	1	Yes	1	Yes	1	Yes	1	no	−1	Yes	1	Yes	1	Yes	1
	3.5. Increase competiveness for supplier	–	0	Yes	1	–	0	Yes	1	Yes	1	Yes	1	Yes	1	Yes	1
	3.6. Increase competiveness for user	–	0	–	0	–	0	Yes	1	Yes	1	Yes	1	Yes	1	Yes	1
	Sub-total basic goal 3		2		3		2		5		4		6		6		6
4 Increase sustainability in surrounding systems	4.1. Use less fossil resources	–	0	n.r.	0	–	0	–	0	–	0	n.r.	0	–	0	–	0
	4.2. Reduce impacts on health of consumers	–	0	Yes	1	Yes	1	–	0	–	0	n.r.	0	–	0	–	0
	4.3. Promote recycling/use in cascades	Yes	1	–	0	–	0	–	0	Yes	1	no	−1	Yes	1	Yes	1
	4.4. Increase economic gains in the region/country: increase revenue for trade	–	0	–	0	–	0	–	0	–	0	–	0	–	0	–	0
	4.5. Increase economic gains in the region/country: revenue for other stakeholders in	–	0	–	0	–	0	–	0	–	0	–	0	–	0	–	0

Table 2 (continued)

Promoting sustainable chemistry through chemical leasing	Case study 1		Case study 2		Case study 3		Case study 4		Case study 5		Case study 6		Case study 7		Case study 8	
the supply chain																
4.6. Reduce poverty in the region	Yes	1	–	0	–	0	–	0	–	0	–	0	–	0	–	0
4.7. Increase employment in the region	–	0	–	0	–	0	–	0	–	0	–	0	–	0	–	0
4.8. Reduce impacts on water in the region	Yes	1	Yes	1	–	0	Yes	1	–	0	–	0	–	0	–	0
4.9. Reduce impacts on air, including greenhouse gases	–	0	–	0	–	0	–	0	–	0	–	0	–	0	–	0
4.10. Reduce impacts on ecosystems/ biodiversity	Yes	1	–	0	–	0	–	0	–	0	–	0	–	0	–	0
Sub-total basic goal 4		4		2		1		1		1		−1		1		1
Total score	9		7		9		7		10		10		13		11	
Promotion justified (every criterion>0, i.e. at least 1)?	Yes		Uncertain		Yes		Uncertain		Yes		Uncertain		Yes		Yes	
Missing data	15		17		15		15		11		10		12		13	

n.r. not relevant

that this has implications for the comparability of case studies belonging to different categories. Consequently, we compare case studies as part of this evaluation within each category in the first place.

Empirical analysis of selected chemical leasing projects in the context of policy making

Focus

For the purpose of this paper, we will focus our analysis on selected cases studies conducted on behalf of UNIDO and governmental organisations of Austria and Germany in the universe of typical chemical leasing applications. The implementation of chemical leasing case studies has the aim to enhance a sustainable use of chemicals. UNIDO and governmental organisations of Austria and Germany[5] have the aim to establish chemical leasing on a broad scale. One main reason for this is the attempt to optimise selection, production and handling as well as application of chemicals. The objective is to reduce the consumption of chemicals and their risks to users by improving chemical handling. In turn, this will improve the protection of human health and the environment. Another reason for the introduction of chemical leasing is the economic benefit that all participants can achieve through this business model. With regard to the economic dimensions, it is necessary to reach the target groups of chemicals producers, chemicals retailers, chemicals users and machine and plant manufacturers. For all target groups, chemical leasing can offer improved competitiveness. For producers, suppliers and users in particular long-term business relationships of chemicals and precise knowledge about customer requirements and range of performances play an important role in economic terms. For producers, compensating for existing competitive disadvantages and more rapid economic returns on R&D investments is important. For producers and users, more intensive communications for process optimisation and, especially for users, process optimisation and cost reductions are of high importance.

In the early years when chemical leasing evolved, only some public measurable distribution of the business model as defined by UNIDO, Austria and Germany took place. Therefore, in order to reach potential chemical leasing partners and sectors as well as to spread the concept, the first case studies were launched: Early chemical leasing pilot projects were successfully established and communicated since 2002 by the Austrian Ministry of Life (Jakl et al. 2004), followed by UNIDO since 2004 (UNIDO 2009) and by Germany since 2007 (UBA 2010).

Case studies

The analysis of the accessible case studies includes status and effectiveness of the respective projects. A comparison between chemical leasing and the typical business with chemicals must be possible and quantitative results should be able to obtain.

Large reduction potential and clear environmental advantages may enhance the attractiveness of the chemical leasing business model. Therefore, an essential part of the research has been the analysis of the achieved reductions in the categories with environmental impact: amount of chemicals used, waste, wastewater, energy and resource consumption. Additionally, contracts must be compliant with the chemical leasing sustainability criteria. A special focus lay on substitution of chemicals being one critical aspect for application of chemical leasing as a tool to protect environmental, health and safety. Therefore, it is not desirable to replace a substance by another substance, which poses a higher risk.

From the economic perspective, chemical leasing can offer an interesting way to launch new, innovative technologies and should have a potential for widespread implementation, since the selected case studies are important for promoting chemical leasing. Good potential for dissemination therefore increases the value of a pilot project. Additionally, chemical leasing can help to expand export opportunities so that model projects in this sector can promote the business model.

In many cases, chemical leasing is only viable above a threshold level of chemicals' consumption. This is more likely to be the case for large companies. Therefore, another important screening criterion for potential case studies was the involvement of small- and medium-sized enterprises in order to cover a broad spectrum of applications for chemical leasing.

Last but not least, the potential of the development of the cooperation between the business partners was an important selection criterion since interaction and mutual knowledge is crucial for successful chemical leasing projects.

[5] Since 2006, the German Federal Environment Agency operates a chemical leasing initiative for Germany. Within this program, a German chemical leasing national working group has been mounted, and several pilot projects have been initiated by the German Federal Environmental Agency. Besides expert monitoring of the case studies, the experiences of existing and initiated case studies fed into the development of sustainability criteria for chemical leasing. Today, the sustainability criteria for chemical leasing are implemented in UNIDO, Austrian and German chemical leasing programs. German environmental authorities have been dedicated to the business model of chemical leasing in general with a special focus on initiating pilot projects since 2007. Today, chemical leasing is established in Germany, triggered by various flagship projects in a number of applications and industries.

Category A

Case study 1: integrated painting of washing machines in the engineering and chemical sectors in Egypt (UNIDO 2011)

The integrated process of painting is essential to ensure the high quality and durability of washing machines. It includes expensive metal pre-treatment (degreasing and phosphating) and electrostatic powder coating, which may cause considerable negative environmental impacts.

The chemical leasing project was implemented at Delta Electrical Equipment (DEA),[6] which brought together three companies, and their respective knowledge: DEA, together with Akzo Nobel Powder Coating SAE (supplier of coating chemicals),[7] and Chemetall Italy (supplier of surface pre-treatment chemicals).[8] The project was developed in close cooperation with the Egyptian National Cleaner Production Centre.

Before becoming involved with chemical leasing, DEA faced various losses and high costs, mainly due to high amounts of waste and inefficient operational management. The knowledge of workers on chemicals and risk management was very limited, which also affected the overall performance of the company.

The *chemicals applied* involved surface pre-treatment chemicals, such as degreasing, conditioning and activation chemicals as well as zinc phosphate; electro-deposition chemicals; and electrostatic powder coating chemicals.

The *scope* of the chemical leasing model applied to the process of washing machine painting included surface treatment, electro-deposition and electrostatic powder coating.

The basis for payment before the introduction of chemical leasing has been Egyptian pounds (EGP) per unit (kilograms, etc.) of chemicals. The processes before the introduction of chemical leasing involved a high consumption of powder coating chemicals due to unnecessarily thick coating layers and a non-optimised coating process. The production costs per washing machine were high (costs of pre-treatment, coating and electrostatic powder coating), and the percentage of reworks and rejects amounted to 9 %. Sludge waste generated during the phosphating process amounted to 0.021 g per unit (approx. 6 t in 2008) and deposited at a nearby landfill site and 30 m^3 of wastewater were generated per day. The 10 % of fine powder was wasted and dumped. There was no full compliance with REACH or RoHS (restriction of hazardous substances directive), and workers had only limited information on chemicals and risk management.

Outcome of chemical leasing

The optimization of the pre-treatment and electrostatic powder coating process resulted in a more efficient use of chemicals. This brought significant cost reduction per unit produced and reduced the amount of chemical waste. In addition, the recycling of chemical waste has been enhanced, and DEA's suppliers began registering their products under REACH, ensuring that they do not contain substances of very high concern. The basis for payment has been changed to EGP per washing machine produced.

The *economic benefits* included a reduced consumption of chemicals for pre-treatment chemicals by 15–20 % and for powder coating by 50 % as well as a reduction of the total cost per washing machine by 15–20 %. Also, the percentage of reworks and rejects could be reduced to 1.5 %, while the losses have been reduced to 1 %.

The *environmental* benefits included the elimination of sludge waste by using environmentally friendly pre-treatment process (e.g. non-cyanide and nickel-free phosphating technologies); the reduction of fine powder waste from 10 to 5 %; the reuse of wastewater; the recycling of waste; and the compliance with REACH.

The *social benefits* included the provision of training and capacity-building for workers on chemicals management and chemical risks.

Case study 2: treatment of drinking water in the water treatment sector in Russia (UNIDO 2011)

In many countries, water used to be disinfected with pure liquid chlorine. It was an effective way of fighting epidemics at the beginning of the nineteenth century but caused serious problems, as chlorine is an extremely poisonous substance. Use of chlorine also meant high operational costs due to additional safety measures, including storage and transportation of significant quantities of the toxic chemical.

Vodokanal of St. Petersburg[9] is the State enterprise that supplies drinking water to more than 4.5 million inhabitants.

[6] *Delta Electrical Appliances* is the leading Egyptian manufacturer of electrical equipment. It is part of the Olympic Group, one of Egypt's foremost companies. DEA mainly produces electrical appliances, refrigerators and washing machines.

[7] *Akzo Nobel Powder Coating SAE* (leading supplier) is part of the international group Akzo Nobel and has a share of around 60 % of the Egyptian powder coating market. It operates mainly in the sectors of domestic appliances, electrical equipment and air-conditioners.

[8] *Chemetall Italy* (subcontractor supplier and co-partner) is a global company in the field of specialty chemistry. The group's activities focus on products and processes for the chemical treatment of metal surfaces and plastics, as well as on selected fields of fine chemistry, such as lithium and caesium compounds. The company is represented in Egypt by its authorised agent Obegi Chemicals Egypt. Chemetall operates in a wide range of industrial sectors (automotive, domestic electrical appliances, and the aluminium and galvanization sectors).

[9] Vodokanal of St. Petersburg is the user of the chemicals and specialises in treating and disinfecting water. Vodokanal of St. Petersburg provides drinking water and wastewater services to over 4.5 million people in private households, as well as to more than 17,500 customers in both industrial settings, and providers of municipal services.

The company was looking for cost-effective, sustainable and safe drinking water treatment solutions to reduce costs and increase the safety of drinking water. In cooperation with the North-Western International Cleaner Production Centre, the company made the switch to chemical leasing.

Vodokanal partnered with Aquatechservice Ltd.[10] in 2006 and began to replace liquid chlorine with diluted sodium hypochlorite (produced from sodium chloride), which is as effective and significantly less harmful.

The *chemicals applied* involved ammonium sulphate (water ammonation); sodium hypochlorite (water disinfection); aluminium sulphate (coagulation of pollutants); and cationic flocculent chemicals (flocculation).

As regards the *scope* of the case study, in 2007, a new production process for the disinfecting solution was introduced. The official ceremony of discarding the last chlorine container was held at the Northern Waterworks on June 26, 2009. Two plants for the production of low-concentrate sodium hypochlorite began operation in St. Petersburg, at the Southern Waterworks (since 2006) and at the Northern Waterworks (since 2008).

The basis for payment before the introduction of chemical leasing has been Russian roubles per kilogram or ton of chemicals used for water treatment and 5.7 t of poisonous liquid chlorine used for water disinfection every day. Chlorine is a highly toxic substance (second hazard class). There has been a risk of accidents during the transportation of the chlorine in the city (in special containers under pressure).

Outcome of chemical leasing

Producing the new process based on the production of diluted hypochlorite solution on-site, water treatment costs were optimised. Aquatechservice Ltd. produces sodium hypochlorite for water treatment from a 3 % sodium chloride solution. The basis for payment has been changed to Russian roubles per 1,000 m^3 of purified water.

The *economic benefits* included a reduction of water disinfection costs by almost 33 %; a reduction of the price for one ton of hypochlorite solution due to optimization of the process; and a reduction of the cost for 1,000 t of purified water due to the optimization of the sodium hypochlorite flow.

The *environmental benefits* included the use of 640 m^3 of sodium hypochlorite solution at a low concentration (environmentally safe) for water disinfection every day as well as the safe transportation and storage of the solid substance (NaCl), which is used for the production of sodium hypochlorite. Also, the processes could be automated. The equipment used for the production of sodium hypochlorite is highly reliable.

The *social benefits* included the improved health and safety of workers.

Case study 3: conveyor lubrication in the beverage sector in Serbia (UNIDO 2011)

The production and sales of bottled water is one of the fastest-growing industries in the world. According to the research of the Worldwatch Institute, the global rate of consumption has more than quadrupled between 1990 and 2005. Spring water and purified tap water are the leading sellers globally, and around 200 billion bottles are consumed per year (New York Times 2008).

One critical point within production of bottled water is the packaging process. Bottled water is commonly packaged in bottles made of polyethylene terephthalate (PET), and this requires a significant amount of energy. In addition, companies face problems ensuring packaging conveyors stay lubricated, due namely to out-dated equipment. Many beverage companies still use old packaging lines with so-called wet lubrication, resulting in high consumption of water, usage of hazardous chemicals for water pre-treatment, high generation of wastewater and high operational risks. The chemical used as a lubricant usually has hazardous properties to prevent the natural growth of microbes in this environment. It causes eye and skin irritation and is toxic to aquatic organisms. In Serbia today, there are over 30 producers of mineral water in the country's market. In 2009, roughly 635 million litres of mineral water were manufactured, and 560 million litres were filled in PET bottles.

One third of the national mineral water is produced by Knjaz Milos.[11] To increase efficiency on the production line, improve the company's performance and strengthen its leading position on the market, Knjaz Milos was looking for innovative solutions to make the production process easier, more efficient and safer. Together with its supplier, Ecolab,[12] and in close cooperation with the Cleaner Production Centre in Serbia, a chemical leasing project was developed and implemented.

The *chemicals applied* involved a lubricant containing alkyl amines and acetic acid was used (corrosive and toxic).

[10] Aquatechservice Ltd. is the chemical supplier, specializing in the development and implementation of innovative water purification processes, and in the exploration and maintenance of equipment, as well.

[11] Knjaz Milos, founded in 1811, is the largest producer of mineral water and beverages in the Republic of Serbia. The annual production capacity amounts to 300 million litres of beverages. In 2008, 220 million litres of mineral water and beverages were produced. The company has about 900 employees and is ISO 9001, ISO 14001 and ISO 22000 certified.

[12] Ecolab is the global leader in cleaning, sanitizing, food safety and infection prevention products and services with sales of US$ 6 billion and more than 26,000 associates. It delivers comprehensive programmes and services to foodservice, food and beverage processing, healthcare and hospitality markets in more than 160 countries. The company is certified according to ISO 9001/14001 and EN 46001 (for medical devices).

The chemical was substituted by an alternative one with fewer negative effects[13]

As regards the *scope* of the case study, as a first step, the production process was modified, and the lubricant was substituted by a non-hazardous dry lubricant. New equipment, such as dosage systems and spraying nozzles, were installed. As a result, the efficiency of the line has increased, and the working life of the conveyor has been extended. Furthermore, a downtime of about 15 min per shift before chemical leasing was eliminated with the new equipment, and the costs of packaging can now be accurately calculated.

The basis for payment before the introduction of chemical leasing has been Euro per amount of chemicals (litres, kilograms). The consumption of chemicals for water pre-treatment and wastewater treatment was high and 1,500 m^3 of water was contaminated annually (the chemical had to be dissolved in water) per production line. Some 6,000 kg of lubrication (chemical with hazardous properties) was used per year per production line. There has been a risk of injuries due to slippery floors

Outcome of chemical leasing

The cost savings were achieved because water and chemicals for pre-treatment and wastewater treatment were eliminated from the process. The basis for payment has been changed to Euro per number of working hours of the conveyor.

The *economic benefits* included total cost savings per packaging line amount to EUR 5,700 per year as well as reduced costs for the lubrication of the packaging line. This resulted in a higher performance of packaging line and reduced handling costs.

The *environmental benefits* included that no water or chemicals were required anymore for pre-treatment and wastewater treatment and a 30 % reduction of chemicals used for lubrication.

The *social benefits* included improved occupational health and safety due to reduced quantity of aerosols in the air, better working environment and a reduced risk of injuries.

Case study 4: newspaper printing in the printing and publishing sector in Sri Lanka (UNIDO 2011)

Newspaper printing requires several types of ink consisting of volatile organic compounds, which can affect both the environment and the health of workers in the company. The optimization of ink usage is highly complex since ink is wasted in a number of different ways, for example, spills, residues in containers and trays, and in the printing process itself. This lead to high costs for energy, wastewater treatment and solid waste. Since the printing area was often closed and air-conditioned, the evaporation of solvents contained in the ink can cause health risks for employees. The chemical leasing business model was implemented at a medium-size printing workshop of the Wijeya Newspapers Ltd,[14] where the leading national newspaper, Sinhala Daily, is printed. The newspaper is sold in various geographical areas of Sri Lanka. In 2009, to improve operations, Wijeya Newspapers Ltd. decided to join hands with its supplier, General Ink Ltd.,[15] to develop a chemical leasing project, supported by the National Cleaner Production Centre of Sri-Lanka.

The *chemicals applied* involved inks that are water-based/solvent-based. The chemicals used in the process are phenolic resins, hydrocarbon resins, alkyd resins, linseed oil, aromatic rubber process oil, petroleum distillate, pigments and carbon black.

As regards the *scope* of the case study, within the project, a number of options were identified to improve the quality of the printed product, which included increasing productivity and reducing the consumption and waste of ink (since ink is the main raw material used for printing). First, ink waste streams occurring during spraying, drum spills and duct cleaning were analysed. Improvements were implemented to reduce ink waste during the process, and a drum rubber beading wiper was installed to stop drum spills.

The basis for payment before the introduction of chemical leasing has been Sri Lanka rupees per kilogram of ink. Waste of considerable amounts of ink (solvent) has been generated during the printing process (about 15 % of total ink). The ink for the initial copies of the run (400 copies) was wasted until the print image is corrected. There was a high amount of ink consumption to print 1 m^2, and the ink consumption amounted to 14,000 kg per month. Given ink penetration from machine speed meant that the floors have to be cleaned once or twice every day. There have also been occupational health problems and increased wastewater generation and treatment costs.

Outcome of chemical leasing

The pilot project has demonstrated that both ink suppliers and printers can benefit from optimised ink usage in newspaper printing (estimated benefits after the full introduction of chemical leasing). The basis for payment has been changed to Sri Lanka rupees per printed copies of newspaper.

The *economic benefits* included a reduction in ink consumption by up to 7 % (3 year target) and annual ink savings

[13] According to the material safety data sheet, no significant effects or critical hazards on human health are known and no information on ecotoxicity is available.

[14] Newspapers Ltd, the ink user, is the leading Sri Lankan newspaper printing company (15 million newspapers per month) and has 1,500 employees.

[15] General Ink Ltd, the ink supplier, is a medium-sized Sri Lankan company with about 50 employees. The supplier has a strong market share, especially in newspaper printing.

of 14,976 kg. Direct ink cost savings amounted to Sri Lanka rupees 5,091,840=US$ 50,000 per year.

The *environmental benefits* included the reduction of ink waste; the improvement of occupational health and safety standards; the reduction of wastewater generation; an improved environmental management system; and compliance with environmental regulations on waste management and work place environment.

The *social benefits* included improved working conditions; better occupational health and safety of employees; the improvement of employee motivation; and long-term business relationship between the partners leading to process improvement and innovation.

Category B

Case study 5: cleaning of pipes and tanks in the food industry (UBA 2010)

A typical business model envisages that chemicals for cleaning pipes, tanks and containers are purchased on the basis of a price per unit volume or weight. This means that the more chemicals are used, the greater is the supplier's profit. With chemical leasing, payment is based on the amount of the final product obtained (e.g. kegs of beer or tons of chocolate) or per operation hours of the cleaning system. Compliance with strict purity specifications and hygiene regulations is a core part of the chemical leasing contract of the partners.

The chemical leasing case study for cleaning of pipes and tanks in the food industry was initiated by UBA and has been successfully implemented in the sector meanwhile. Consequently, the use of quantitative chemical leasing has today established a strong presence in this area. According to statements made by manufacturers of cleaning products, there are more than 300 chemical leasing contracts in breweries (personal communication).

The main areas of application are breweries, dairies, fruit juice industry, bakery and confectionery products, fish processing and meat processing. The supplier structure in Germany affects 14 equipment suppliers and about 120 chemical suppliers.

Outcome of chemical leasing

The chemical leasing business approach in this sector leads to a lower consumption of cleaning agents. These reductions are due to process optimisation and can be expected to be stable. The lower consumption leads to a reduction in waste and to reduced effluent load. The analysis of the UBA pilot project in this sector showed a reduction of 30 % for acid, 25 % for solvent and 10 % for stabilizing agent; the use of alkaline cleaning agent remains even. Energy will also be conserved, both through direct effects (e.g. less heating and pumping due to fewer cleaning cycles) leading to an approximate reduction of 10 %, and indirect savings due to a reduced flow of materials leading to an approximate reduction of 25 %.

The realised savings in chemicals used, waste, wastewater and energy are in particular achieved by optimised Computer Integrated Processing, which are continuously measuring the process parameters and the use of special additives and stabilisers. There is a remarkable new development in the field of chemical leasing when already in the design and construction of production facilities, e.g. in a brewery the application of chemical leasing is integrated.

Problems with regard to the use of chemical leasing in this sector relate to the distribution of the efficiency gains that go mainly to the user. At a workshop in Mexico, German manufacturers have introduced the business model and are contacted with Mexican customers (personal communication). This shows that potential major export opportunities exist.

Case study 6: use of abrasives in the metal industry (UBA 2010)

The research on alternative uses of abrasives in the metal industry was initiated by the UBA. The conventional method of charging for the amount of abrasive used in the metal industry is replaced by charges. These are either based on the area of sheet metal being treated or on the length of ground rail. The contractors have an interest in using as little abrasive as possible.

This example does not involve chemicals in the narrower sense or within the meaning of legislation on chemicals safety,[16] because abrasives are classified as tools or "articles". However, the example shows that the principles and quality criteria applied in chemical leasing are applicable in this sector.

Outcome of chemical leasing

Chemical leasing is very well established in this sector with over 100 contracts in the metalworking industry and in foundries. Through user-oriented chemical leasing contracts particular measure to extend the service life of abrasives are initiated. This leads to a reduced material consumption and therefore to environmental benefits in terms of resource and energy consumption amount of waste and wastewater. Products with low material consumption (e.g. diamond grinding

[16] The major legislative act on chemicals safety in Europe is provided by REACH—Registration, Evaluation, Authorisation and Restriction of Chemicals—Regulation (OJ 2007). Article 3 defines articles as "means an object which during production is given a special shape, surface or design which determines its function to a greater degree than does its chemical composition."

tools) are preferably used. The chemical leasing business model leads to about 40 % reduction in the consumption of abrasives. This in turn leads to a corresponding reduction in waste. Air emissions are also reduced, although these could not be quantified in this case study.

As barriers to wider implementation of chemical leasing in this sector, in particular, liability issues and billing procedures are called. Potentials and opportunities are seen especially in EU countries where diamond tools show strong growth in market share. A use in developing countries is evaluated sceptically as the actors expect problems due to billing practices.

Case study 7: metal cleaning (Jakl and Schwager 2008)

Research on applications of chemical leasing for metal cleaning was partly funded by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management, and meanwhile there is a rapid expansion in Germany and Europe. The provider of the chemical leasing for metal cleaning is a consortium of two players: The manufacturer of the cleaning machine and the producer of the cleaning agents. The unit of payment is Euro per hours of operation of the cleaning machine.

The chemical leasing business model of the provider of the cleaning agents includes safe delivery, storage, on-site transportation, transfer of solvent and take-back of waste by deploying a certified container system. Thereby, worker exposure is reduced by avoiding emissions during solvent transfers. The concept includes professional oil–solvent compatibility determination, analytical solvent quality monitoring and subsequent process recommendations as well as optimization of stabiliser additions and fresh solvent usage, without compromising the cleaning performance, due to increased solvent lifetime. Furthermore, documentation of solvent quality monitoring results provides the possibility to monitor improvements and increasing the equipment recycling efficiency on-site leads to minimization of solvent waste.

Outcome of chemical leasing

Environmental benefits are achieved through the closed container and cleaning machine systems: There are virtually no emissions to the working environment and mankind. The solvent consumption savings are due to an optimisation of solvent maintenance and machine technology improvement. The development of less solvent usage at customer sites leads to reduced solvent production at provider, which is also the producer of chemicals. This, in turn, is strongly linked with energy savings. Through enhanced coordination of cleaning requirements, cleaning machine and detergent the consumption of chemicals can be reduced more than 20 % compared with cleaning systems, which are considered state-of-the-art. In addition, energy savings of over 25 % can be achieved compared with conventional cleaning systems.

In terms of economic benefits, the applied chemical leasing business model enables customers to achieve the required quality by using the optimum solvent technology within an optimised cleaning process and therefore keeps them competitive in global markets and improves public image for all involved partners. Furthermore, the customer can also benefit from energy and waste management cost reductions. The economical benefits for the provider are foremost sustainable growth, added-value creation, customer loyalty and additional business opportunities for partners. The enhanced customer loyalty leads to cost effectiveness of the sales efforts and intensive partnership. Moreover, training, monitoring and continuous solvent recycling are part of the overall solution chemical leasing in this application.

Case study 8: surface coating (UBA 2010)

In a typical chemicals business model, substances are bought for the pre-treatment or coating of surfaces by weight, so that the revenue of the supplier of chemicals increases if more chemicals are consumed. With chemical leasing, the payment is based on an agreed price for each unit area, which is pre-treated or coated. As units of payment various user-oriented accounting variables are used: Euro per square meter surface coated or pre-treated surface; Euro per basket purified components; Euro per hours of its operation; Euro per month.

Chemical leasing in the surface coating is characterised by its technical diversity. Most applications are in the areas of cleaning, pre-treatment and coating of metal surfaces. Chemical leasing is established as a principle along the entire production chain.

Outcome of chemical leasing

The chemical leasing business model leads to process optimisation and the reduced consumption of chemicals for surface treatment (pre-treatment/powder coating). These reductions can be quantified as follows—20 % reduction of cleaning agents; 5 % reduction of phosphating chemicals; 15 % reduction of powder-based paint. The reduced consumption also leads to indirect energy savings of about 15 % (through material flows) and direct energy savings of less than 5 % (as the result of process changes).

The chemical leasing case study for surface coating was initiated by UBA, and currently, over 20 contracts are realised in Germany. Success factors include simple contracts and a detailed explanation of the benefits to the customer. Thus, for example, the supplier of cleaning agents is satisfied with the developed chemical leasing price mechanism. Potential lies in particular in connection with the REACH Regulation (EC 2006) and any required authorisation processes. Chemical leasing business models in the sector of surface coating are currently also successfully exported.

Assessment of the contribution of the chemical leasing case studies to sustainable chemistry

Using available information on all eight case studies presented in the section on "Case studies" and on the grounds of the methodology described in the section "Assessment methodology" we have synopsised our evaluation in Table 2. As this table shows, for all of the four basic goals, there is a varying number of sub-goals g_{ij} across the different case studies, for which either no data are available or where sub-goals g_{ij} of a specific basic goal g_i were not relevant.

On average, evaluation of the promotion of sustainable chemistry through chemical leasing could be provided for approximately half of the 23 sub-goals g_{ij}. Evaluation of sub-goals $g_{4,1}$ to $g_{4,10}$ of goal g_4 (i.e. increase sustainability in surrounding systems) has proven to be particularly difficult to assess. However, given that according to our method, a single positive measurement is, *ceteris paribus*, sufficient for the positive evaluation of any basic goal, a large number of missing values do not impede a positive overall evaluation of sustainability.

Apart from that, there are a small number of evaluation scores equal to {0}, which were deemed not relevant, since they could not apply to the case study under consideration. All these scores refer to basic goal g_2 (reduction of adverse effects on health and environment) and mainly to achievement of substitution of carcinogenic, mutagenic and toxic chemicals. Since some chemicals used before introduction of chemical leasing did not have such properties and were not substituted for by alternatives after the application of chemical leasing, there is no reason for assessing any contribution of chemical leasing to sustainability. Again, the non-relevance of a few criteria does not impede a positive overall evaluation of sustainability.

Regarding the achievement of the four basic goals and their sub-goals as means to promote sustainable chemistry through chemical leasing, we remark:

- When basic goal g_1 is reached, not only the use of chemicals, but particularly the volumes of waste and wastewater are reduced by the application of chemical leasing.
- Basic goal g_2 is most frequently met by achievement of a reduced impact on labour health.
- Similarly, basic goal g_3 is most frequently met by achievement of optimised handling, storage and logistics.

It is less apparent how basic goal g_4, i.e. sustainability in a broader context of a case study, can be promoted through chemical leasing. Possibly due to the large number of missing values, results of our assessment do not indicate a clear pattern of prevailing sub-goals $g_{4,1}$ to $g_{4,10}$ under this basic goal. In terms of the assessment methodology elaborated here, we suggest that there is a need for more dedicated information about the linkages of chemical leasing to sub-goals, such as reduced impacts on consumers' health, regional poverty or greenhouse gases.

According to our assessment, chemical leasing, within our proposed methodology, can be regarded as promoting sustainable chemistry in five case studies with certainty. However, on the grounds of our assessment, we cannot conclude with certainty that chemical leasing has equivalent contribution to sustainable chemistry in respect of three further case studies. Two of them are concerning projects in category A (drinking water and news paper printing), and one is a sector study (abrasives in the metal industry). Uncertainty about the promotion of sustainability may be attributed to different reasons, i.e. regarding achievement of different basic goals. In case study 2 (drinking water), increase in overall resource efficiency has not been assessed to improve after chemical leasing. In case study 4 (news paper printing), introduction of chemical leasing has not been proven to enhance expected substitution of hazardous chemicals with chemicals of lower risk. In case study 6 (abrasives in the metals industry), available information is not sufficient for qualifying sustainability in a general context, for recycling and use of cascades have not actually improved after introduction of chemical leasing. In the case of the sector studies (category B), energy savings through chemical leasing could be demonstrated. The gross of the energy savings in these examples derived from an energy reduction due to less produced chemicals to be used in the applications.

The application of chemical leasing actually promotes sustainability in comparison to existing chemicals production and management system especially in the areas of chemicals used and the linked resource demand for their production, waste and wastewater volumes for all analysed case studies (category A+B) as well as for energy savings for the sector case studies (category B). For other areas, the effect of chemical leasing is not yet penetrated completely. This might be explained by shortcomings in terms of the current practice to assess the effects of chemical leasing in the respective basic goals areas.

Outlook for further work on chemical leasing and sustainable chemistry and conclusions

Outlook for further work on chemical leasing and sustainable chemistry

Data availability

The analysis of chemical leasing contributing to sustainability revealed that for many sub-goals no specific data are available. Especially the sub-goals comprising the basic-goal g_4, *increase sustainability in surrounding systems* display severe data gaps in reference to all eight case studies. We suggest that there is a need to gather more information on potential effects of chemical leasing in regard to sustainability, covering also regional and trans-ecological issues related to sustainability as comprised by the list of sub-goals presented in this study. We assume that the contribution to sustainability will rise with an increase in data acquisition, especially in the fields were no data are available so far. In principle, the analysis of chemical leasing projects is currently only possible for successfully established pilot projects since only for this type of project are non-confident data available. Moreover, the basic principle of typical chemical leasing—i.e. a manufacturer is offering a chemical within a service (e.g. cleaning, sizing, painting, solving)—has been applied in chemical industry for years and is practiced by individual companies in different variations. A systematic penetration of processes or industries has not happened as well as public communication or a holistic scientific review has not taken place yet. Moreover, a systematic recording of all exiting chemical leasing activities is simply not feasible today. There are two main reasons for this:

1. Potential partners in the chemicals sector, which have switched from mass selling of chemicals to service orientated business models are using so-called grey chemical leasing services. At the best, the proposed service applies the same basic principles but does not use the name chemical leasing. This would be then also typical chemical leasing, concerning the definition of UNIDO, Austria and Germany.
2. Confidentiality and knowledge maintenance of the actors involved is crucial to many actors in the field of chemical service solutions. For providers of the chemical leasing service, this hindrance has the chance to overcome mostly only with long-standing customers. Trusted business relationships are crucial in areas where companies put high efforts in evolving specialised technical solutions. Even then, the willingness to advertise and publicise chemical leasing activities might be low due to persistent confidentiality reasons.

Methodological considerations

The proposed methodology is a first attempt towards the question whether a specific chemical leasing case study can be considered to contribute to sustainable chemistry with an acceptable level of certainty. As a threshold limit for this first approach, we have set the condition that for each basic goal g_i; the aggregated scores need to be larger than zero (see Eqs. 2, 3, 4 and 5). This can be seen as a minimum requirement to arrive at an acceptable level of certainty.

The following five examples outline possible approaches to refine the methodology in the future.

1 Threshold limits x_i for the condition set out in Eqs. 2, 3, 4 and 5 can be set more strictly as follows:

$$\sum_{j=1}^{4} g_{1j} > x_1 \quad (6)$$

$$\sum_{j=1}^{6} g_{2j} > x_2 \quad (7)$$

$$\sum_{j=1}^{6} g_{3j} > x_3 \quad (8)$$

$$\sum_{j=1}^{10} g_{4j} > x_4 \quad (9)$$

with $x_{1,2,3,4} > 0$ *and* $x_1 = x_2 = x_3 = x_4$. This would raise the threshold value for conclusions whether a chemical leasing case study can be considered as contributing with certainty to sustainable chemistry.

2 The threshold limits x_i for each basic goal g_i can be set in such that $x_1 \neq x_2 \neq x_3 \neq x_4$. This would accord a different importance to the four basic goals g_i that may result in more refined conclusions with regard to the contribution of case studies to sustainable chemistry. This could be important, when, for example, evaluating case studies from the two categories A and B.

3 Moreover, it will be possible to introduce weighing factors y_{ij} for each sub-goal g_{ji}. The calculation of the Total Score would be modified as follows:

$$\text{Total Score} = \sum_{i=1}^{4} \sum_{j=1}^{n} y_{ij} \cdot g_{ij} \quad (10)$$

4 Our analysis of the case studies provided information on the linkages of some chemical leasing project studies to other aspects that promote the environmentally sound management of chemicals. This could comprise the areas of policy-making and legislation and the extent chemical leasing promotes, for example, compliance with multilateral environmental agreements, regional legislation on chemicals management (for example REACH), or national legislation. The impact of the implementation of chemical leasing on a broader definition resource efficiency or substitution as well as on environment and health could be included as well. These additional positive impacts have

not been included in the calculation of the Total Score as suggested in the current methodology on assessing sustainability of chemical leasing case studies. Here, additional sub-goals g_{ji} that cover the above aspects could be added as a refinement.

5 The current methodology does not take into account 'indirect effects', which would imply that a certain score for a sub-goal g_{ji} would trigger a similar or opposite score for another sub-goal. These inter-linkages exist in reality and their consideration would represent a further refinement of the methodology.

Conclusions

The findings presented in this paper have been derived by comparing the achievement of 26 sub-goals before and after the introduction of chemical leasing for eight case studies. Out of 26 sub-goals, we were able to provide entries for 23 of them. Only for three sub-goals, we were not able to derive any data at all. The sub-goals of concern are all listed under basic goal 4 on increasing sustainability in surrounding systems. They relate to a possible increase of revenues for trade (g_{44}) and for other stakeholders in the supply chain (g_{45}) in the region or country and the reduction of impacts on air, including greenhouse gases (g_{49}).

The fact that no data are available for these three sub-goals can be best explained with the apparent shortcoming in the impact assessment of chemical leasing in surrounding systems. Future research is necessary to investigate whether this is due to a lack of funding to undertake such assessment or whether other reasons, such as flaws in the current assessment approaches, hampers the collection of such data.

In concluding, we reiterate that the main objective of chemical leasing case studies supported by international and government organisations was to set incentives, to overcome hindrances and in this way to initiate the self-supporting dissemination of this business model. In summary, the incentives and communications measures of the case studies should concentrate on informing producers, suppliers and users of the kind of the business model and the raising of the awareness about its advantages. This includes the optimisation of processes and the handling of chemicals. Potential partners need supporting measures to increase trust between them (e.g. by helping to produce the clear and transparent data needed for the monetary settlement) and to overcome the traditional sales concept (payment of chemicals by quantity).

Additionally, suitable financing instruments must meet investment requirements. Last but not least, it is regarded as essential to develop suitable monitoring and controlling systems and to provide further documented pilot projects as references. Besides all external state incentives and targeted communications, it will only be possible to realise the potentials if the participating companies will develop their own initiatives.

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ARTICLE IV

Environmental protection between chemical practice and applied ethics: a critical review

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Abstract

Finding solutions for the struggle to provide food security and access to water are among the most challenging tasks for our century. Chemistry, as one of the principal scientific and technological foundations of modern societies, can provide such solutions.

Chemicals play an important role in the efforts of countries to achieve economic growth and their development objectives. Chemicals, however, can have a dual nature. As much as they are vital for ensuring food security and economic growth, their unsound use can adversely affect human health and the environment.

This paper critically reviews the changes in the perception of society towards the risks of chemicals. For this, risk reduction strategies are put side by side with the advancements of chemistry as a science. The paper also outlines the underlying ethical consideration of risk assessment methods.

As these complex tasks concern as much the field of chemistry as they concern other scientific disciplines, this paper outlines the unique positions of universities to engage such a broad range of different stakeholders involved in these debates. The paper concludes with an evaluation of the role that the higher education organizations can play in integrating these different fields into a single coordinated approach.

Key words: chemistry, science, sustainable development, environmental ethics, universities

1. Introduction

Chemicals are indispensable in the functioning of modern societies. They are produced and used in key sectors of the economy, and the global chemicals turnover in 2012 was valued at EUR 3,17 billion. China presently contributes the largest amount, followed by the United States, Japan, and Germany. In the European Union (EU) the chemical industry employ a total of about 1.2 million persons and has contributed to 1.1 per cent of the EU's Gross Domestic Product (GDP) of the EU. Chemicals play a particular role in the industrial sectors in the EU, such as the rubber and plastic, construction, pulp and paper, and the automotive industries. But also other sectors, like agriculture or services benefit from chemicals industry (CEFIC 2013).

It is evident that chemistry is one of the principal scientific and technological foundations of the modern world and plays an important role in the efforts of developing and developed countries to achieve the development objectives of the MDGs (MDGs 2000). At the same time, many chemicals pose threats to human health and the environment through emissions to air, water and soil as well as through the generation of wastes. Direct risks of some chemicals to human health were already perceived in the early twentieth century, but their indirect impacts on the environment were only recognized when their production volumes and open applications tremendously increased in the second half of the last century.

As a consequence, new laws and international treaties have been introduced at the national and global levels. This has happened often from the moment societies became aware of the respective global ecological problems (Moser and Dondi 2012). Table 1 provides a timeline of action taken by the international community in the 20th and 21st century.

Table 1. Landmark events and treaties on the protection of the environment from industrial and agricultural chemical pollution

Year	Description
1948	International Union for Conservation of Nature
1972	United Nations Conference on the Human Environment
1972	Establishment of United Nations Environment Programme (UNEP)
1972	Club of Rome (Limits to Growth)
1979	Convention on Long-range Transboundary Air Pollution
1985	Vienna Convention on the Protection of the Ozone Layer
1987	Montreal Protocol on Substances that Deplete the Ozone Layer
1987	Our Common Future Report of the World Commission on Environment and Development

Year	Description
1989	Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal
1992	United Nations Conference on Environment and Development/Agenda 21
1992	United Nations Framework Convention on Climate Change
1997	Kyoto Protocol
1997	Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction
1998	Aarhus Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters
1998	Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade
2000	Protocol on Liability and Compensation for Damage Resulting from Transboundary Movements of Hazardous Wastes and Their Disposal
2001	Stockholm Convention on Persistent Organic Pollutants
2003	Kiev Protocol on Pollutant Release and Transfer Registers to the Aarhus Convention
2002	Johannesburg Declaration on Sustainable Development
2003	Protocol on Civil Liability and Compensation for Damage Caused by the Transboundary Effects of Industrial Accidents on Transboundary Waters
2006	EU regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)
2013	Minamata Convention on Mercury

Table 1 will serve as a basic reference of this paper. It allows a both a synthetic and analytical overview on how the international community has addressed environmental problems in the past sixty years. Many of these events and treaties directly and indirectly address chemistry or environmental problems that are related industrial and agricultural chemical pollution.

As is evident, chemistry represents a root cause for environmental degradation. At the same time, chemistry provides solutions to identify and better understand the risks of chemical pollution, for example, with the development of analytical instruments. Finding solutions to address this dual nature of chemicals is a challenging task that calls for a deeper understanding of the ethical principles of chemistry. Here, chemists must accept that they have a particular responsibility in resolving this dichotomy.

Nobel laureates like Roald Hoffmann and Richard Ernst have been showing dedication and keen interest in reforming the mission of scientists. Both were of the standpoint that scientists should no longer work purely to advance the scientific knowledge. Instead, they should strive to perform their work with the highest standards in ethics and responsibility (Hoffmann 1990; Kovacs and Weisberg 2011; Ernst 2003; Ernst 2007a; Ernst 2007b). This also calls for a deeper understanding of the relationship between men and nature. Here, Prigogine and Stengers proposed that men should move away from the common notion that nature can be possessed. Men should rather form an alliance with nature (Prigogine and Stengers 1984). Recognizing the underlying ethical principles of well-established approaches of addressing environmental problems, such as Environmental or Green Chemistry, became an increasingly important undertaking.

The past decades has also witnessed a deep and radical change of how the environmental crisis is perceived by society. It is not anymore a nature in danger, but a world at risk. The views and opinions of laypersons, public advocacy groups or non-governmental organizations need to be taken into account in finding solutions for management of risks of chemicals at the global level. Contributions by specific groups of society, such as laypersons, are equally important. Authors like Lovelock have no doubt that "actions taken by individuals [...] could halt the growing depredation of the Earth" (Lovelock 1979, 120).

However, addressing the risks of chemicals and the implications to sustainable development are far to complex to be solved within the boundaries of the field of chemistry alone. The tasks ahead concern as much the field of chemistry as a discipline as they concern the social sciences. This warrants a closer integration of the humanities in the continuing debates on addressing the risk of chemicals for human beings and the environment with a view to better understand the underlying ethical considerations.

The purpose of this paper is to highlight this complex process of integrating these different fields into a single coordinated approach. It follows chronologically the changes in the way society perceives the risks of chemicals and describes how risk assessment methods in chemistry have changed in the past decades. The major achievements in reducing these risks then are put side by side with the advancements of chemistry as a science and, in particular, of analytical equipment. This paper will also identify the relevant sociological, philosophical and economic aspects of assessing the risks of chemical substances.

We will conclude with an outlook on the role that higher education organizations can play in the ongoing debate on assessing and managing the risks of chemical substances. Particularly universities have a unique position to engage a broad range of different stakeholders involved in these debates. They must therefore assume a lead role in achieving these objectives (Ernst 2007a; Ernst2007b).

This paper represents a first attempt to describe the different developments in social and moral ethics in chemistry in a concise and coherent manner. It must be noted that it does not encompass plagiarism, data manipulation and other ethical concerns related to the praxis of conducting research. While we maintain that the paper is far from being exhaustive, we believe that we are in a position to conclude with a first outlook of how universities can shape the education of future chemists in embracing ethical concerns in chemical sciences.

2. Chemical industry in the 19th and early 20th century and the scientific instrumental revolution

Chemical industries have been established as early as the 18^{th} century. In their beginning, they have serviced a broad range of different sectors, such as the glass, paper or textile industries. Also, the growing population in the middle of the 20^{th} century forced countries to increase their agricultural output to feed the people. As a result, artificial fertilizers needed to be produced in large quantities.

By then chemical industry focused on synthesizing inorganic and mineral compounds. Organic chemistry was born with the synthesis of urea by Friedrich Wöhler only in 1828. It has grown, in the first part of the 20^{th} century, into one of the most important sectors of chemical industry. This was spurred by the increasing needs of synthetic dyes, pesticides, such as DDT[41], or certain other pharmaceuticals, such as acetyl salicylic acid (Aftalion 1991; Landau 1994; Arora and Rosenberg 1998; Murmann and Landau 1998).

Chemists in these early days of chemical industry had one primary objective: to transform inorganic and organic raw materials into commodities through chemicals synthesis. Chemistry as a profession was entirely subsumed in the efforts of countries to strengthen their economies.

In the first half of the 20^{th} century, society considered the environment as a repository for industrial activities. It also did not believe that producing and using chemicals was risky. In fact, it was a common believe that chemicals would simply disappear once released into the environment (Colten 1994; Landau 1994). This view was spurred by general lack of analytical instruments and knowledge of environmental pollutants. In fact, society gained the ability to analyse the physical properties as well as the nature and composition of such pollutants only at a much later stage.

Thus, scientific information derived through analytical methods, which would pinpoint the effects of chemicals in the environment, was hardly available by that time (Baird 1993). Accordingly, not much information on the environmental impact of the activities of the chemical industries of countries existed before the 1950ies (Landau and Rosenberg 1992; Stine and Tarr 1998). This, however, has changed dramatically in the 1950ies and 1960is of the last century. Tragic industrial accidents involving chemicals draw the public attention to an uncontrolled use, and sometimes misuse, of chemicals.

As much as these accidents revealed that industrial technologies were often inadequate, these decades were also characterized by the progress made in analytical science. The so-called scientific instrumental revolution increased the sophistication and precision of analytical instruments and methods. In the period from 1920 to 1950, various analytical instruments and methods have been developed. From the 1950ies on, chemists were able to use various analytical methods, such as infrared, ultraviolet, and nuclear magnetic resonance spectroscopy (NMR) or mass spectrometry (MS) (Baird 1993). James Lovelock, for example, has worked in the 1950ies on the smog in Los Angeles and invented the electron capture detector in 1957 (Lovelock 1958). His work laid the fundament for the ground-breaking discoveries of the persistence of chlorofluorocarbons (CFCs)

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[41] DDT or dichlorodiphenyltrichloroethane is an organochlorine insecticide. While DDT has been first synthesized in 1874, its insecticidal properties have been discovered in 1939 only.

and their role in stratospheric ozone depletion (Rowland and Molina 1975; Crutzen 1974) in the 1970ies.

Thanks to the instrumentation revolution, it was now possible to analyse the chemical composition of an unknown sample. However, identifying complex cause and effect relationships was still not possible with the instruments available in the 1960ies. This still required another revolution in the 1980ies: the raise of the personal computer. Refining analytical methods, such as gas chromatography (GC), high-performance liquid chromatography (HPLC), and the related hyphenated techniques GC-MS, or HPLC-MS further supported this development. This and the advancements in environmental toxicology allowed defining the problems of environmental contamination in a more precise and reliable manner. The formation of public advocacy groups on environmental issues has been a direct result of this increased awareness and knowledge of environment problems. The following section describes their origins and foundations.

3. The dawn of environmental awareness in the 1960ies and 1970ies

Environmental conservation efforts started as early as the late 19th century. However, the environmental movement received momentum only in the decades after the Second World War. More precisely, this happened in the 1960ies, when societies started to realize the properties and behaviour of chemicals in the environment are not well understood (Dunlap 1981; Colten 1994; Worster 1994). The growing awareness was partly due to the increases in wealth in the post-war years. This has changed the opinions of citizens that pollution was a necessary result of economic growth (Hays and Hays 1989). Also, the 1960ies marked the dawn of carbon chemistry with an intensifying use of chemicals, pesticides, and organic solvents.

The releases of such chemicals into the environment and the generation of hazardous wastes were major driving forces for the emergence of environmental movements in that decade. Rachel Carson, with her book “Silent Spring” (1962), was one of the founding figures of this movement (Rome 2003) and she greatly influenced the public opinion of environmental problems. Her discoveries were amplified by increasing evidence that an unregulated use of chemicals can become a threat to public health and the environment (Smith 2000).

What added to the complexity of the debates in the 1960ies, was that many chemicals that were used by that time, like dichlorodiphenyltrichloroethane (DDT), showed a low acute-toxicity. Nonetheless, the environmental movements were able to prove that their overuse and environmental releases causes problems.

The 1970ies then were recognized as a decade, in which an increased use of chemicals in agriculture and commodities incurred unknown environmental and societal risks (Commoner 1971). This was proven in a tragic manner by a series of industrial accidents. An example in Europe is the release of about 1 kg of the highly toxic and persistent 2,3,7,8-tetrachlorodibenzo-p-dioxin at Seveso, Italy, in 1976. Through this accident a residential area of 20 km^2 with more than 100,000 inhabitants was contaminated. An even more severe accident at Bhopal, India, in 1984 led to the release more than 30 tons of methyl isocyanate from an insecticide production site close to the main train station into the atmosphere. This resulted in the immediate asphyxiation of about 8000 people and an overall estimated death toll between 15,000 and 30,000.

Scientists in that time also became increasingly sensitized to the dose response principle (“dosis sola venenum facit”), which is generally attributed to Paracelsus. The principle states that any chemical has toxic properties depending on the dose by which humans and ecosystems are exposed to it. Toxicologist, therefore, inferred that safe chemicals do not exist. Thus, the argument that releases of chemicals into the environment are risk-free did not hold anymore (Løkke 2006). In fact, dose dependent chemical laws all over the world are still based on these findings. Implementing such laws required the identification of threshold levels below or above of which exposure to the chemical of concern can be considered safe or toxic. Toxicologists have been instrumental in identifying such levels in the following decades (Rozman and Doull 2001; Rogers 2003). However, equilibrium and non-equilibrium processes are yet another aspect that still needed to be discovered. This included the bioaccumulation, biomagnification or long-range transboundary transport of chemicals in the environment.

As is evident from this section, the prevailing perception of society in the 1960ies and 1970ies was that nature itself was at risk. Environmental laws and improved technologies have been the predominant means to mediate these risks. Countries, however, soon became increasingly reliant on atomic energy and other high-risk technologies. This shift fundamentally changed the views of society towards risks. It is also the onset of the broader concept of "Risk Society" introduced by Ulrich Beck in 1992 (Beck 1992). Other economic, sociological and philosophical consideration entered the stage, too. This will be the topic of the following section.

4. The changing perception of environmental risks in the 1990s and 2000s

Industrial production in the 1980ies shifted towards high-risk technologies. Accidents, like the nuclear disaster in Chernobyl in 1986, have not only changed the perception of society towards environmental risks. They also placed the concept of responsibility in a more prominent light. Authors like Hans Jonas considered the responsibility of individuals and states as an imperative feature of society (Jonas 1984). The emphasis on responsibility also changed the traditional fields of environmental ethics.

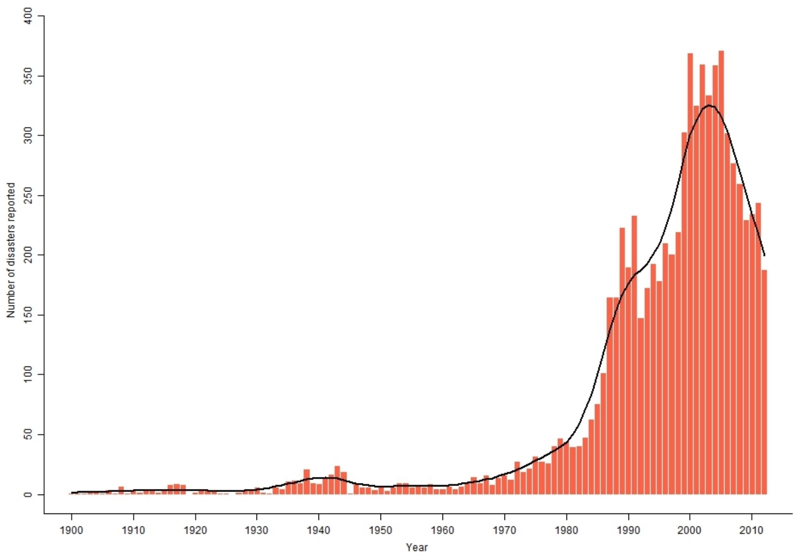
Hans Jonas' milestone publication on "The Imperative of Responsibility: In Search of an Ethics for the Technological Age" (Jonas 1984) and Ulrich Beck's book on "Risk Society" (Beck 1992) are renowned contributions that will form the basis for this section. Both authors sought to advance the field of ethics as a philosophical discipline to meet ethical demands of the technological age. Ulrich Beck described the social order of the reflexive modernity as 'Risk Society'. According to Beck, the public is largely exposed to risks that have emerged as a product of modernization itself (Beck 1992, p. 21). This can include, for example, nuclear power generation, climate change or the production and use of chemicals. We will limit our discussion in this paper to the topic of chemicals.

The so-called first modernity is the predecessor of the reflexive modernity. Here, chemicals have played a key role to overcome material needs in the emerging industrial societies. This was relevant for combatting famines and diseases (Beck 1992; Strydom 2002; Landes 2003). Chemicals, in fact, continue to play an important role in the reflexive modernity. However, it became increasingly clear that many chemicals that are developed to provide benefits are, at the same time, capable of doing harm. Chemical weapons are an example for substances that possess such a 'dual nature'. These chemicals or their precursors can either be peacefully applied in the production of goods or be used as chemical warfare agents. The Chemical Weapons Convention (see Table 1), which entered into force in 1997, is a global treaty that bans a list of chemicals that exhibit such a dual nature (Trapp 2008).

The above-mentioned industrial accidents in Bhopal and Seveso in the 1970ies and 80ies not only brought the debates on the risks of producing and managing hazardous chemicals into the public sphere. They also revealed serious flaws in the production processes themselves. This concurred with general trend to minimize production and labour costs at the expense of safety standards and an ever-growing pressure of fast moving markets to decrease of the time to bring products to the market.

As can be seen in Figure 1, technological disasters have increased exponentially since the chemical accidents in Seveso and Bhopal and nowadays still remain at a high level. One of the reasons for this is that the industrial production of chemicals often has shifted to developing countries, which lack the technical and institutional capacity to ensure that chemicals are produced according to international safety standards.

Figure 1: Technological disasters reported from 1900 to 2012



Source: database of the Universitè Libre de Louvain (http://www.emdat.be/database) accessed on 13 February 2015

The above challenges as well as the continuing introduction of new chemicals into global markets and the related doubt about their immanent risks increasingly began to impact the debates between scientists and decision-makers on the underlying ethical aspects of producing, using and assessing the risks of chemicals. These discussions also considered the context of sustainable development and depleting natural resources.

The hypothesis of unlimited growth has been the chief economic model in the decades after World War II. It was first challenged in the report of the Club of Rome (Meadows et al. 1972), a landmark publication that shaped the outline of the principle of sustainable development. The discussions informed the report of the World Commission on Environment and Development (WCSD) on "Our Common Future". The report was transmitted to the General Assembly of the United Nations in 1987 (Brundtland 1987, see Table 1). It considers sustainable development as a key ingredient for ensuring economic growth in the 21st century.

Since 1960ies, many concepts and principles have been discussed and developed to address environmental and human health risks. The debates on environmental protection now focused on new and innovative concepts, such as sustainable development and the precautionary principle. The deliberations in this new field of ethics culminated in the United Nations Conference on Environment and Development (UNCED) in 1992, as upheld by Callicott and Da Rocha (1996). The United Nations Conference on Environment and Development was a landmark event, which gave these ideas the proper place and audience. The Rio Declaration contains 27 principles, including the concepts of sustainability, responsibility or the precautionary principle. It guides countries in their efforts to address environmental and development issues (UNCED 1992).

Besides the international action taken at UNCED, the community of chemists was able in that time to optimize production procedures and technologies. This also included new ways of selling chemicals. These activities led to a safer production and use of chemicals and took increasingly into account ethical considerations. Nonetheless, this period also saw a strong, and perhaps increasing, divergence between the two cultures of science and technology. This contrast has created both opportunities and challenges for managing the risks of chemicals.

Countries in these two decades also negotiated a range of multilateral environmental agreements (MEAs) that aim at protecting human health and the environment from the adverse effects of hazardous chemicals and wastes. The 1989 Basel Convention deals with the Control of Transboundary Movements of Hazardous Wastes and their Disposal. The 1998 Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides deals with international trade of chemicals. Finally, the 2001 Stockholm Convention deals with the production, use and disposal of Persistent Organic Pollutants. All three MEAs aim at reducing the risks of chemicals and waste management (UNDESA 2011, see Table 1).

The International Labour Organization, for example, is setting standards for safe use of chemicals at work such as the Conventions on safety in the use of chemicals at work (No. 170, 1990), and the Prevention of Major Industrial Accidents (No. 174, 1993). Protecting workers from the harmful effect of chemicals has also been supported by the development of chemical safety information systems. (Obadia 2003)

These examples outline the progress made in environmental diplomacy in the United Nations system. It is evident that these efforts of the international community to address these challenges were to be supported by the development of strategies to manage and assess the risks of chemicals through other actors. This paper focuses on regulation and the development of innovative approaches to manage the risks of chemicals by industry.

5. Innovative solutions for managing the risks of chemicals

The implementation of national laws and international environmental treaties has been a direct result of the growing knowledge of societies of the impact that chemicals have on human health and the environment. This has been partly due to the advancements in science and public awareness described in the preceding sections. But also the advancements in environmental law making supported this development.

The burden of proof, for example, is a specific domain of environmental law and an important step in regulating chemical substances. This area saw a drastic evolution in the past decades. Historically, it was under the authority and responsibility to proof whether certain chemicals are to be regulated or not. The European Union (EU) Regulation on Chemicals and their Safe Use, which entered into force in June 2007, has shifted the burden of proof to manufactures of chemicals that seek to introduce certain chemicals into the EU market. A key objective of the ordinance on the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) is to strengthen the environmentally sound management of certain chemicals while, at the same time, ensuring competiveness and innovation of the European chemicals industry, which is a key requirement in fast-moving global industries.

Studies suggest that the introduction of REACH helped the development of a single chemicals market by overcoming the burdensome, inefficient and fragmented system that was in place before. (EC 2012) REACH also had a positive impact on the exchange of information across the entire supply chain. This, in turn, has stimulated the identification of innovative market opportunities, which helped to decrease the time-to-market for new substances. At the same time, REACH has set global standards for the manufacturing and use of chemicals that can be replicated in developing countries through 'trading up' processes (Vogel 1997; Seling and VanDeveer 2006). It can be expected that this will help to reduce the likeliness of accidents in manufacturing processes of chemicals, as shown in Figure 1 above.

The objectives of REACH are also aligned with the goals adopted by the Johannesburg World Summit on Sustainable Development (WSSD). These are, by 2020, to produce and use chemicals in ways that lead to minimizing significant adverse effects on human health and the environment. REACH ensures the free movement of substances and seeks to strengthen competitiveness and innovation of chemicals industry. It also promotes alternative methods for assessing hazards of substances (EC 2007; WSSD 2002).

Other examples for national and international legislation that seek to promote the principle of sustainable development includes, for example, the German Act for Promoting Closed Substance Cycle Waste Management and Ensuing Environmentally Compatible Waste Disposal (KrW-/AbfG 2012), the European Community directive 2002/96/EC on waste electrical and electronic equipment (WEEE 2003) or the directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS 2011). These laws promote the closing material flows and restrict the use of hazardous substances. The goal of closed cycle waste management is reached by setting collection, recycling and recovery targets for materials.

On the side of chemical industry, the principle of sustainability resulted in a change of the way by which companies are producing and selling chemicals. For example, Fabrizio Cavani, Gabriele Centi, Siglinda Perathoner and Ferruccio Trifirò in their book on "Sustainable Industrial Chemistry: Principle, Tools and Industrial Examples" stressed the need to adopt new strategies for industrial chemistry as this would lead to lower development and investment costs and quicker market introduction of chemicals (Cavani et al. 2009). Green Chemistry represents another new and emerging field. It aims at achieving sustainability by focusing at the molecular level (Anastas and Eghbali 2010).

Chemical Leasing is another business-centred approach. It seeks to align the objectives of policy makers to reduce the risks emanating from the production and use of chemicals. At same time, Chemical Leasing creates a win-win situation for both the chemicals' producer and the user

(Jakl 2004; Schwager and Moser 2006; Lozano et al. 2013). The United Nations Industrial Development Organization (UNIDO) has played an important role in the global introduction of this business model. It has developed a definition of Chemical Leasing as follows (UNIDO 2011).

"Chemical Leasing is a service-oriented business model that shifts the focus from increasing sales volume of chemicals, toward a value-added approach. The producer mainly sells the functions performed by the chemical, and functional units are the main basis for payment.[42] *Within chemical leasing business models, the responsibility of the producer and service provider is extended and may include the management of the entire life cycle. Chemical leasing strives for a win-win situation. It aims to increase the efficient use of chemicals while reducing the risks of chemicals, and protecting human health. It improves the economic and environmental performance of participating companies, and enhances their access to new markets. Key elements of successful chemical leasing business models are proper benefit sharing, high-quality standards and mutual trust between participating companies."*

Chemical Leasing has vast potential to contribute to a more sustainable production and use of chemicals. Authors argue carrying out chemical leasing increases the effectiveness of managing the risks of hazardous chemicals. It also reduces asymmetric information about their properties (Jakl et al. 2004, 3; Perthen-Palmisano and Jakl 2005; Ohl and Moser 2007; Ohl and Moser 2008; Lozano et al. 2013).

Other voluntary industry initiatives include the Responsible Care initiative. It focuses, among others, on the health, safety and environmental performance of companies and on developing and applying sustainable chemistry. Responsible Care, thus, represents a contribution of chemicals industry to sustainable development (Responsible Care 2014). Chemical Industry in the European Union is thus an industrial sector having the lowest accident and personal injury rates.

As shown in the preceding paragraphs, concerted global action has been taken by many stakeholders to protect the environment from chemical releases. This included introducing new laws addressing chemical pollution at the national, regional and national level and voluntary action taken by industry itself. This action not only made producing chemicals more sustainable. It also curbed environmental pollution through better control mechanisms.

Despite the measures taken, some challenges still remain to be solved. Many entities involved in the environmentally sound management of chemicals and wastes are increasingly acknowledging the necessity to promote gender equality in their operations. Accordingly, the United Nations Development Programme, the Secretariat of the Basel, Rotterdam and Stockholm Conventions or the Global Environment Facility have recently developed actions plans that seek to promote the consideration of gender issues in hazardous chemicals and wastes management in developing countries. (UNDP 2011; BRS 2014; GEF 2014)

The tensions between science and technology and society as a whole are another important challenge that remains to be addressed in a more coherent manner. The following section describes the strains caused by a growing involvement of different groups, such as experts and laypersons, in

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[42] Functions performed by a chemical might include: number of pieces cleaned; amount of area coated, etc.

the debates on the sound management of chemicals.

6. Challenges to overcome the tensions between experts and laypersons and the role of universities

Strains between experts and scientists from the natural and social sciences on one side and the broader public and laypersons on the other side (Strydom 2002; Shrader-Frechette 2010) have been driving factor for the debates on environmental protection. However, these groups often entered the discussions with diverging backgrounds and objectives. These groups not only often have opposing opinions of what frames an environmental crisis, they also used diverging methodological norms to assess and manage the risks of environmental pollution. These norms are further described in this section.

A first methodological norm can be summarized as 'naïve positivism'. It claims that the process of evaluating risks is generally objective. An increasing sophistication of analytical methods and equipment in the 1980ies and 1990ies allowed experts to better understand the complex relationships of chemicals in the environment. Technical engineers or health and toxicology experts were the key advocates of this norm. According to the approach of 'naïve positivism', risks that differ in their nature can be appraised by the same rules. Proponents of this concept also argued that risks below a certain probability are insignificant.

In contrast to the above, a second group of experts followed the methodological norm of 'cultural relativism'. These were mostly social, political, or anthropology scientists arguing that risks are social constructs. Therefore, this group claimed that increasing the knowledge about such risks and more reasoning would not result in a more rational approach of society towards environmental risks (Shrader-Frechette 1991).

A 'naïve positivist' may thus have felt the satisfaction of having more and more sophisticated technological means to assess the risks of chemicals in the environment. At the same time, a scientist belonging to this group would have been increasingly exposed to a controversial discussion of the very methodology he or she used to assess these risks. This is because until the 1980ies the discussions on these risks have mainly taken place within an exclusive group of experts. In the "Risk Society", however, the debates have entered the public spheres with various actors involved. Nowadays, the public and private sectors, academia, and social movements, are contributing, often in decentralized manner, to the debates on risks and the uncertainties stemming from technological advancements (Strydom 2002: 2).

Kerstin Shrader-Frechette introduced the method of 'Scientific proceduralism' as a possible solution to mitigate the conflict between these two opposing grounds (Shrader-Frechette 1991). The method is situated between the extreme positions of 'naïve positivism' and 'cultural relativism'. 'Scientific proceduralism' aims at mediating between the views of technical experts and affected persons. At the core of this method is the belief that laypeople may be able to act as rationally as technical experts when evaluating possible hazards. The method still requires the application of scientific methods and the work of experts, but considers ethical aspects as well.

Key aspects of Shrader-Frechette's proposed norm of 'Scientific proceduralism' remain highly relevant in the debates on how modern societies are assessing technological risks. Scholars like Piet Strydom (2002) have concluded that these debates have entered the public spheres and introduced a new critical theory of the so-called cognitive society. The theory is based on the methods of cognitive sociology and seeks to understand the way in which sociocultural factors shape and guide scientific processes. It discusses in detail the different types of laypersons, or collective agents, involved in the risk assessment debates, such as the public and private sectors, academia, and social movements. A key hypothesis of this work is the inhomogeneity of the various groups of collective agents. Strydom concludes that many collective agents cooperate with each other, but conflicts among the different actors are more the norm than the exception (2002: 2).

As is evident, converging these often opposing standards does not happen automatically, but requires a neutral facilitator. According to Strydom (2002), universities as a collective agent of knowledge have a particular responsibility to foster a crosscutting dialogue among the different actors, particularly if they come from different scientific disciplines, such as science on the one side and sociology or philosophy on the other side. This is particularly important, since these at times complex tasks require the focus and attention of the academic-educational system as a whole. Here, universities are well placed to engage the different scientific disciplines in the advancing debates on environmental protection. In particular, they can play a particular role in ensuring the early and effective participation of different of groups in risk assessment studies and decision-making (Hartley and Wood 2005).

The method of ‘scientific proceduralism’ and the move towards a cognitive society, which have been introduced in this section, can guide universities in fulfilling this task. That is because this method promotes democratic and transparent processes and therefore supports the principles of the Aarhus Convention (see Table 1). It also integrates various environmental, economic, and social aspects, in which all possible alternatives of managing environmental risk are considered and shared.

Resolving this seeming conflict between experts and the often-conflicting groups of laypersons represents an important task for societies. This section has provided evidence how universities can facilitate the debates among the different scientific disciplines and the broader public. We conclude this paper with an outlook for further work in this field.

7. Conclusions and outlook for further work

As shown in the preceding section, societies can benefit from a closer engagement of universities in the debates on managing the risks of chemicals. Universities, as the main provider of both research and higher education, are in fact uniquely positioned to facilitate the debates on contemporary ethical and methodological norms to assess the risks of chemicals (Dondi and Moser 2014). In the following, we will present an outlook for further areas of work for universities.

We concur with scholars, who note a general lack of the ethical principles in the natural science curricula of universities (Frank et al. 2011; Weber and Duderstadt 2012). For these reasons, we believe that universities should feature ethical consideration more prominently in their curricula (Kovac 2003). This enables them to arrive at objective conclusions and findings that modern societies need for progress and prosperity (Morin 1999; Shrader-Frechette 1994; Shrader-Frechette 2014; Bok 2010). In fact, scholars, like Edgar Morin, are of the opinion that universities have a moral duty to prepare future scientists to fulfil their important role they have within society. Morin, in his publication on “Seven complex lessons in education for the future” (1999), maintains that “education should include the study of uncertainties that have emerged in the physical sciences […], the sciences of biological evolution, the historical sciences.” Other scholars, like Kristin

Shrader Frechette, support this by underlining that researchers “have a moral obligation to question the value-laden interpretations of alleged facts that they and others use” (Shrader-Frechette 1994, 61). Courses on the underlying ethical norms of risk assessment methods for chemicals, in fact, can be instrumental for fostering a more widespread application of the precautionary principle in all fields of chemicals management (Strydom 2002; Frank et al. 2011; Dondi and Moser 2014).

On the other side, modern universities benefit from a high professional competence of their teachers and staff and high-tech equipment. They also have the organizational structures in place that ensure, in principle, their independence from external influences. Thus, universities have the right setting that makes them lead institutions for spreading knowledge about the underlying ethical and scientific principles of assessing chemical risks with a view to help level the societal playing field to promote equal opportunities and protection from harm (Shrader-Frechette 2014). Here, universities can support the shift of focus from regulating chemicals towards preventive measures. (Shrader- Frechette 2012) A particular important area for such an engagement of universities is preventing the exposure of vulnerable groups, such as children and women, to endocrine-disrupting chemicals in food and consumer products, as recently recommended by a white paper on developmental toxicity (Barouki et al. 2012). In addition, the recent development of technologies to manage and share information also means that information is more readily available. Universities may therefore have more time available to realign their curricula to teach students the underlying ethical principles of chemicals management.

Given their unique position and role in advancing knowledge on sustainable development, universities should also be more actively involved in the sustainable development agenda (Weber and Duderstadt 2012). In 2012, the Secretary-General of the United Nations launched the United Nations Sustainable Development Solutions Network (SDSN), which brings together a broad array of different groups. The objective of the SDSN is to solve problems linked to sustainable development by mobilizing scientific and technical expertise from academia, civil society, and the private sector. The network is intended to support the Sustainable Development Goals (SDGs), which will build upon the MDGs and converge with the post 2015 development agenda (SDGs 2014).

Many practical approaches exist nowadays that can easily be put in practice by universities. An example is the project on Science Education for New Civic Engagements and Responsibilities (SENCER). This project is geared towards science and technology faculties of universities (Middlecamp et al. 2006; SENCER 2014). By offering a SENCER course, universities can build a bridge between science and civic engagement as recommended by Richard Ernst (Ernst 2003; Ernst 2007a; Ernst 2007b) or recently by Kristin Shrader-Frechette (2014, chap. 15). By adding a green chemistry perspective in a SENCER course in the field of organic chemistry, students have been exposed to other scientific disciplines, such as industrial chemistry, molecular biology or toxicology (Doxsee and Hutchinson 2004; Anastas and Eghbali 2010). This multidisciplinary setting helped to better understand the importance of ‘greening’ of the synthesis of chemical substances (Bhattarcharyya 2010, 87).

Further action can include the active participation in working groups, such as the Working Party on Ethics in Chemistry, which has been established in the framework of the European Association for Chemical and Molecular Sciences (EuChMS) (EuCheMS 2014).

In concluding, we argue that universities should take a more active role and engage in projects and initiatives, such as the EuCheMS Working Group on Ethics in Chemistry, SENCER or SDSN. This will not only prove beneficial for their students who will be exposed to the underlying ethical principles of their work at an early stage in their careers. Through such an engagement, universities will also be able to live up to the important role that is accorded to them by society and shape the discussion on sustainable development and other ethical principles in the 21st century.

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University and the risk society

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The social order of the new modernity is often referred to as "risk society." The growing complexity of the new modernity generates hazards and insecurities at unprecedented pace and level of severity. This necessitates a more informed discourse on the underlying sociological and ethical principles within universities as part of the curriculum and with universities as a collective agent of the risk society. This paper addresses the role, responsibility, and tasks of science and universities in providing solutions to control such hazards and insecurities in a "risk society." We identify three distinct fields. First, we examine how the inherent limits caused by the probabilistic nature of natural laws impacts the work of scientists assessing and forecasting risks. Scientists, when determining risks, often use the Bayesian approach as a surrogate for knowledge. We argue that these conditions often limit the ability of scientists to forecast precisely risk events. We then discuss methods for assessing complex systems with statistical or soft modeling approaches and examine their limits in drawing conclusions from the results of such an investigation. For this, we will highlight a number of examples drawn from the field of chemometrics and engineering science: the inherent type I and type II errors of statistical testing methods as well as the application of soft modeling approaches and conventionalism as an alternative for physical models. We argue that when applying such models scientist should consider the underlying ethical concerns and declare them when reporting the results of their assessment. Failure to declare those ethical concerns may influence validity and reliability of their results. In the third part, we examine the communication between the scientist and the broader public, often laypersons, which are exposed to certain types of risks. Scientists and universities, given their specialization and expertise, play an important role in ensuring transparent communication about research programs that are a concern to public health. The principle of transparency also calls for the disclosure of any potential conflict of interest that researchers and universities may have. This holds particularly true when considering the changing opinion of society towards science's apparent "monopoly on truth".

Keywords: ethics; science; universities; code of conduct; risk management; risk prevention

Introduction

Ulrich Beck, in 1992, described the social order of the new modernity as "risk society." According to Beck, society is exposed to risks that have their origins in the attempt of society to control the hazards and insecurities that have emerged as a product of modernization (Beck 1992, 21).

At the same time, the public perception of environmental risks has fundamentally changed in the last four decades, a trend that continues to gain momentum. While in the past the discussions on environmental risks have taken place within exclusive group of

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experts, this is no longer the case. Today, the discussion has entered the public spheres with debates among different types of collective agents, such as the public and private sectors, academia, or social movements (Strydom 2002, 2).

Collective agents can be either collaborative or in conflict with one another. This paper seeks to analyze their roles in the debate on environmental risks. Literature has broadly examined the roles of the public and private sectors as well as those of social movements in the past decades (Worster 1994; Cranor 1993; Carson 1962; Colten 1994; Commoner 1971; Hays and Hays 1989). We will therefore focus chiefly on the role of universities.

Particularly, the growing complexity of society in the new modernity requires a more informed discourse on the underlying sociological and ethical principles within universities as part of the curriculum and with universities as a collective agent of the risk society. A significant number of contributions from researchers on the societal role of universities can be found in scientific journals, magazines, or interviews. In the field of chemistry, reference must be made to the contributions of Richard R. Ernst, Chemistry Nobel Prize laureate (Ernst 2003, 2007a, 2007b) and Piero Pozzati, who has written an important book on "Verso la cultura della Responsabilità" (Pozzati and Palmeri 2007). Both the authors, R. Ernst and P. Pozzati, claim that the debate on environmental risks must be addressed both from the natural and social science points of view (Pozzati and Palmeri 2007, chapter 7). They further claimed that such a synergistic approach requires a thorough consideration of the underlying ethical principles and, as a precondition, the development of a sense of environmental responsibility among scientists (Pozzati and Palmeri 2007, chapter 8).

Taking into account the principles and ideas of these seminal contributions by Ernst and Pozzati, this paper examines the nexus between ethics and science in the debate on environmental risks. In the first step, we describe the different approaches and strategies used by researchers in these two spheres. Here, we seek to identify which arguments applied in the debate on environmental risks have their roots in the field of ethics and which belong to the field of science or, more precisely, to chemical sciences. Based on this analysis, we are identifying in the second step the unifying links between the spheres of ethics and science. While this analysis will be far from exhaustive, the findings of this paper will provide input for a more in-depth analysis of the nexus between ethics and science and provide a useful contribution to the debate on environmental risks.

The context

Risks, risk society, and science

We are living in what has been coined by Anthony Giddens as the "second or reflexive modernity" (Giddens 1990). We are experiencing a phase of human development in which progress itself constitutes the root cause for the growing risks societies are exposed to: modern society is not affected anymore by natural disasters alone, but largely manufactures these risks itself.

The term "risk society," coined by Ulrich Beck in his well-known essay on the topic, became synonymous for the description of modern societies. Beck claims that "in advanced modernity the social production of wealth is systematically accompanied by the social production of risks" (Beck 1992, chapter 1).

Table 1. Comparison of the concepts of "wealth" and "risks".

Definition of "wealth"	Definition of "risks"
• Constitutes class position	• Risks affect everybody irrespective their class position ("democratic" nature)
• Desirable in times in scarcity	• Incidental problem of modernization in undesirable abundance
• Wealth causes distribution conflicts	• Risks are denied or reinterpreted
• Wealth provides pleasure	• Risks cause stress
• Positive logic of acquisition	• Negative logic of disposition
• Individuals can be wealthy	• Individuals can only be affected by risks
• Wealth can be transmitted voluntarily to future generations	• Risks can be transmitted involuntarily to future generations
• Wealth is tangible	• Risks are intangible
– Can be experienced by individuals	– Mediated through argument
	– Requires expert judgment
	– Needs to be objectively determined through theories, experiments and measuring instruments

Source: Adapted from Beck (1992).

The creation of wealth and risks, the main products of risk society according to Beck (1992), is inherently linked to each other as shown in Table 1. The creation of wealth is limited to a small group of society. While the concept of wealth is tangible and can be transferred, on a voluntary basis, to the next generation, the concept of risk is broader, as it affects all members of the society equally. Its intangible nature makes it more difficult to understand for laypersons. Risks can also be transferred involuntarily to the next generation.

Bauman (1993, 1994, 2005, 2009) adds that the creation of wealth in advanced modernity is accompanied by a transformation of a producing into a consuming society in the second half of the twentieth century. As a result of this transformation society has lost control over the risks that it has generated itself. Beck poignantly describes this loss of control as a main feature of a "risk society" (Beck 1992). According to Bauman, a consumer society provides short-term remedies that evoke the false security that risks can be calculated, assessed, and managed. Consumerism hence encumbers society to understand and cope with the risks introduced by the reflexive modernity. Risks and consumerism can hence be considered as two sides of the same medal.

Here, science offers tools, such as the development of theories, undertaking of experiments, or the discourse of experts. These, in turn, support societies in their efforts to identify and manage risks.

Beck's criticism of risk society is, however, deep and radical as he states that "the production of risks is the consequence of scientific and political efforts to control or minimize them." He further claims that "risk society begins where nature (. . .) and tradition" end (Beck 1998, 10 and 12).

The "dual nature" of science represents another root cause for the occurrence of these risks in the reflexive modernity. Many products of science that are developed to provide benefits are at the same time capable of doing harm. In other words, a hammer can serve either as a tool or as a weapon to commit murder (Tucker 2012).

An example of this duality from the field of chemistry is the topic of chemical weapons. Many toxic chemicals have a dual nature. They can be used as chemical weapons or, peacefully, in the production of goods (Trapp 2008). To address this complex issue, the international community has negotiated the Chemical Weapons Convention, which entered into force in 1997. The Convention is a global treaty that requires states that are a Party to adopt, among other things, the necessary measures to ensure that toxic chemicals and their precursors are only developed, produced, otherwise acquired, retained, transferred, or used within their territory or in any other place under their jurisdiction or control for purposes not prohibited under the Convention.

The complexity of this dual nature of science calls for a coordinated approach of all collective agents in the assessment and analysis of risks. (Beck 1992) claims that such an approach could be based on the concept of cognitive sociology, i.e., that part of sociology investigating the ways in which sociocultural factors shape and guide the process of human thought (Cerulo 2005). According to Beck, the "theory of the risk society is in essence cognitive sociology, not only the sociology of science, but in fact the sociology of all the admixtures, amalgams and agents of knowledge, in their combination and opposition, their foundations, their claims, their mistakes, their irrationalities, their truth and in the impossibility of their knowing the knowledge they lay claim to" (Beck 1992, 55). Shrader-Frechette (2007) argues in a similar manner. She claims that arriving at sound conclusions when assessing, for example, environmental risks cannot be fully achieved with the application of pure or "classic" science alone, but requires the input of other disciplines, such as philosophy or sociology.

Universities as the main provider of both research and higher education can provide a valuable contribution to address the uncertainties stemming from this dual nature of science. Edgar Morin, in his landmark publication on "Seven complex lessons in education for the future" (Morin 1999a, 2) published by the United Nations Educational, Scientific and Cultural Organization (UNESCO), agrees that "education should include the study of uncertainties that have emerged in the physical sciences [. . .], the sciences of biological evolution, the historical sciences." The concept of "cognitive sociology" can guide universities in their attempts to collectively address this duality and the resulting uncertainties.

According to Strydom (2002), collective agents of knowledge – such as universities – have a particular responsibility in understanding the methods of cognitive sociology and the way in which sociocultural factors shape and guide scientific processes. This holds particularly true for scientific processes that, for example, result in the assessment of environmental risks and hence should be free of errors.

Accordingly, environmental risks should not remain undetected due to negligence of considering the dual nature of science. Kristin Shrader-Frechette claims that risk may remain undetected "whenever people assume that because current evidence (like monitoring data) does not prove harm, there is no harm." She further argues that "from flawed or incomplete evidence – ignorance – no conclusion follows." Shrader-Frechette identifies flawed science as a root cause for this error and claims that this often leads to flawed ethics as well (Shrader-Frechette 2007, 5–6).

In conclusion, environmental risks can be effectively mitigated, if ethical considerations, such as taking into account sociocultural factors, are integral parts of scientific processes. It is also evident that "classic science" is still indispensable to arrive at sound conclusions, for example, in assessing the risks of a specific technology. But the prerogative of science, and thus of universities, to hold the monopoly on truth may become an obstacle in modern societies for arriving at sound conclusions regarding environmental risks. It is rather the conscious application of the principles of cognitive sociology, taking into account the duality of science, that provides universities with a constructive role within the plurality of collective agents and their inherent interrelationships.

We will focus in the subsequent section on the limitations of science and in particular the changes in the perception of society who holds the monopoly of truth.

On the limits of "classic science" in the prediction of natural disasters

It is debatable whether the perception of the broader public in the "first modernity" or industrial society that science holds the "monopoly of truth" originated from the pertinent contributions of science in ensuring food and water security, combating diseases, or to the unprecedented technological advancements of mankind in the past century (Beck 1992).

The landmark contributions of science to the betterment of society, however, have given rise to expectations among laypersons that scientists, as long adequate information is available, are able to predict any aspects of nature (Prigogine and Stengers 1979). A suitable example that shows how the broader public came to this belief is the application of Newton's law of motion: Newton's findings enabled mankind to make precise predictions about the movement of stars and planets, a model that chemists have later used to describe the atomic structure.

However, nature is more complex than the motion of stars and planets, as described in the chaos or complexity theory (Prigogine and Stengers 1979). Despite the increase in efforts to predict the occurrence or related risks of natural disasters or technological catastrophes, they continue to take a toll on mankind. It is evident that science may not have the means to fully predict such events. We therefore believe it is worthwhile to analyze the origins of this unpredictability and related ethical considerations.

A feature of many socioeconomic systems is that they can organize themselves into "critical states" that can get catastrophically unstable (Bak 1996). Catastrophic events originating from such an unstable organization of critical states have proven to be unpredictable. This unpredictability, moreover, appears to be "ubiquitous" (Buchanan 2000) as it affects a broad range of systems. Buchanan states "that networks of things of all kinds – atoms, molecules, species, people, and even ideas – have a marked tendency to organize themselves" into critical states (Buchanan 2000, 21).

The unpredictability, therefore, does not stem from imperfect knowledge of scientists, but has its origin rather in natural or socioeconomic processes themselves. The Nobel Prize laureate in Chemistry Ilya Prigogine pointed out that nature could not anymore be perceived as a passive system that behaves like an automaton (Prigogine and Stengers 1984). This is the case, for example, when systems are far from their equilibrium state and are characterized rather by chaotic behavior dominated by fluctuations and by pitchfork bifurcations (Prigogine and Nicolis 1989). The principle of sufficient reason according to Hume states that "whatever begins to exist, must have a cause" (Hume 1978). This statement may not hold any longer, as the complexity of chaotic systems goes far beyond this simple deterministic explanation (Prigogine and Stengers 1988). Under these chaotic conditions, the laws of nature are rather expressed in possibilities rather than in certainties (Prigogine 1996). This, at the same time, means that the status of unpredictability within science could not be attributed anymore to imperfect knowledge or of insufficient control (Stengers 1977, 39).

Prigogine and Stengers (1979) pointed to an additional important limit of scientific methods of investigation: it is the arbitrary role of the experimenter in his dialogue with nature that he or she intends to interpret. "The experiment interrogates nature, but as a judge, in the name of principles he postulates. The nature of the response is recorded with the utmost precision, but its relevance is assessed in relation to the idealization that drives the hypothetical experiment" (Prigogine and Stengers 1979, 78). On the other hand, Hermann Weyl expressed his "deep respect for the work of the experimenter and for his fight to wring significant facts from an inflexible Nature, who says so distinctly 'No' and so indistinctly 'Yes' to our theories" (Weyl 1950).

This shows that the status of unpredictability is inherently linked not only to natural and socioeconomic systems but also to the scientific methods of investigation themselves. Analyzing the impact of unpredictability on the assessment of risks, therefore, must be addressed both from a scientific and a philosophic point of view.

The Bayesian approach as a surrogate for knowledge

The shortcomings of science to predict complex phenomena by using physical models paved the way for more practical scientific approaches, particularly in the area of climate change and research of climate change related risks. The Bayesian framework for probabilistic inference, for example, provides such an approach. In the Bayesian approach, large sets of a-posteriori observations are collected. This data is then used to update a-priori uncertainties through the process of probabilistic inference. The application of the Bayesian approach has increased the accuracy of the knowledge of the effects of climate change in the various editions of the reports of the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2014). Since the validity of the Bayesian approach largely depends on the reliability of the a-priori knowledge and is based on probabilities, it does not allow arriving at a status of perfect knowledge or certainty. The question of the responsibility of scientists applying the Bayesian approach is, therefore, not straightforward and needs to be considered in the debate on predicting complex phenomena.

On the unpredictability of rare events

Many of the recent catastrophic events, such as the nuclear accidents in Fukushima or Chernobyl, can be characterized as highly improbable or rare events. It is thus worthwhile to consider the impact those hard to predict events have on risk assessment procedures. Risk can be defined as the product of probability of the occurrence of a catastrophe multiplied with the severity of the expected injuries:

$$\text{risk} = \text{probability} \times \text{injury}. \tag{1}$$

The relative uncertainty can be calculated by partial differentiation:

$$\left|\frac{d\ (\text{risk})}{\text{risk}}\right| = \left|\frac{\partial\ (\text{probability})}{\text{probability}}\right| \pm \left|\frac{\partial\ (\text{injury})}{\text{injury}}\right|, \tag{2}$$

which cannot be calculated when:

$$p \Rightarrow 0 \text{ and injury } \Rightarrow \infty.$$

Since injuries caused by nuclear accidents are usually severe, the above condition of injury $\Rightarrow \infty$ is met. As a consequence, the relative uncertainty of such risks cannot be calculated precisely. The conventional probabilistic approach to assess the risks, hence, cannot be applied for catastrophic events with likely severe injuries.

Another problem with regard to the unpredictability of catastrophic events becomes apparent when inductive inference with true premises leads to false conclusions. This phenomenon is commonly referred to as the inductivist criticism of the Bayesian approach. In this regard, Bertrand Russell states that "the frequent repetition of some uniform succession or coexistence" should not be "a cause of our expecting the same succession or coexistence on the next occasion." His famous example on the "(t)he man who has fed the chicken every day throughout its life at last wrings its neck instead" proved "that more refined views as to the uniformity of nature would have been useful to the chicken" (Russell 1957, chapter 6).

We argue that the above two sub-sections on the Bayesian approach and the unpredictability of rare events provide a useful foundation for Beck's claim that scientists cannot possibly possess "the knowledge they lay claim to" (Beck 1992, 55), as this impossibility is inherently embedded within the fundamental principles of nature itself, as well as within the methods of investigation scientists apply.

When assessing the risk of environmental hazards, as a first step it appears to be important to estimate the severity of potential injuries. This estimation is to be done independently from assessing the probability of the occurrence of the hazard.

In the subsequent sections of this paper, we examine why and how scientists can take into consideration the unpredictability of natural systems and the often-resulting lack of knowledge in their daily work.

On the lack of knowledge and the relationship with liability and responsibility

In the previous sections we have shown that unpredictability seems deeply rooted in natural systems. A related issue that is often a result of coping with unpredictability is the lack of knowledge of scientists researching complex systems. This section deals with the ramifications of accidents that happen due to a lack of knowledge for liability of actors involved in these accidents. We will discuss the implications by means of two very different case studies, the story of Oedipus from Sophocles' tragedy "Oedipus Rex" and the Chernobyl nuclear accident.

Oedipus, while traveling to Delphi, killed in self-defense contrast for establishing the precedence right – a group of travelers, including Laius, then king of Thebes, without knowing that it was his father (Sophocles 2006, verse 810–813). While Oedipus can be accused of having escalated the use of violence ("he was paid with interest"), one could argue that he could not be accused of willful patricide, as he has killed his father without intention to kill and not-knowingly. Nevertheless, in modern moral ethics, the willful use of violence would lead to the liability of Oedipus. In 1986, some days before the nuclear disaster in Chernobyl, the vice chief engineer of the Chernobyl Nuclear Power Plant 3 and 4 decided to conduct an experiment that then led to the catastrophic nuclear meltdown. In 1987, he was found guilty "for criminal mismanagement of potentially explosive enterprises" and was sentenced to 10 years in prison. He did not purposely cause the nuclear disaster, but willfully conducted a risky experiment that eventually led to the catastrophe (Moynagh 1993).

The consequence for the main actors of the tragedy of Oedipus Rex and the Chernobyl disaster both depict a legal system that is based on moral responsibility, where a lack of knowledge is no excuse (Luban, Strudler, and Wasserman 1992).

This conclusion is highly relevant for the daily work of scientists that may not be always fully aware of the consequences of their actions. This holds particularly true taking into account the above-postulated unpredictability of catastrophic events, which seems to be deeply rooted in the new modernity as tragic feature of the risk society. The chemical accidents in Seveso in 1976 or in Bhopal in 1980 have demonstrated this in a drastic and catastrophic way.

Edgar Morin reinforces this predicament by stating that:

> (t)he unexpected surprises us. Because we are too safely ensconced in our theories and ideas, and they are not structured to receive novelty. But novelty constantly arises. There is no way we can predict it exactly as it will occur, but we should always expect it, expect the unexpected. And once the unexpected has happened, we must be able to revise our theories and ideas instead of pushing and shoving the new fact in an attempt to stuff it into a theory that really can't accommodate it. (Morin 1999a, 1999b, 11).

The interrelationship between the lack of knowledge and liability calls for a closer discussion of the specific responsibilities of scientists within a risk society. The responsibility to "expect the unexpected" is best translated in the formulation of the precautionary principle. It states that "(w)here there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation" (UNCED 1992).

The unpredictability of catastrophic events may have serious ramifications for the liability of scientists. Recognizing their special responsibility, this gives rise to a more widespread application of the precautionary principle. We conclude by stating that universities as institutions of higher education and research are particularly well placed to teach young scientists the principles of unpredictability, responsibility, and precaution in the context of a risk society.

Ethics and sciences

On the exploration of interrelationship between science and ethics

The fields of science and ethics have a long-standing and important relationship. It is evident that the argument that science and ethics are distinct research fields without any apparent interrelationship does not hold true. The outcomes of ethical debates, in fact, are often implicitly and explicitly applied in science and research. The report by the National Academy of Sciences "On being a scientist: Responsible Conduct in Research" (IM/NAS/NAE 2009) was first published in 1995 and suggested methods for promoting responsible research and dealing with misconduct.

Despite the efforts made by various actors in analyzing the underlying ethical foundation of science and research, other authors contend that methodological errors in the detection of truth and error continue to exist. Morin 1999a pointed out that "everything we know is subject to error and illusion." The play of truth and error particularly "functions (. . .) in the invisible depths of paradigms," which according to Morin 1999a constitute "primordial relations that form axioms, determine concepts, command discourse, and/or theories" (Morin 1999a, 1999b). As is evident, education, and therefore universities serving as an institution for higher education, needs to continue to confront the problem of error and illusion.

In statistical testing, errors of first and second kind (Cranor 1993; Shrader-Frechette 1994; Frank et al. 2011; Vandenginste et al. 1997) occur in the application of testing practices. These errors are associated with either incorrectly rejecting a true null hypothesis (type I error or false positive) or the failure to reject a false null hypothesis (type II error or false negative). The application of chemometrics, for example, in setting limits of detection (Vandenginste et al. 1997) or in deciding whether a drug needs to be rejected because of its hazardous characteristics (Cranor 1993) are examples for the application of statistical testing methods. The paradigm of neutrality often guides scientists to be indifferent regarding the preference of one error over the other, for example in field of chemometrics. However, assuming a strict neutral position in this regard may, at the same, jeopardize a researcher's ability to consider the underlying ethical value judgments connected with one of these two types of errors.

According to Morin, it is the task of education to reveal the existence of "blinding paradigms" (Morin 1999a,1999b, 8). In our example, the paradigm of neutrality for the application of chemometrics, a position often assumed by naïve positivists, may be a blinding paradigm, as neutrality in some specific cases may not take into account normative components. This holds true when it is favorable, for example, to favor type I (false positives) over type II errors (false negatives) in the regulation of harmful substances or the other way around in criminal justice systems.

The debate on the discovery of blinding paradigms, which according to Morin is a key task of education, has an apparent ethical dimension, which is rooted in the field of applied ethics.[1] Blinding paradigms, therefore, cannot be discovered by science alone.[1]

Multidimensionality is another important aspect in the discussion on error and illusion. Here, Morin (1999a) states that "complex unities such as human beings or societies are multidimensional" and concludes that "(p)ertinent knowledge must recognize this multidimensionality and insert its data within it" (Morin 1999a, 14).

This claim of Morin contains a call for action for universities in general, and scientists in particular. By recognizing the multidimensionality of complex systems, scientists would imperatively need to take into account ethical and, if appropriate, other dimensions of the scientific investigation methods they use. A researcher would therefore need to avoid presenting categorical conclusion from the data he or she generates. On the contrary, this researcher would need to be aware of and report on the degrees of uncertainties that may occur in the application of the scientific method of his or her choice.

The following three cases constitute examples of Morin's notion of blinding paradigms and multidimensionality: soft modeling as surrogate of hard modeling, dimensionality reduction methods in the context of pattern recognition in multidimensional data analysis, and the application of conventionalism in the assessment and management of risks.

In the previous section, the limits of "classical science" to predict disasters due to the inherent lack of precise and exhaustive deterministic models of reality and the resulting lack of knowledge have been discussed. However, some scientific methods use flexible mathematical tools for the analysis of data with less stringent measurement requirements. "Soft modeling" approaches, for example, are used as an alternative when "hard modeling" methods are not available and only describe the part of reality that is of immediate interest to the investigator (Falk and Miller 1992). The availability of complete information hence is not a necessary precondition. By applying "soft modeling" methods, like multivariate curve resolution, researchers are able to analyze processes without making explicit reference to the related basic models (de Juan et al. 2000). Such procedures, however, often require the scientist to make decisions regarding statistical parameters and which sub-set of reality to focus on. It is evident that these decisions can have an ethical dimension.

Modern analytical methods currently applied in environmental research, such as mass spectrometry of hyphenated techniques, produce multidimensional data. Chemometric methods are required to reduce the dimensionality and facilitate pattern recognition, for example, by applying the method of principal components (Vandenginste et al. 1997). It is worthwhile to remember that these numerical procedures belong to correlation analysis and correlation does not prove cause−effect evidence. Moreover, application of these procedures requires and leaves room to choices and decisions of the researcher, for example, which factors to choose and neglect or what level of noise in the data to disregard.

The application of conventionalism in the assessment and management of risks is another example that is closely connected to the debate on risk management and mitigation. The purpose of introducing here the topic of conventionalism is less to highlight the theoretical discussion on the sources of absolute truths or the conventionalist views, as introduced by Poincaré in his argumentation in comparing Euclidean and non-Euclidean geometries (Poincaré 1902; Ben-Menahem 2006). This paper rather seeks to emphasize the intrinsic risks of trusting data derived with methods following a conventionalist approach. As outlined by Pozzati (2004), this appears to have a particular relevance given the far-reaching technology-driven advancements of society in the age of industrialization and the related socioeconomic transformations that came with it.

According to conventionalism, we tend to define, for each particular field of knowledge, assumptions and basic properties or, in other words, conventions. Such conventions are by definition approximate in their nature and may contain specific restrictions, which limit their validity (Pozzati 2004). Conventions, however, allow for the development of direct concrete applications in the fields they have been put forward. The conclusions derived with methods and techniques following the conventionalist paradigm thus do not aim at being either "true" or "false," but only "applicable" or "not applicable" under *given limits*. Pozzati (2004), in his example of seismic structural analysis based on spectral analysis, pointed out the underlying ethical aspects of these *given limits*. The possibility of imprecisions, according to Pozzati, implies that it is ethically reprehensible to present any such calculations as reliable. Instead, researchers should proactively evaluate the reliability of the calculation carried out and openly discuss their impact on the related safety factors (Pozzati 2004; Pozzati and Palmeri 2007, 208−209).

Following a conventionalist approach in science or technology may well deliver the desired outcomes. With regard to the example introduced by Pozzati, this can include the design and construction of admirable structures and buildings. However, conventionalism is an example of a highly pragmatic and specialized approach (Pozzati 2004). In line with Morin, universities, in general, and researcher, in particular, need to take into account that such hyper-specializations may hamper a more holistic view on global problems. "Weakening the global perception bring us to weakening of the sense of responsibility since each one tends to be responsible of its own specialized task" (Morin 1999b, 7). Moreover, any tension in the interrelationship between science and society represents a particular call for action to ensure accountability of science towards democratic and social values (Kitcher 2001; Beck 1995; Mehta 2004).

Choices between two options and the irreducible role of values

In certain contexts of environmental governance, decision-makers have the choice between two or more options, such as focusing on nuclear or renewable energy sources or choices between two alternative technologies. In order to arrive a defendable political decision, it is often necessary to assess the risks of all involved options. The fact that it is not possible to simply compare two alternatives based solely on the respective probabilistic risk (see Equations (1) and (2)) clearly shows the ethical dimension of the respective selection procedures.

When deciding whether to build or not a nuclear power plant, one can be tempted to compare the probabilistic risk of living near to a nuclear power plant with the risk of riding a bicycle. However, the negative consequences of living nearby a nuclear power plant may well affect future generations in case of genetic damage caused by nuclear radiation. It is evident that the risks of riding a bicycle cannot be compared with the cross-generational impacts of exposure to nuclear radiation. The different ethical implications of these two choices obviously restrict their comparability.

A deeper understanding of the principle of naturalistic fallacy, as coined by G.E. Moore, can support decision-makers in arriving at ethically sound decisions when choosing between alternatives. Typical examples of naturalistic fallacy, which belong to the field of meta-ethics[2] are: (1) replacing ethics for natural science; (2) deriving "ought" (i.e., evaluative, normative, emotive, or prescriptive) from "is" (i.e., non-evaluative, descriptive, or factual) statements; and (3) disregard of "open questions" (Moser and Dondi 2012; Shrader-Frechette 1980, chapter 4). Table 2 describes two examples of such a naturalistic fallacy.

A similar topic examined by I.M. Golkany refers to the application of the precautionary principle in practical situations (Golkany 2001). Here, the impacts of a decision – for example, the banning of dichlorodiphenyltrichloroethane (DDT) – can differ significantly if one focuses on ecosystems or society: while the impact on bird populations will be positive, the socioeconomic impact on banning DDT in tropical or sub-tropical malaria-prone regions may be detrimental to the people living in these regions due to a possible increase in malaria cases. For the application of the precautionary principle under competing uncertainties, Golkany suggests a framework that is based on hierarchical criteria and ranking of possible threats based on their characteristics and degree of uncertainty (Harremoës et al. 2002). It is worthwhile to recall that although the use of DDT in the context of the Stockholm Convention on Persistent Organic Pollutants and the World Health Organization (WHO) is restricted, its use for specific exemptions or acceptable purposes nevertheless continues to be permitted (WHO 2011). The example of

Table 2. Two examples of naturalistic fallacy in energy production by fission.

Example 1 "What is normal" as a criterion of "What it is moral"	Example 2 "Probability of accident risks"
• Nuclear fission (A) is necessary because a country needs to maintain its the current level of energy usage (B)	• Risks of death or of injury from nuclear power plants (A) are lower than from other human caused accident already accepted by society (B)
• However, (B) – maintaining the current level of energy usage – is an open question.	• Risks that are lower than those ones that already tolerated by society constitute a "normal" magnitude of risk
• The question whether (B) is desirable is assumed rather than being argued	• Therefore, (A) is acceptable
• Naturalistic fallacy: defining that (B) is desirable without considering the underlying ethical question:	• Naturalistic fallacy: concluding that a normal magnitude of risk is acceptable without considering the underlying ethical questions:
Why should (B) be desirable in the first place?	Are such risks in (A) preventable?
	Did the affected persons give their free and informed consent to (A)?
	Do the risk in (A) result in inequitable risk burdens?

Source: Adapted from Shrader-Frechette (1980, chapter 4).

the use of DDT is only one of many environmental problems that, given their complexity, need to be addressed from an ethical, sociological, and scientific point of view.

The ethical dimension of scientific methods, such as the statistical−mathematical aspects of chemometrics, conventionalism, or the technical aspects of assessment procedures, manifests itself in various forms, from the discussion of the acceptability of error levels to the evaluation of the ethical soundness of the chosen assessment procedure.

In concluding this section, we argue the complexity of the interactions between science and ethics calls for a more structured debate between researcher and philosophers and, ultimately, between different faculties within universities (Shrader-Frechette 1985). The role of science in general, and universities, in particular is to strengthen the interrelationship and build bridges between the scientific and humanistic domains (Ernst 2003, 2007a, 2007b).

Collaboration and conflicts between collective agents of risk society in a macro-ethical context

Science, democracy, and universities

The complexity of the problems connected to (Beck 1992) risk society reveals itself not only in the assessment of the type and levels of risks by experts, but also in their perception by those who are exposed to them.

The assessment of the acceptability of certain risks yet adds another layer that we would like to highlight in this paper. Authors like Kirstin Shrader-Frechette claim that this kind of assessment needs to be undertaken by the potential victims of the negative impact of the risks, who are in most cases laypersons. While it is debatable that non-experts can distinguish between the actual risks calculated by experts and the perceived risks postulated by laypersons, Shrader-Frechette suggests that a "layperson's risk aversion may be reasonable, rather than merely a product of their erroneous risk perceptions" (Shrader-Frechette 1991, 93). Experts on the other side, the followers of naïve positivism, often fail to recognize the underlying ethical dimensions of probability estimates and tend to define ethical and political issues as merely technical ones. However, history is full of environmental disasters that experts failed to predict, such as the nuclear disaster in Chernobyl in 1986, but that were perceived by laypersons as likely events.

This dichotomy between the naïve positivism of scientists and experts and cultural relativism of affected persons can be resolved, according to Shrader-Frechette, by a middle position, the so-called "scientific proceduralism," an approach that links science and democracy. Following the concept of scientific proceduralism, risk evaluations are still undertaken by experts, but scientific objectivity can only be guaranteed if the opinion of laypersons that are likely affected by the risks are taken into account in the debate (Harremoës et al. 2002, 198). Likewise, the sociologist Piet Strydom developed a new critical theory that calls for a "cognitive perspective" based on the "concatenation of risk, knowledge, and communication." According to Strydom, not only knowledge in the sense of content, but also communicative processes are important ingredients of evaluating risks in modern societies (Strydom 2002).

Emphasis needs to be placed on the collective responsibility of the different actors in the risk society. This also opens new perspectives and opportunities for university and scientists. Research should be conducted at a slower pace and be accompanied by constant reflection on critical threshold values undertaken jointly by science and the broader public. Progress should be monitored and regulated by global reflexive institutions, such local or national committees, as described by Pozzati (2007, chapter 9), that operate at a level that is coextensive with the impact of the potential risks.

Laypersons can indeed be the useful observers in detecting potential risks at early stages and in raising the awareness about such risks. Whistleblowing is commonly referred to an act of person that brings corrupt, illegal, fraudulent, or harmful activity of an organization to the attention of internal or external entities that have the ability to act on such conduct. It is often driven by the conviction that the public interest overrides the interest of the organization that the whistleblower serves (Benchekroun and Pierlot 2011).

Whistleblowing can be a useful mean in the prevention of risks. This holds particularly true if such risks originate from misconduct or from hazardous activities that can result in accidents or major disasters. Here, whistleblowers can play an important role in the anticipation, prevention, or minimization of the effects and consequences of such events (Shrader-Frechette 2007; Benchekroun and Pierlot 2011).

The important role that whistleblowing plays for modern society needs to be recognized and adequately protected by law. Its function should therefore be recognized in education and covered by the codes of conduct of academic institutions.

Bearing in mind that modern society as a whole becomes more "communicative, discursive, and reflexive" (Strydom 2002, 157), all collective agents of the risk society are able in the future to become better observers. We argue that this new macro-ethics of global responsibility provides a blueprint for science departments of universities, as stated by the Nobel Prize laureate Richard Ernst, to integrate "societal concerns and questions of global relevance in their courses and daily discussions" in order to "succeed in overcoming the present difficulties of recruiting students" (Ernst 2003, 4436).

Conclusions

As we have seen from our analysis in this paper, the growing complexity of society in the new modernity requires a more informed discourse on the underlying sociological and ethical problems of the risk society.

While many collective agents in the risk society cooperate with each other in a constructive manner (Strydom 2002), we have shown that conflicts among the different players still exist. Exerting power in political and scientific debates or the conflicting interests of different agents is often the cause of these divergences.

Universities as institutions of higher education and research are well positioned to act as a mediator for conflicts between collective agents of the risk society. We believe that the following non-exhaustive list constitutes a concrete proposal of actionable items that universities at a global level can implement (Shrader-Frechette 2007).

(1) Universities should promote transparency when carrying out studies of direct or indirect impact on public health.
(2) Universities should avoid any potential conflict of interest, which is often the root cause of flawed science leading to flawed ethics (Shrader-Frechette 2007).
(3) Universities should develop codes of conduct that govern consultant activities for external institutions (IM/NAS/NAE 2009).
(4) Universities should make provisions for whistleblowing procedures in case the conduct of business of universities poses serious threats to human health and the environment. This should include a protection program for employees that report possible violations. Universities should also promote whistleblowing functions for risk prevention and include the concept in their scientific programs and curricula.

(5) The European scientific institutions in chemistry should continue developing common codes of conduct to address the "dual nature" of science and technology (Tucker 2012; Santacesaria 2011). Likewise, universities should include the concept of the duality of science and technology as a key component of higher education in biological and chemical sciences.
(6) Political institutions should promote a framework in which different collective agents of the risk society, such as academia, industry, states, environmental agencies, or social movements, each work together to overcome the complex problems of the risk society (Beck 1998).
(7) Universities should more actively engage students in the debate on the ethical aspects of scientific research, particularly during Ph.D. programs (Frank et al. 2011, paragraph 3; Pozzati and Palmeri 2007; IM/NAS/NAE 2009; Morin 1999a).

Notes

1. See definition of "applied ethics". http://www.iep.utm.edu/ap-ethic/ (accessed on 20 March 2014).
2. See definition of "Meta-ethics". http://www.iep.utm.edu/metaethi/ (accessed on 25 March 2014).

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ARTICLE VI

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OPINION

On the road to Rio + 20: the evolution of environmental ethics for a safer world

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Chemicals: vital role and environmental concerns

Chemicals are indispensable in the functioning of modern societies. They are produced and used in key sectors of the economy, and the global sales in 2010 were valued at €2350 billion. China presently contributes the largest amount, followed by the United States, Japan, and Germany. In the European Union (EU) the chemical industry gave work to 5.4% of the total number of employees in 2007 (CEFIC 2011).

Despite the crucial role that chemicals play in the global economy and in everyday life, many of them may pose threats to human health and the environment. Many states have therefore chosen to regulate their production, use, and release into the environment. Direct risks of some chemicals to human health were already perceived in the early twentieth century, but their indirect impacts on the environment were only recognized when their production volumes and open applications tremendously increased in the second half of the last century.

The perception of environmental risks associated with the production and use of chemicals was initially based on the fairly naïve supposition that chemicals would simply disappear once released into the environment. This only changed in the 1960s, when the scientific community, lawmakers, and the general public started to realize that this hypothesis was based on an insufficient understanding of the properties and behavior of chemicals in the environment.

A series of industrial accidents raised attention to the fact that chemical production involving hazardous chemicals may be associated with health risks to neighborhoods when accidents occur, such as the release of about 1 kg of the highly toxic and persistent 2,3,7,8-tetrachlorodibenzo-*p*-dioxin at Seveso, Italy, in 1976, which contaminated a residential area of 20 km^2 with more than 100,000 inhabitants. Another example was the accident at Bhopal, India, in 1984, when more than 30 tons of methyl isocyanate were released into the atmosphere from an insecticide production site close to the main train station – an area inhabited by the poorest – with the immediate asphyxiation of about 8000 people and an overall estimated death toll between 15,000 and 30,000.

National, regional, and international regulation of chemicals

The growing sensitization of society gave impetus to a change of paradigm of governments toward the regulation of chemicals and hazardous waste at the national, regional, and

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international levels (Løkke 2006). Landmark legislation at the national level includes the Clean Air Act in the United States, signed in 1970 to curb emissions of air pollutants that cause smog, haze, acid rain, cancer, and other adverse health effects. The Clean Air Act also triggered the termination of production and the use of ozone depleting substances.

At the regional level, in Europe the 1979 Geneva Convention on Long-Range Transboundary Air Pollution sought to address the issues of environmental damage, such as acidification of lakes through airborne pollutants that may travel long distances before being deposited. The Convention was the first internationally binding legal instrument emphasizing the need of cooperation between states at a regional level to tackle issues related to environmental degradation.

At the global level, the international community addressed the environmental governance of chemicals and hazardous wastes through the negotiation of multilateral environmental agreements. The 1989 Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, the 1998 Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, and the 2001 Stockholm Convention on Persistent Organic Pollutants (POPs) share the common objective of protecting human health and the environment from the adverse effects of hazardous chemicals and wastes, and help to assist countries to manage chemicals and wastes at all stages of their life-cycle (UNDESA 2011).

In June 2007, the EU Regulation on Chemicals and their Safe Use (EC 1907/2006) entered into force. The EU ordinance on the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) seeks to improve the protection of human health and the environment from the risks posed by chemicals, while at the same time enhancing the competitiveness of the EU chemical industry. REACH shifts the burden of proof from governments to companies, which are now responsible for identifying and managing the risks linked to chemical substances that are manufactured and introduced into the EU market. With its far-reaching scope, REACH enables authorities to restrict the use of certain hazardous chemicals with a long-term goal of introducing less dangerous alternatives.

Perception of risks in society: evolution of ethical theories and international environmental governance

Carson's (1962) book "Silent Spring" contributed to raising the awareness of the general public with regard to environmental problems and the degradation of ecosystems caused by the increasing use of chemicals in the second half of the last century. Carson was an ardent advocate of the environmental movement and her book vividly outlined how indiscriminate and extensive use of the, in terms of acute-toxicity, fairly innocuous dichlorodiphenyltrichloroethane (DDT) can become a threat to the environment. Carson's work greatly contributed to growing general public awareness of a nature in danger.

The groundbreaking publications of Jonas (1984) on "The Imperative of Responsibility: In the Starch of an Ethics for the Technological Age" and of Beck (1992) on the "Risk Society: Towards a New Modernity" marked a change of paradigm toward the perception of risks in society. These two important contributions in the field of environmental ethics and sociology are closely linked to the warnings of Carson and are responding to the intrinsic possibility of industrial accidents.

While both Jonas and Beck advanced the public perception of risks, a third key area emerged with the publication of the report of the Club of Rome (Meadows et al. 1972)

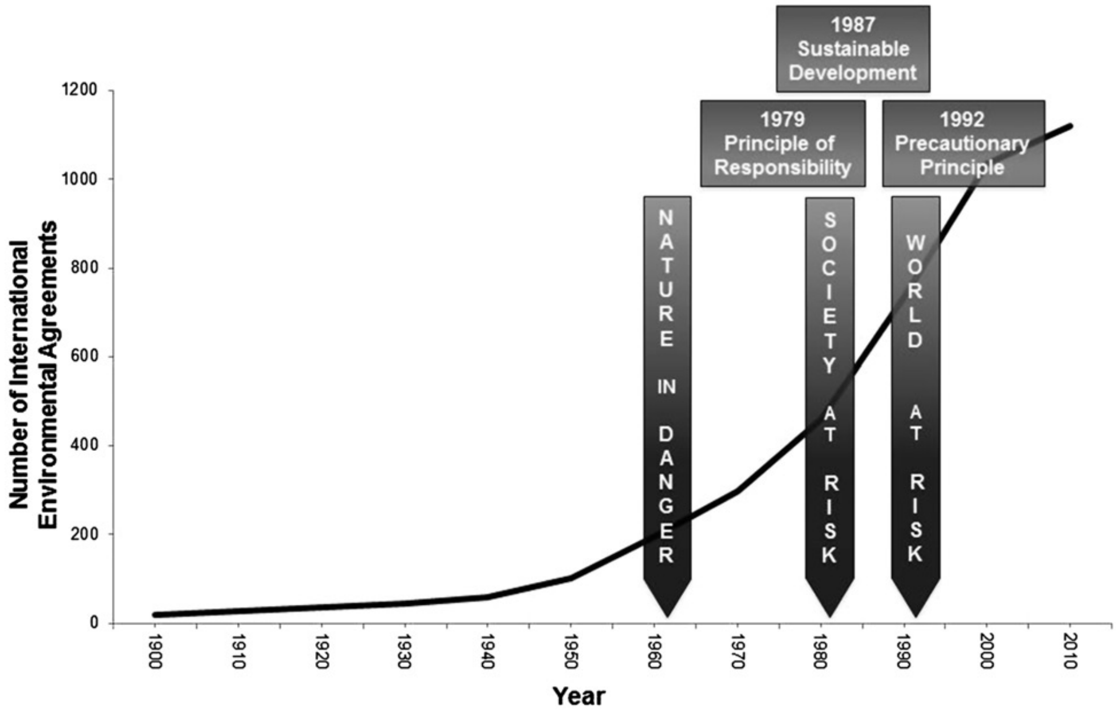

Figure 1. International Environmental Governance and environmental ethics: evolution of the perception of risks by public opinion, ethical theories, and the increase of the number of international treaties in the last 111 years (Source: authors' elaboration based on Mitchell (2012).

which focused on the "Limits to Growth" of the economic development model of the time. The report of the World Commission on Environment and Development on "Our Common Future," transmitted to the General Assembly of the United Nations in 1987 (Brundtland 1987), confirmed the conclusions of the Club of Rome by addressing the need for changing the paradigm of unlimited growth by introducing the concept of sustainable development.

Subsequently, in 1992 the United Nations Conference on Environment and Development adopted the so-called Rio Declaration. This set of concepts and principles was aimed, among other aspects, at assisting societies in their efforts of managing risks that, according to Beck (1992, 21), are defined "as a systematic way of dealing with hazards and insecurities induced and introduced by modernization itself." Among the most prominent and far-reaching concepts are the principle of responsibility, the precautionary principle, and the focus on sustainable development.

Figure 1 shows the evolution of international environmental governance outlining an exponential increase of the number of multilateral environmental treaties in the last 60 years, showing the key turning points of public opinion about risks [Nature in Danger (1960s), Society at Risk (1980s), and World at Risk (1990s)] and the evolution of environmental ethics with "The Imperative of Responsibility" (1979), the concept of Sustainable Development (1987), and the Precautionary Principle (Rio World Summit in 1992).

Unresolved issues in managing risks: the need of an integrated approach in ethics, science, education, and politics

While significant progress has been made in the past decades in assessing and managing risks associated with the production and use of chemicals, some aspects of the question on how such risks can best be managed still remain unanswered. With a general skepticism of society toward chemistry, the sciences, and the scientific-industrial community as a whole (Frank et al. 2011), it is therefore imperative for modern societies to better understand the underlying ethical and scientific concepts of assessing chemical risks at both individual and societal levels.

According to Beck this is particularly important, as ‘‘ecological and high-tech risks . . . have a new quality.’’ These modern threats, such as environmental pollution by POPs, are of global nature, outlast generations and, in many cases, affect people who live far away from the sources where these substances have been released (AMAP 1998).

Kerns (2001) and Shrader-Frechette (2002) both support the argument of the need to change the way in which we are assessing risks of modern threats. They argue, among other things, that risk assessments in their current form are often based on insufficient understanding of the complexities of the natural environment. The use of simple models and of aggregated data in an attempt to cope with the complexity of the real world may lead to inaccuracies, particularly when determining long-term consequences of continued exposure to low levels of hazardous chemicals. Also, risk assessments are often based exclusively on scientific methods determining cause-and-effect relationships. The underlying uncertainties or value judgments of science and of the risk assessment methodologies themselves, however, remain largely disregarded.

Assessments of risks affecting public welfare intrinsically involve both policy and scientific judgments. Authorities hence must ensure that risk assessments are not exclusively based upon scientific methods (Shrader-Frechette 2010); ethical considerations are to be taken into consideration as well. This calls for the full participation of representatives of the public as stakeholders of a truly democratic society. These challenges call for integrated approaches for the management of risks emanating from the production and use of chemicals.

Integration between experts and affected persons: scientific proceduralism

With the objective of establishing a bridge between technical experts and the affected persons, the method of ‘‘scientific proceduralism’’ (Shrader-Frechette 1991) is an example of an integrated approach for managing chemical risks.

In the debate on the spectrum of methodological norms, the method of scientific proceduralism is occupying a central position between ‘naïve positivism’ and ‘cultural relativism’. Technical engineers and health and toxicology experts usually apply the first methodology. A general claim of this group is that the evaluation process is objective in the sense that different risks may be appraised according to the same rules, stipulating that risks below a certain level of probability are insignificant. The members of the second methodology are usually social, political, or anthropology scientists arguing that risks are social constructs and that increased knowledge, and additional reasoning about risks do not make people more rational about hazards (Shrader-Frechette 1991).

Scientific proceduralism still requires the application of scientific methods and the work of experts, while at the same time involving the conscientious integration of ethical approaches. The method suggests that laypeople may be able to act as rationally as technical experts when evaluating possible hazards. This is translated into the fact that its outcomes should be the result of a well-established democratic process in which all possible options are considered.

Being placed at the interface between environmental, economic, and social spheres, scientific proceduralism appears to be a suitable methodological approach for evaluating, managing, and handling the risks of chemicals in an integrated manner.

Integration between science and ethics: the role of academia

A lack of ethical considerations can be observed in the natural science curricula of universities, predominantly geared toward teaching future generations how scientifically sound conclusions can be derived from experimental findings. The need of impartiality of science, in this regard, is translated into the necessity to disfavor any preference of type I errors (false positives) over type II errors (false negatives) and vice versa.

While for most research questions in natural science it is mandatory to maintain this strict impartiality, this may not hold when assessing the risks of environmental pollution. This is particularly true for risk assessment studies that suggest associations between exposure to chemicals and adverse effects, which fall short of providing conclusive proof. Here, science may fail to arrive at valid recommendations on the regulation of potentially hazardous chemicals.

Lack of proof, however, must not lead to the conclusion that the exposure to the respective chemical is safe. This error may particularly occur when scientists undertaking research on the adverse effects of environmental pollution use toxicological test systems that are limited in their scope and relevance and do not reflect the complexity of nature. It is incorrect to assume that the absence of the evidence of adverse effects in such limited experimental settings is evidence for the absence of adverse effects of pollutants on the environment as a whole (Shrader-Frechette 2007). In addition, in this setting multiple exposures to hazardous chemicals and their possible interactions are not taken into account.

To overcome the general skepticism of society toward science in general and chemistry in particular, it is essential to minimize the occurrence of type II errors (false negatives). The ethical imperative to allow down-regulation of a relatively harmless substance (type I error) rather than risking the continued exposure to environmental pollution by a chemical of unknown but high eco-toxicity (type II error) can be summarized in the application of the precautionary principle. And also the principle of naturalistic fallacy, introduced by the British philosopher G.E. Moore, can support scientist and lawmakers in making informed decisions about these two types of errors (Shrader-Frechette 1980). Typical examples of naturalistic fallacy are: (a) replacing ethics for natural science; (b) deriving "ought" (i.e., evaluative, normative, emotive, or prescriptive) from "is" (i.e., non-evaluative, descriptive, or factual) statements; (c) disregard of "open questions."

Expectations and outlook: the Rio ± 20 Earth Summit and beyond

Twenty-five year ago, Beck poignantly argued that "[it] remains unrecognized that a social, cultural and political meaning is inherent in . . . scientific . . . formulae" (Beck 1992, 24). It is up to the scientific community today to show through the integration of ethical approaches in chemistry that Beck's observation is no longer valid.

Bearing in mind Beck's pessimistic view, the international community in 1992 provided with the Rio Declaration on Environment and Development an equally poignant response. The declaration advanced a commonly accepted definition of the precautionary principle:

"In order to protect the environment, the precautionary approach shall be widely applied by states according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation" (UNCED 1992).

The change of paradigm in terms of applying ethics-based approaches such as the precautionary principle in assessing environmental risks has to start by changing our current approach toward assessment and perception of risks associated with environmental pollution. The incorporation of ethical considerations in science and in university education must be based on the assumption that the information required to guide environmental policies cannot to be provided by scientists alone. The Rio + 20 Earth Summit in June 2012 will undoubtedly provide further impetus to reach this ambitious goal in the coming years.

Disclaimer

The views expressed in this publication are not necessarily those of the United Nations Environment Programme (UNEP).

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ARTICLE VII

L'UNIVERSITÀ E LA RICERCA NELLA SOCIETÀ DEL RISCHIO

NELLA SOCIETÀ DEL RISCHIO,. INVESTIGAREI IL GRADO DI IMPREVEDIBILITÀ È COMPITO NON SOLO DELLA SCIENZA, MA ANCHE DELLA FILOSOFIA. IN UN PARADIGMA DI SCIENZA PROBABILISTICA, CERTEZZE E RESPONSABILITÀ SONO LIMITATE. LA DICOTOMIA TRA ASPETTI POSITIVISTICI E CULTURALI DEVE TROVARE UN PUNTO DI EQUILIBRIO IN UNA "PROCEDURA".

Il titolo e il tema del convegno che ruotano attorno ai concetti di *rischio*, *conoscenza* e *responsabilità* chiamano in causa tra i numerosi interlocutori anche l'università cui la nostra Costituzione assegna il compito istituzionale dell'alta formazione e della ricerca.

Riflessione sul rischio.

Stiamo vivendo in quella che è stata definita la *"seconda modernità"* o *"modernità riflessiva"* da Anthony Giddens [1]. Stiamo cioè vivendo una fase dello sviluppo umano nella quale lo stesso progresso è un problema a causa dei numerosi rischi che con sé esso porta: possiamo infatti essere colpiti da catastrofi non più solo di origine naturale, ma anche di origine tecnologica
Come magistralmente ha affermato Ulrich Beck [2, *Introduzione*], nella modernità avanzata la produzione sociale di "ricchezza" è accompagnata dalla produzione di "rischi": questi due prodotti sono quasi intrinsecamente "gemellati" pur avendo essi caratteri e caratteristiche opposte [3]. La "ricchezza" è ricercata e ostentata, è per pochi, si può trasmettere in modo volontario agli eredi, è tangibile. I rischi vengono negati, sono "democratici" nel senso che colpiscono tutti, possono essere trasmessi in modo involontario agli eredi, sono spesso difficili da cogliere. Ma è in quest'ultimo aspetto che la "scienza" viene rivalutata in quanto essenziale: gli "organi della scienza" sono infatti gli strumenti che ci aiutano a identificare i rischi, attraverso la teoria, gli esperimenti, il ricorso agli esperti.
Dove sta quindi la responsabilità della scienza tanto volte posta sul banco degli accusati come corresponsabile dei "rischi"? Sta, sempre secondo Beck [2, p. 55], *"in quell'amalgama di presunta completa conoscenza che essa in realtà non ha (o non sempre ha), ma che spesso essa afferma (in bocca a taluni) di avere"*.
Kristin Shrader-Frechette [4] propone una analisi assai cruda di tante situazioni di rischi non previsti: gli errori accadono poiché correntemente si presume che quando non c'è *evidenza* di danno o rischio, il danno o il rischio siano anche assenti, il che evidentemente non è vero. È quindi una *scienza taroccata* che conduce a un'*etica taroccata*, mentre molte tragedie sono prevenibili.

Sui limiti della scienza "classica" nelle previsione delle catastrofi

È bene analizzare l'origine di questa "imprevedibilità-prevedibilità" per gli aspetti etici che ne conseguono.
Molti eventi catastrofici sono risultati essere assolutamente "imprevedibili" e questa "imprevedibilità spazio-temporale" sembra essere "ubiquitaria" [5]: citiamo come esempi lo scoppio della prima guerra mondiale dopo l'attentato di Sarajevo, il propagarsi degli incendi, i terremoti.
Una simile "imprevedibilità" non è sempre associabile a una nostra imperfetta conoscenza: il premio Nobel per la chimica Ilya Prigogine ha spiegato che questa imprevedibilità ha origine nei processi naturali stessi quando essi siano fortemente lontani dalle condizioni di equilibrio termodinamico (le così dette biforcazioni dominate dalle fluttuazioni).
Prigogine assieme a Isabelle Stenger [6] ha inoltre ben richiamato il "ruolo arbitrario" dello sperimentatore nel suo dialogo con la natura che intende interpretare: "l'esperimento interroga la natura, ma come un giudice, nel nome di principi postulati. La risposta della natura è registrata con la più grande precisione, *ma la sua pertinenza è valutata con riguardo all'idealizzazione ipotetica che guida l'esperimento*" (il corsivo è del sottoscritto). L'imprevedibilità è quindi una proprietà del mondo naturale ed è anche legata al nostro grado di conoscenza dei fenomeni. Investigare quale sia questo grado di imprevedibilità che caratterizza il rischio e come esso sia associato al nostro immaginario scientifico è un compito non solo della scienza, ma anche della filosofia della scienza.

Modelli della natura, responsabilità e limiti nelle previsioni

Gli indubbi successi della scienza nel combattere la fame, le malattie (la "prima modernità"), nell'assicurare successi a lungo insperati come la conquista della Luna, hanno purtroppo ingenerato tra la gente comune attese (o pretese) [4] che la scienza tutto potesse sapere e prevedere, purché fossero ad essa fornite adeguate informazioni. È questo il modello della scienza così detta "newtoniana" che ha saputo così perfettamente interpretare e modellare lo spettacolo grandioso delle stelle e il moto dei pianeti nel cielo: un modello che i chimici hanno poi ritrovato nella struttura degli atomi.
Il mondo è tuttavia assi più complesso rispetto alla perfezione del moto dei pianeti o alla stupefacente bellezza della Tavola periodica: è fatto di terremoti, di catastrofi naturali, di catastrofi "tecnologiche". Una nuova scienza si è però sviluppata negli ultimi 50 anni [6]: la nostra conoscenza spazio-temporale dei fenomeni è intrinsecamente "probabilistica".
Nell'impossibilità quindi di prevedere "a priori" fenomeni complessi", la nostra conoscenza si affida alla raccolta di dati "a posteriori": si tratta in questo caso dell'approccio così detto *"bayesiano"*, un po' come certi tipi di diagnosi in campo medico. Questo è, ad esempio, il tipo di conoscenza che noi abbiamo dei cambiamenti climatici, il cui grado di precisione si è accresciuto nelle varie edizioni successive dei rapporti Ipcc [7]. Si tratta però di una conoscenza non di tipo causa-effetto, ma solo probabilistica. Certezze e responsabilità sono quindi limitate, un po' come al medico non può essere attribuita responsabilità per diagnosi sbagliate basate su conoscenze bayesiane.

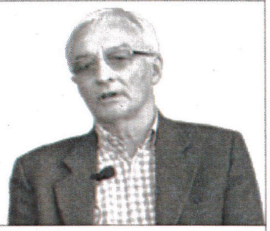
Dove stanno le scienze e dove sta l'etica

La scienza negli ultimi anni si è trovata quindi ad avere una difficile convivenza con l'etica. Molti addirittura ritengono che scienza ed etica siano distinti e distanti. Ma questo non è vero: molti sono gli aspetti etici adottati nella prassi scientifica.
Accenniamo ad esempio ai cosiddetti *errori di prima e seconda specie* [8-10] che si commettono nel rigettare le ipotesi quando esse sono vere (ipotesi di eguaglianza e diversità, rispettivamente) a causa della imprecisione dei nostri strumenti. L'entità degli errori ammissibili nell'esecuzione di un test obbedisce a criteri di opportunità, compreso anche l'aspetto economico, connesso quest'ultimo alla ripetizione degli esperimenti. Ricordiamo qui le procedure di tipo chemiometrico che concorrono a definire i limiti di rilevabilità, rigettare un farmaco perché dannoso [10]. Simili problemi esistono anche per l'accettabilità di un errore giudiziario. Si tratta in questi casi dell'*etica normativa*, perché ha a che fare con i principi che guidano chi mette in pratica una determinata scelta nel contesto dell'*etica applicata*, cioè di una conseguente applicazione corretta delle procedure, senza errori materiali o dolo.
In un paragrafo precedente si è poi accennato ai limiti della scienza "classica" nelle previsione delle catastrofi. Molto spesso, tuttavia, non è necessario avere un modello interpretativo di una porzione estesa di realtà. È invece spesso necessaria solo la conoscenza di un dominio "limitato" di realtà, e ciò consente di far ricorso a strumenti matematici più flessibili. Si tratta del così detto *soft modeling*, come alternativa ai modelli fisicamente più fondati, detti di *hard modeling* spesso non disponibili. Le indagini ambientali, grazie alla moderna strumentazione analitica, possono disporre di una grande quantità di dati spazio-temporali multidimensionali (ad esempio le spettrometrie di massa, e in generale le tecniche così dette accoppiate). Nella rappresentazione e interpretazione di questa massa di dati si fa necessariamente ricorso a tecniche chemiometriche di riduzione della dimensionalità e di riconoscimento degli andamenti rilevanti (ad esempio il metodo dell'analisi dei componenti principali). L'applicazione di queste procedure richiede e lascia spazio tuttavia a scelte e decisioni del ricercatore, ad esempio su quali fattori scegliere o su quale livello di "rumore" dei dati trascurare. Questa fase, diversamente dal caso precedente in cui si seguivano norme pre-definite, può comportare arbitrio, negligenza o dolo. Si tratta, anche in questo caso, di una questione di etica applicata. Il ricercatore può essere in questa caso paragonato a un

> In un mondo iperspecializzato, ciascuno tende a essere responsabile del proprio frammento di conoscenza, il globale e l'essenziale si dissolvono con una conseguente perdita di responsabilità, poiché ciascuno tende a essere responsabile del proprio compito specialistico.

CHI È

FRANCESCO DONDI



È professore ordinario di Chimica analitica presso il Dipartimento di Scienze chimiche e farmaceutiche dell'Università di Ferrara. Dirige il master in *Scienza tecnologia e management* dell'Università di Ferrara. I suoi interessi sono rivolti particolarmente alla chimica analitica, alla scienza delle separazioni, alla cromatografia.
È inoltre molto attivo nel campo dell'etica e della scienza per l'ambiente.
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FRANK MOSER

È laureato in Chimica all'Università di Costanza (Germania), ha un Master in Economia. Dal 2003 al 2009 ha lavorato presso organizzazioni Onu allo sviluppo della metodologia del *Chemical Leasing* per la minimizzazione di costi, impatto ambientale e rischio nelle attività industriali chimiche. Attualmente lavora all'Unep di Ginevra presso il segretariato delle convenzioni di Basilea, Rotterdam e Stoccolma. Contemporaneamente segue il programma di Dottorato di ricerca presso l'Università di Ferrara sull'argomento dell'Etica in chimica (tutore F. Dondi).

giocatore che bara o si comporta in modo scorretto o che, più semplicemente, affronta un avversario o una gara in modo impreparato. L'informazione ambientale importante poteva infatti trovarsi nei componenti trascurati (o addirittura non investigati) o anche all'interno dello stesso livello di "rumore" dei dati che è scartato nel corso della procedura interpretativa.
Piero Pozzati da par suo ha egualmente sottolineato l'aspetto etico-economico del cosiddetto *"convenzionalismo"* nel calcolo strutturale sismico [11].
In questo modo i rischi nascosti possono manifestarsi senza essere stati adeguatamente previsti o prevenuti. A mio avviso il ricercatore è condannabile in caso di negligenza oggettiva, sulla base del principio di precauzione, stabilito dalla Convenzione di Rio nel 1992.

Sulle scelte tra due opzioni

In molti contesti di rilevanza ambientale si ha a che fare con due o più opzioni (ad esempio nucleare sì/nucleare no) o due tecnologie in alternativa. Si rende necessario predisporre delle procedure di valutazione sulla cui base prendere decisioni politiche, ma questo comporta aspetti etici specifici. In questi casi sono di particolare rilievo le caratteristiche logiche e metodologiche delle procedure di confronto, oltre e al di là dei contenuti etici specifici. Si tratta cioè della cosiddetta *metaetica*, che discende dall'etica di Moore [12]: ad esempio, non è possibile confrontare le due alternative sulla sola base dei valori quantitativi dei rispettivi rischi probabilistici (ad esempio confrontare il rischio dell'andare in bicicletta con quello del vivere accanto a una centrale nucleare [13, 14]).
Un ulteriore aspetto importante connesso alle varie opzioni, alle scelte e ai rischi connessi è il loro cadere sotto più domini scientifici (geologia, chimica, meteorologia, aspetti ingegneristici, rilevanza per la salute, aspetti economici ecc.). In un mondo iperspecializzato, ciò crea non pochi problemi: ciascuno tende a essere responsabile del proprio frammento di conoscenza, il globale e l'essenziale si dissolvono con una conseguente perdita di responsabilità, poiché ciascuno tende a essere responsabile del proprio compito specialistico [15].
È compito urgente delle università e dell'organizzazione scolastica porre rimedio agli aspetti negativi di scienze frammentate e autarchiche nella formazione culturale dei ricercatori.

> Molti pensano che nella Società del Rischio sia rimasta una sola autorità, quella della scienza. Questa affermazione rivela non solo una incomprensione ed un fraintendimento della scienza e dei suoi compiti: vi sta anche una totale incomprensione della nozione del rischio.
>
> **Ulrich Beck**

Scienza e democrazia

Quanto sinora affermato non esaurisce la complessità dei problemi. Infatti, mentre la scienza "determina" (o può determinare) i rischi, è la popolazione che ha dei rischi la *"percezione"*: un esperto può valutare l'entità o l'accettabilità di un rischio, mentre sono i non-esperti, cioè le vittime potenziali, a valutare l'accettabilità di determinati rischi.
E occorre dare a essi un credito di razionalità, ovviamente diversa da quella meramente scientifica, ma tuttavia non meno solida e importante [16].
Oltretutto, la storia è piena di catastrofi negate dalla scienza ma paventate dai non esperti e che si sono poi verificate.
Questa dicotomia tra aspetti positivistici (propria degli scienziati e degli esperti) e culturali (propri della società e dei soggetti esposti) deve trovare un punto di equilibrio attraverso una "procedura", il cosiddetto *"proceduralismo scientifico"* nel quale sono ancora chiamati a dire la loro gli esperti, messi a confronto anche con le persone potenzialmente esposte, secondo quindi un metodo che metta d'accordo scienza e democrazia.

Alcune proposte

Le questioni esaminate sono oltremodo complesse e queste considerazioni non possono essere esaustive, ma possono essere il punto di partenza per un approccio etico-scientifico alla *governance* dell'ambiente. Avanziamo concretamente alcune proposte:
1. non deve esserci obbligo di segretezza


FOTO: GOOGLE MAPS STREET VIEW

da parte di istituzioni pubbliche come le università, quando esse siano chiamate a effettuare studi sulla qualità dell'aria, dell'acqua ecc., nei casi di riflessi sulla salute pubblica

2. colui che dall'interno di un ente, industria o luogo denunci casi anomali dannosi per la sicurezza e la salute (il cosiddetto *"whistleblower"* o "uomo del fischietto") dovrebbe essere adeguatamente protetto: si tratta in questo caso di un problema di etica applicata che deve saper distinguer tra gli obblighi di "fedeltà" al datore di lavoro e gli obblighi di "responsabilità" di appartenenza a una comunità

3. occorre ridefinire la responsabilità dello scienziato e delle università nei riguardi della società. Richard R. Ernst, premio Nobel per la chimica, ha dato e sta dando a tal riguardo un insegnamento fondamentale [17]

4. occorre sviluppare processi decisionali democratici.

Accenniamo ai casi dell'Ilva di Taranto, a casi di malfunzionamento di inceneritori, a incidenti tecnici catastrofici in cui si dice *"molti sapevano"* o che *"la tragedia era annunciata"*: quanti di questi eventi avrebbero potuto essere evitati?

I vari attori istituzionali e non, quali le università, gli enti di controllo quali l'Arpa, gli enti di ricerca (Cnr ed Enea) i vari portatori di interesse, il governo e il parlamento hanno ruoli specifici inderogabili.

Concludiamo questo studio prima con questa considerazioni di Ulrich Beck: *"Molti pensano che nella Società del Rischio sia rimasta una sola autorità, quella della scienza. Questa affermazione rivela non solo una incomprensione ed un fraintendimento della scienza e dei suoi compiti: vi sta anche un totale incomprensione della nozione del rischio"* [18]. La risposta può essere sintetizzata in questa affermazione-proposta di Kristin Shrader-Frechette: *"Da una collaborazione interdisciplinare possiamo forse creare una visione globale di una società giusta, partecipata e sostenibile, nella quale una giusta, partecipata e sostenibile verifica [dei rischi] sia la norma"* [19].

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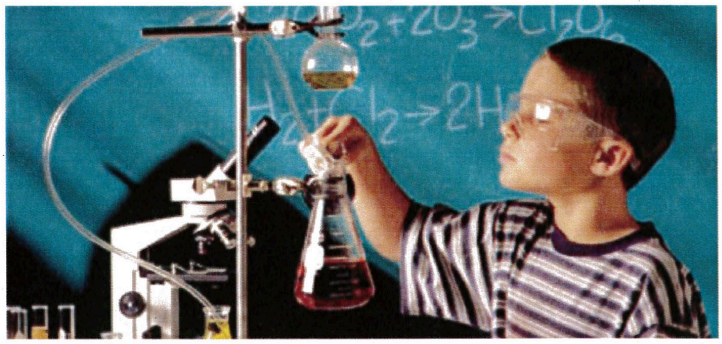
1 Un'immagine del progetto di Google Street Maps all'interno del Cern di Ginevra. Questo è l'Atlas, un rivelatore di particelle che sta indagando sulle particelle fondamentali, tra cui il bosone di Higgs.

FIG. 1
L'ARCO DELLA CONOSCENZA

L'arco della conoscenza e il ruolo aggiuntivo dell'etica.

Fonte: Vandeginste, Massart et al., Handbook of Chemometrics and Qualimetrics, Part B, Elsevier, Amsterdam, 1998, p. 2.



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ARTICLE VIII

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CHEMICAL LEASING: ETHICAL APPROACH IN THE MANAGEMENT OF CHEMICAL SUBSTANCES?

The paper at hand responds to the recognized need to reduce the risks connected to the production and use of chemical substances and suggests that any measures that reduce such risks can be considered as strategy to mainstream ethical approaches in chemistry if their underlying objective is to avoid harm to human health and the environment.

The chemical substances of concern for this paper are those chemicals that small and medium-sized enterprises (SMEs) frequently use in their production processes. Since the application of chemicals often is not part of the SME's core competency, it was argued that many SMEs in the productive sector often do not have sufficient information on characteristics and properties of the chemicals they apply. Furthermore, it was argued that the lack of information increases the likelihood of an inefficient application of the chemicals by the SME, which, in turn, will increase the overall risks emanating from the use of chemicals.

Following this argumentation, the paper at hand has sought to identify solutions that facilitate the increase of information on chemicals at the side of the SME with the aim to reduce the risks of applying chemical substances.

While the producer of chemicals have been identified to be a viable source of information on the characteristics and properties of chemical substances, it was demonstrated that the current sales concept does not provide incentives to transfer such knowledge from the producer to the SME. Based on this finding, it was shown that a possible strategy to overcome this shortcoming is the introduction of service-oriented so-called chemical leasing business models. Based on the findings of pilot studies on the introduction of these innovative business models at the global scale the paper concluded that Chemical Leasing can be considered as an effective means to mainstream ethical approaches in the management of chemical substances.

Chemicals contribute to a large extent to economic growth and social welfare of modern societies. With a trade surplus in chemicals of € 35.4 billion in 2007*, the chemical industry is one the largest industries in Europe, selling its products to end users, such as SMEs. Particularly for SMEs, the use and consumption of chemicals in production processes often play an important role and thus are vital for their economic success. At the same time, many chemicals pose serious threats to human

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health and the environment. In the past decades, industry, governments and regional entities have responded to these threats by calling for business approaches and legislative frameworks that minimize the risks that chemicals pose to human health and the environment.
The public sector has responded to this by incorporating approaches, such as the precautionary or cradle-to-cradle principle, at the very core of national and regional legislation or international legally binding instruments, such as the Stockholm, Rotterdam or Basel Conventions or voluntary frameworks, such as the Strategic Approach to International Chemicals Management (SAICM).
Private sector approaches to minimize the risks of chemicals include the development and implementation of strategies, such as Corporate Social Responsibility (CSR) and the Responsible Care initiatives in production processes and supply chain management.
While multinational private sector companies have the financial means to implement such risk reduction strategies, this may not be the case for SMEs.
The objective of this paper is to analyze why SMEs often lack capacity to implement such risk management strategies. Following the analysis, the paper will provide a solution to overcome these shortcomings by introducing the Chemical Leasing business model.

Ethics in chemistry

The paper at hand responds to the need recognized by the private and public sectors to identify and foster business approaches and regulatory frameworks that are capable to reduce the risks connected to the production and use of chemical substances.
In the context of this paper, any change of process or behavior that leads to the minimization of negative effects of chemicals shall be considered as ethical approach if the following two conditions are met. First, the underlying objective of the measures undertaken shall be to avoid harm to human health and the environment [1] and, secondly, the approach should confirm to the basic rules of society embodied in law and in general ethical customs [2].
Several risk reduction strategies for chemicals management have been identified, which allegedly have a vast potential to facilitate the mainstreaming of ethical approaches in chemistry. These strategies include the reduction of consumption of chemicals; the optimization of processes, in which chemicals are produced or applied; and the implementation of general safety measures throughout the life cycle of chemicals.
For the following discussion, the paper will evaluate the potential of identified solutions to facilitate the implementation of the above-mentioned risk reduction strategies and, as reasoned above, the mainstreaming of ethical approaches in chemistry.

The application of chemicals in SMEs

For the following analysis, the paper focuses on those SMEs in the productive sector that apply chemicals in their production processes. A key assumption of the subsequent discussion is that for this type of SME, the application of chemicals plays only a minor role in the overall production process and, therefore, is not a part of the core competency of the firm.
As a consequence, many SMEs often do not have sufficient information on the characteristics and environmental impact of chemicals substances they apply.
The paper at hand argues that the lack of information on the properties and characteristics of chemicals applied by SMEs results in their inefficient application. A likely consequence of such inefficient application, for example, can be the overconsumption of the chemical or spillages and accidents.
Following this argumentation, the overall risk of negative effects to human health and the environment in this context should be significantly increased.
As the lack of information of the SME on characteristics and properties of its chemical substances is a crucial factor for negative effects on human health and the environment, any approach that increases the information at the side of the SME should be capable to reduce the overall risk of applying chemicals.
According to the above definition, such approaches can be considered as ethical approaches, if they have a potential to reduce the consumption of chemicals; to optimize processes, in which chemicals are produced or applied; or to implement general safety measures throughout the life cycle of chemicals.
The key question that this paper seeks to answer, therefore, is: *are approaches that facilitate the increase of information on chemicals an effective and efficient means to mainstream ethical approaches in chemicals management?*

Information transfer from external sources

SMEs, particularly in times of economic downturn, may spend available financial means rather on the strengthening of core competencies than on the gathering of information on minor important production processes, such as the application of chemicals.
Due to lack of financial means to change this situation, it is likely that the above identified information deficiencies of SMEs on chemicals that they apply will persist [3, 4].
Ohl and Moser (2007 and 2008) have demonstrated that a possible strategy to overcome this shortcoming is the transfer of information from external sources to the user of chemicals, which for this paper is the SME.
It is straightforward to see that producers of chemicals are a valuable external source for information on characteristics of chemical substances, as the production and management of chemicals, including storage and handling, is an integral part of their core competency.
Ohl and Moser furthermore demonstrated that within the current business concept of selling chemical substances, there is no incentive for the producer of chemical substances to transfer its knowledge to the SME, as this would result in increased efficien-

*www.cefic.org/factsandfigures/downloads/Facts_and_Figures_2009_Ch2.pdf

cy and thus reduce overconsumption.
As the SME in this case would need to acquire lesser quantities of the chemical, the producer's sales volume and hence the revenues would directly decrease. The current sales concept of chemical industry, therefore, provides no automatism to transfer such information from the producer to the SME.
The paper at hand therefore suggests that the current sales concept falls short of providing incentives for mainstreaming ethical approaches in chemistry through the introduction of effective and efficient strategies to manage the risks of chemical substances. It hence proposes as a possible solution the introduction of such business models that foster the transfer of information from the producer to the SME.
Ohl and Moser have demonstrated that Chemical Leasing business models are a convincing strategy to achieve this objective.

Chemical Leasing business models

Chemical Leasing is an innovative business model that changes the way in which chemicals are sold.
While in the current sales concept, the producer sells the chemical by transferring the ownership of chemical to the SME, with Chemical Leasing, the producer stays the owner of the chemical.
Since the producer "leases" the chemical to the SME, the basis of the contract between the producer and the SME is not anymore the chemical substance itself, but the service that the chemical provides to the SME.
The remuneration shifts from a price per volume or weight in the current sales concept, typically, to a unit price for the provided service. Depending on the conditions of the Chemical Leasing contract, the basis for remuneration can be, for example, the price per treated surface or treated piece.
Since the producer stays the owner of the chemical, the responsibility of the producer to guarantee the environmentally sound management and disposal or recycling of the chemical is expanded over the whole life cycle of the chemical.
Ohl and Moser were able to demonstrate that, given the expanded responsibility, which ideally comprises the recycling of the chemical, the producer has a stake in ensuring that the chemical is applied more efficiently. This is due to the fact that, since the producer stays the owner of the chemical, any overconsumption now directly increases the costs and, therefore, reduces the income of the producer.
By introducing two business models, where the first model is nearest to the current business concept of selling chemicals and the second model differs the most, Ohl and Moser demonstrated that Chemical Leasing business models are capable to transfer knowledge and/or technologies from the producer of the chemical to the SME.
The likeliness of the business models to transfer knowledge and/or technologies is supported by the fact that the producer and SME, by shifting to Chemical Leasing contract, enter into longer standing business relationships compared to the current sales concept.

Pilot studies

In the past years, several pilot studies have been undertaken to demonstrate the vast potential of Chemical Leasing to generate win-win situations and to improve the overall risk management of chemical substances [5, 6].
In analyzing the pilot studies, it was demonstrated that the introduction of Chemical Leasing delivered the following key outcomes: - Change of management behavior and improvement of internal communication; - Enhancement of the supply chain management of chemicals management; - Improved process efficiency; - Know-how exchange between supplier and users of chemicals (involvement of -technology suppliers); - Capacity building of operation staff; - Positive effects on occupational health and safety of workers by improving workplace conditions.
Besides these favorable outcomes, other positive driver that support the introduction of Chemical Leasing includes the entry into force in 2007 of a new regulatory framework for the Registration, Evaluation and Authorization of Chemicals (Reach) in the European Union.
Reach shifts the responsibility to gather of information on the characteristics of chemicals to producers and users of chemicals. Chemical Leasing with its potential to induce an exchange of information on chemicals between producers and users of chemicals, therefore, supports the implementation of Reach through lowering the costs, particularly for SMEs, to gather information on chemicals applied in production processes.

Conclusions

The outcomes of the pilot studies clearly demonstrate the vast potential of Chemical Leasing business models to reduce the consumption of chemicals; to optimize processes, in which chemicals are produced or applied; and to implement general safety measures throughout the life cycle of chemicals.
The demonstrated knowledge transfer between the producer and the SME and the improvement of the workplace conditions convincingly show that Chemical Leasing business models are capable to reduce negative effects of chemicals to human health and the environment.
The introduction of Chemical Leasing business models thus can be considered as an effective means to mainstream ethical approaches in the management of chemical substances.

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