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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:

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

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:

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

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

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

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

[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:

$$\sum_{j=1}^{4} g_{1j} > x_1 \tag{6}$$

$$\sum_{j=1}^{6} g_{2j} > x_2 \tag{7}$$

$$\sum_{j=1}^{6} g_{3j} > x_3 \tag{8}$$

$$\sum_{j=1}^{10} g_{4j} > x_4 \tag{9}$$

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:

$$\text{Total Score} = \sum_{i=1}^{4} \sum_{j=1}^{n} y_{ij} \cdot g_{ij} \tag{10}$$

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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