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Letter from the Editor

The chemical industry under pressure

In the last quarter of 2015, exchange rate effects as well as the lower growth rates of emerging countries kept the chemical sector busy. The strong dollar weighed on performance measures of many international chemical giants. For example, Merck experienced a major decline in sales in the last quarter of 2015. The same applied to DuPont's profits. In addition, the drops in crude oil and gas prices affected the sector, particularly petro- and basic chemicals manufacturing. BASF experienced a significant decrease in earnings before interests and taxes due to the corresponding value adjustments. Low price levels could as well be registered for other materials (such as silicon or grain) affecting several segments of the chemical industry. Compensating resulting cost pressures and losses with profits from other business areas was thus not possible or often insufficient. In consequence, productivity improvement and cost-cutting programs are in progress. Projections for 2016 are as well not very promising and the announced merger of DOW and DuPont will, amongst other topics, determine the mood in the industry and might initiate further consolidation. The Journal of Business Chemistry, however, starts the year with more enthusiasms. The first issue of this year comprises the following articles:

The first research paper of this issue "Are behavioral pricing tactics also present in the B2B context? Evidence from a complex chemical B2B product" by Thomas Hamadi and Maike Strudthoff analyzes the comparability of pricing strategies for B2C and B2B sectors. The authors review the scientific literature on different price ending theories before they present their results drawn from an exploratory study on price endings of bead prices. Their findings suggest that price-ending effects, which have so far only been identified in B2C contexts, are transferable to B2B products.

Evripidis Lampadarios presents an overview on SMEs active in chemical distribution in his paper headlined "Critical challenges for SMEs in the UK chemical distribution industry". After giving an outline on SMEs and the current situation of the UK chemical distribution sector, the author uses qualitative survey data in form of exemplary statements of SME owners and managers to identify and discuss the main challenges affecting small- and medium-sized firms' success, i.e. regulatory compliance, supplier management, human capital and access to capital.

In the first article of the Practitioner's section, Thorsten Daubenfeld and his co-authors Jonas Dassow, Maximilian Keßler and Jonas Schulze conduct a PEST analysis in order to facilitate "Understanding the market dynamics of biosimilars". By using different kinds of data, the current state and essential conditions for biosimilar development such as a favorable regulatory framework and the availability of manufacturing technologies are detected. The article ends with a discussion on the changing attitudes towards biosimiliars, potentially enabling a positive future development of the corresponding market.

The article "PhytoGerm: Extraction of germanium from biomass - An economic pre-feasibility study" by Lars Rentsch, Ines Aubel, Norbert Schreiter, Michael Höck and Martin Bertau deals with a new way to extract germanium and its economic efficiency. By comparing the expenditures and yields of different approaches to germanium extraction, the authors show that their project's phytomining process is preferable over comparable ones but certain conditions are required in order to replace traditional germanium production processes.

Please enjoy reading the first issue of the thirteenth volume of the Journal of Business Chemistry. We are grateful for the support of all authors and reviewers for this new issue. If you have any comments or suggestions, please do not hesitate to contact us at contact@businesschemistry.org.

Birte Golembiewski
(Executive Editor)

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Research Paper

Are behavioral pricing tactics also present in the B2B context? Evidence from a complex chemical B2B product

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Applying behavioral pricing tactics is common in business-to-consumer (B2C) markets and can result in a competitive advantage. One aspect of behavioral pricing is the use of price ending effects. While a lot of prior research focused on B2C markets, little research has been done to provide insights on price ending effects in business-to-business (B2B) markets. This study adresses this research gap by investigating price endings using the example of a highly complex chemical B2B product. The results reveal a high use of dominant price endings, indirectly indicating positive price threshold effects for this B2B product. The identified dominant price endings are similar to those observed in B2C studies and are thus strongly suggesting that current B2C price ending theories may also be applicable to B2B markets.

1 Introduction

The behavioral pricing research adds psychological and behavioral aspects to pricing research by applying theories from social cognition and behavioral decision research (Somervuori, 2012). Albeit some reviews on behavioral pricing have been conducted (e.g. Monroe, 1973; Winer, 1988), there is still no clear, uniform conceptualization (Somervuori, 2012). Behavioral pricing can be defined as follows: *"Behavioral pricing constitutes an expansive subset of pricing research wherein prices and pricing are examined with respect to their human elements – that is, with respect to how humans attend to, perceive, process, and evaluate price information, as well as how they go about determining the price at which a particular item should be sold or purchased"* (Miyazaki, 2003, p. 471).

In order to influence the demand positively, behavioral aspects in pricing tactics are commonly used in B2C markets (Hinterhuber and Liozu, 2014). One of these effects is the compromise effect, where customers tend to avoid extreme options and instead choose intermediate options (Simonson, 1989). Therefore, pricing managers can increase the likelihood that the customer buys the premium product by adding a super-premium product to the portfolio (Hinterhuber and Liozu, 2014). Another important aspect of behavioral pricing research are price threshold and price ending effects which have so far almost exclusively been detected in the B2C context (Hinterhuber, 2015; Monroe et al., 2015). Companies active in B2C markets already use specific price endings in pricing tactics in order to affect customers' behavior. The question is whether those price ending effects are also transferable to the B2B context (Hinterhuber and Liozu, 2014; Monroe et al., 2015; Wilson, 2000). If so, findings concerning B2C price endings might open up new opportunities for B2B companies with regard to influencing their customers' decision-making. To provide an answer concerning the transferability, this exploratory study is thus investigating the price endings used within the B2B market on the basis of the example of a highly complex chemical product. In this study, the focus lies on identifying the frequency of occurrence of certain price endings and deducing whether or not behavioral pricing tactics are also present in the B2B context. After this introduction, the literature on price thresholds and price endings is summarized and hypotheses concerning price endings in B2B markets are deduced. In the subsequent sections, the underlying data and method of this exploratory study are described and the results are presented and discussed. This paper concludes with the findings and an outlook on further research.

2 Literature review

The following section provides an overview of the current state of price threshold and price ending research. Relevant price ending theories and empirical evidence are summarized before deducing the hypotheses for pricing tactics in B2B contexts.

2.1 Price thresholds and price endings in B2C markets

The concept of price thresholds addresses the sudden change in the customer's price evaluation at a specific price point, whereby a distinction is made between absolute and differential price thresholds (Monroe, 1973). Absolute price thresholds are price points where customers stop purchasing due to the fact that some customers will either find the product/service too expensive (upper absolute price threshold) or too cheap so that they become suspicious of its quality (lower absolute price threshold) (Bruno et al., 2012; Monroe et al., 2015). The upper and lower absolute price threshold border the range of prices where a customer considers purchasing a product/service. This is referred to as acceptable price range (Monroe, 1971). In contrast, differential price thresholds are sudden changes in the customer's price evaluation within the acceptable price range. Those abrupt changes in the perceived relative expensiveness of the offering occur with increasing prices (Monroe, 1973). However, the perceived price difference does not necessarily lead to a shift in the buying behavior. For instance, George et al. (1996) showed that a price change of more than 8-10% is required in order to significantly influence the purchasing behavior in the case of household products of varying brands.

The existence of price thresholds has been accepted, in particular with regard to odd and round prices, which differ in their rightmost digit. Round prices are often defined as 0- or 5-ending prices (e.g. $130 or $145). In contrast, odd prices include one of the other eight possible digits at the rightmost position, whereby the price threshold research has so far focused on the digit 9 (Janiszewski and Lichtenstein, 1999; Kalwani et al., 1990; Schindler and Kirby, 1997).

The existing empirical research shows that 0-, 5-, and 9-ending prices are more regularly used compared to other price endings in the B2C context. Table 1 provides an overview of the shares of specific price endings identified by selected studies. Those studies reveal that the digit 9 is the most frequently applied price ending in the B2C context, but the magnitude of relative frequency varies across product categories. In addition, there is a tendency of using 9-ending prices more often for low-priced or low-quality products, while 0- and 5-ending prices are either used for high-priced or low-priced products (Kreul, 1982; Lee et al., 2009; Naipaul and Parsa, 2001; Stiving, 2000). For example, in the restaurant industry, price endings on the digit 5 are used for high-quality food whereas 9-ending prices are characteristic for low-quality food (Naipaul and Parsa, 2001). Lee et al. (2009) found similar results for products in internet-based selling. They showed that internet retailers use 9¢ price endings for low-priced products (prices < $100) and 0¢ and 5¢ price endings for prices over $100.

2.2 Price ending theories

A number of theories has been proposed to explain the frequent use of 0-, 5-, and 9-price endings. Relevant theories also applicable to the B2B context are the cognitive accessibility theory (Schindler and Kirby, 1997), affective effect theory (Nguyen et al., 2007), image effect theory (Stiving and Winer, 1997), perceived gain effect theory (Schindler and Kirby, 1997), rational inattention theory (Levy et al., 2007) and underestimation theory (Schindler and Kirby, 1997).

The cognitive accessibility theory is based on the observation that in different numerical estimation tasks, people show a strong tendency towards 0- and 5-ending numbers (Hultsman et al., 1989; Tarrant and Manfredo, 1993). In pricing context, Schindler and Wiman (1989) investigated this phenomenon and found that customers tend to produce 0- and 5-ending prices when recalling prices. Thus, the digits 0 and 5 are more accessible in memory (Fazio et al., 1982; Higgins et al., 1977), which is also valid within the pricing context as 0- and 5-ending prices seem to be more cognitive accessible than the other eight possibilities (Estelami, 1999; Guido and Peluso, 2004, Schindler and Kirby, 1997). In addition, results suggest that 0-ending numbers have a higher cognitive accessibility than 5-ending numbers (Schindler and Kirby, 1997). It seems as if this tendency to favor round numbers is very deeply ingrained in human cognitive processing (Schindler and Kirby, 1997; Yoshida and Kuriyama, 1986). Thus, the frequent use of this kind of prices is explained as they are easier perceived, remembered and compared (Estelmani, 1999; Schindler and Kirby, 1997).

Affective effect theory states that odd prices (e.g. 9-ending prices) can be perceived as a manipulative marketing tool by customers, leading to a negative affective state (Schindler, 2006). In contrast, round prices can elicit a positive affective state if customers perceive them as honest and

Table 1 Overview of the relative frequency of specific price endings in the B2C context.

Data	Frequency of occurence (%)			Study
	9-ending	5-ending	0-ending	
Catalog prices of women's clothing by two companies	52 68	n/a	n/a	Anderson, Simester (2003)
Menu prices of 242 restaurants	58[a] 11[b]	35[a] 71[b]	6[a] 15[b]	Kreul (1982)
3,290 menu prices from fine-dining restaurants	13	57	31	Naipaul, Parsa (2001)
2,878 menu prices from quick-service restaurants	33	37	30	Naipaul, Parsa (2001)
1,538,872 prices from different product categories in internet-based selling	39	14	16	Lee et al. (2009)
Prices and food & nonfood product categories	54	17	5	Macé (2012)
1,415 prices in newspaper advertisement	31	19	27	Schindler, Kirby (1997)
24,770 prices of tuna	51	n/a	0	Stiving, Winer (1997)
2,464 prices of yogurt	36	n/a	11	Stiving, Winer (1997)

[a]price ≤ $6.99; [b]$7.00 ≤ price ≤ $10.99

unchanged (Suri et al., 2002). Thus, in order to avoid negative affective states coupled to the use of odd prices and rather stimulate positive affective states, this theory favors the use of round prices.

Image effect theory distinguishes between two effects to explain the frequent use of specific price endings: the price image effect and the quality image effect. The price image effect argues that 9- and 99-ending prices indicate low prices leading to a low-price image and therefore potentially to higher sales. In contrast, the quality image effect argues that odd prices (e.g. 9- and 99-ending prices) indicate low quality, while round prices (e.g. 0-ending prices) are a signal for high qualitative products which might enhance its desirability. Thus, by choosing price endings, companies can either produce a low-price or a high-quality image (Stiving and Winer, 1997).

The perceived gain effect is based on the higher cognitive accessibility of round numbers. The digits 0 and 5 are reference points in price evaluations for customers. According to the prospect theory (Kahneman and Tversky, 1979), 9-ending prices can be framed as a round price with a small gain (Schindler and Kirby, 1997). Here, the perception of gains is disproportionate to the gain's small size, which is thus enhancing the evaluation of prices ending with a 9 (Schindler and Kirby, 1997; Thaler, 1985). This enhancement is termed perceived gain effect and could be an explanation of why companies favor 9-ending prices (Schindler and Kirby, 1997).

The rational inattention theory suggests that customers may be rational inattentive to the rightmost digit(s) of prices due to being constrained by time, limited resources or information processing

capacities (Levy et al., 2007). Thus, companies favor setting the last digit as high as possible at 9¢ or $9 (Lee et al., 2009).

Considering the findings that customers tend to process prices from left to right and favor round prices (Poltrock and Schwartz, 1984), the underestimation effect theory states that customers may truncate an advertised price into a round-number mental presentation. For example, a price such as $799 would be encoded as $790 if just the first two digits are processed (Schindler and Kirby, 1997). This leads to an overrepresentation of 9-ending prices.

In sum, all presented theories indicate that customers tend to process prices not as a whole and that the specific price endings may affect the customer's buying behavior (Lee et al., 2009).

2.3 Empirical evidence

A lot of studies have been conducted to support each theory and to explain the dominance of specific price endings, especially 9-endings. Table 2 summarizes selected empirical studies on price endings in the B2C context. Interestingly, the studies show inconclusive results, e.g. concerning the quality image effect (Dodds and Monroe, 1970; Naipaul and Parsa, 2001; Stiving, 2000). Furthermore, while some studies provide evidence that 9-ending prices increase sales (Anderson and Simester, 2003; Lee et al., 2009; Schindler and Kibarian, 1996), other studies do not detect any effects (Dodds and Monroe, 1985; Ginzberg, 1936).

2.4 Price endings in B2B markets

Although B2B markets include challenges that differ from those in B2C markets, e.g. price negotiations (Stanton, 1981) and purchases by a buying center (Bonoma, 1982), many behavioral characteristics are present across diverse contexts. This leads to the assumption that there are "fundamental similarities within human choice-making" (Wilson, 2000, p. 781) in B2B and B2C markets and that many behavioral pricing theories in B2C markets could be applicable to B2B markets as well (Monroe et al., 2015). Up to date, only Larson et al. (2014) investigated the impact of price endings on the demand in a B2B context. The authors found that 9-ending and 0-ending prices strongly affect the demand for telecommunication services. Their findings also indicate 0-ending prices to have a higher impact on the demand than 9-ending prices. Based on their findings, they conclude that positive price thresholds also exist in B2B markets. As there are no further studies analyzing the impact of price endings on B2B products, this study addresses this research gap by investigating the frequency of price endings for a highly complex chemical B2B product in order to answer the question whether or not B2C price ending theories may also be applicable to B2B markets due to similarities within human behavior (Monroe et al., 2015; Wilson, 2000). Previous research has shown that price setters in B2C markets frequently use 0-, 5-, and 9-endings, which is in parts consistent with the results of Larson et al. (2014). Therefore, the following hypotheses are proposed for price endings in B2B markets:

Hypothesis 1a: Dominant price endings are present in B2B markets.

Hypothesis 1b: The price endings are not evenly distributed.

Hypothesis 2: The most frequently used price endings in B2B markets are 0-, 5-, and 9-endings.

3 Method and data

This study uses an exploratory approach. The frequency of occurrence of price endings in a B2B market is investigated by means of complex chemical products. These B2B products are so-called "beads", i.e. spherical, non-porous, monodisperse nano- and microparticles, which are mainly used in biomedical applications (Bi et al., 2009; Cha et al., 2009; Dunbar, 2006; Liu et al., 2009; Safarik and Safarikova, 2009; Seydack, 2005; Ugelstad et al., 1993, Vignali, 2000). Due to their variety in functionality and the usage for highly specialized applications, small niche markets exist. In order to provide consistency, this analysis only takes those beads into consideration that consist of commonly used bulk materials. Such bulk materials are polymers (e.g. polymethyl methacrylate or polystyrene) and silica (Bake and Walt, 2008; Chen et al., 2006; Kang et al., 2006; Yalçın et al., 2006). Other (inorganic) materials are not considered.

Price negotiations are a common practice in B2B markets (Stanton, 1981). Due to different reference prices, price negotiations can lead to variations in the agreed price (Moosmeyer et al., 2012). To avoid biases, only internet-based catalog prices are sampled for this analysis.

Previous studies mainly focused on price endings in cents but research indicates that price ending effects occur as well for endings in dollar (Larson et al., 2014; Lee et al., 2009; Levy et al., 2007). Thus, this study analyzes price endings in dollars and cents.

A total of 6,724 prices were sampled from 9 US companies – a representative sample in view of the fact that the US bead market only consists of a few

Table 2 Selected empirical studies on price ending theories in B2C contexts, adapted from Lee et al. (2009), p. 132f.

Study	Theories	Findings
Anderson, Schindler (2003)	PIE, UEE	▪ Use of 9-ending prices increases customer demand ▪ 9-ending effect is context-dependent
Blattberg, Wisniewski (1987)	PIE, UEE	▪ Use of 9-ending prices increases customer demand
Dalrymple, Haines (1970)	PIE	▪ Odd prices are positively related to sales
Dodds, Monroe (1985)	PIE, QIE	▪ No effect of price ending on perceived quality, perceived value, and willingness to buy
Ginzberg (1936)	PIE	▪ Inconsistent results on sales effects of odd prices
Huston, Kamdar (1996)	PIE, UEE	▪ Number of digits is positively related to 9-endings ▪ Opposing results to price image effects
Lambert (1975)	UEE	▪ No significant underestimation results ▪ Lower prices illusions associated with odd prices
Lee et al. (2009)	PIE, QIE, RIA	▪ Use of 9-ending prices increases customer demand ▪ 9-ending prices signal low quality ▪ No significant correlation between number of digits in prices and 9-endings
Naipaul, Parsa (2001)	PIE, QIE	▪ Firms and customers use price endings as signal of quality and value of products
Schindler (1984)	UEE	▪ Poorer memory for odd prices than for even prices ▪ Odd prices indicate no recent price increase and low price image
Schindler, Kibarian (1996)	PIE, QIE	▪ 99-ending prices signal low price image and discounts ▪ 99-endings have negative effect on quality image
Schindler, Kibarian (2001)	PIE, UEE	▪ Use of 99-endings leads to increased customer purchasing
Schindler, Kirby (1997)	PGE, UEE	▪ 9-ending prices are less frequent in longer prices ▪ More use of 9-ending prices for price types where relative potential underestimation is higher
Schindler, Wiman (1989)	UEE	▪ Underestimation of odd prices rather than round prices ▪ Customers may process only leftmost price digit
Stiving (2000)	QIE	▪ More round prices for higher quality products and high-priced firms
Stiving, Winer (1997)	PIE, QIE, UEE	▪ Left-to-right processing of digits in a price ▪ Opposing implications of prices and quality images in 9-ending prices
Thomas, Morwitz (2005)	UEE	▪ Underestimation effect happens when customers compare two prices and the prices being compared are close to each other

Note: PIE (price image effect theory), QIE (quality image effect theory), UEE (underestimation effect theory), PGE (perceived gain effect theory), RIA (rational inattention theory).

competing companies. The prices were exactly coded as listed in the internet catalog of each company. The advertised prices ranged from $50.00 to $8,872.50[1] and the mean value of the whole sample was $422.56. Table 3 provides an overview of the descriptive statistics of this data set.

4 Results and discussion

As shown in table 4, the rightmost digits of bead prices are not evenly distributed among the 10 possibilities ($\chi^2(9) = 49{,}760$; $p < 0.001$). As the "Total" row of table 4 shows, the ending 0¢ is greatly overrepresented with 92%. Furthermore, 6 of 9 companies are solely using 0¢ endings for bead prices. The other 9 possible price endings for the rightmost digit are underrepresented and account together for only 10%. Although the 5¢ ending occurs solely for 5% of the prices, it is the second highest frequency of occurrence within this sample. An explanation for this result could be the 100% use of this price ending by the company Phosphorex. One company uses a 9¢ ending price but to a negligible percentage which becomes not evident within the table due to rounding. This result deviates from the findings of Lee et al. (2009) although the price level is as well between $100 and $1,000 for all companies. For products priced above $100, they find that 28% of the prices end with 0¢, 21% with 5¢, and 25% with 9¢, respectively. In their study, the use of the price ending 0¢ increases for products above $1,000. Thus, the price ending strategies of companies within the present study seem to be different. One possible explanation for this obser-

Table 3 Descriptive statistics for internet-based catalog prices of beads-selling US companies.

Company	Data points	Mean price ($)	Std. Dev. ($)	Min. price ($)	Max. price ($)
Bangs Laboratories, Inc.	1,757	783.10	894.25	70.00	4,817.00
Life Technologies, Inc.	271	454.54	621.86	134.07	8,872.50
Polyscience, Inc.	542	395.35	372.13	93.00	3,074.00
Magsphere, Inc.	725	374.09	350.22	85.00	2,000.00
Sigma-Aldrich Corp.	124	351.41	157.24	115.50	1,080.00
Spherotech, Inc.	643	313.46	381.90	100.00	4,200.00
Corpuscular, Inc.	1,432	287.25	110.42	74.00	982.80
Phosphorex, Inc.	348	211.21	123.19	54.95	499.95
Cospheric LLC	882	143.69	70.71	50.00	595.00
Total	6,742	422.56	565.10	50.00	8,872.50

[1] It is not expedient to consider the quantities corresponding to the prices (often stated in g or ml) as the exclusive focus of this study is on price endings, so that quantities do not have to be comparable.

vation might be the already described strong tendency to use round endings, particularly 0¢, for high prices, potentially in order to signal higher quality (quality image effect) (Stiving, 2000). In addition, Stiving (2000) found that this relationship is even stronger when the customer does not know the true level of quality prior to the purchase, which is the case for beads due to their high technological complexity.

Table 5 shows the frequency distribution of the last two digits in cents within the sample. As expected, also the last two cent digits of bead prices are not equally distributed among all 100 possibilities ($\chi^2(99) = 432{,}015$; $p < 0.001$). As illustrated in the "Total" row of table 5, the 00¢, 50¢, and 95¢ price endings are overrepresented, reflected by 80% for 00¢, 8% for 50¢, and 5% for 95¢, respectively. The other price endings are accounting for 7%. Companies examined in this study show a strong tendency to use especially 00¢ ending prices. In contrast, only the company Phosphorex prices all beads with 95¢ endings. The company Life Technologies follows an entirely different pricing strategy, 23% of the bead prices end with an unusual price ending of 48¢ and solely 9% show a 00¢ ending.

The frequency distribution of price endings in dollar is reported in table 6, clearly indicating that the last digits of bead prices in dollar are unevenly distributed among the 10 possibilities ($\chi^2(9) = 1{,}752$; $p < 0.001$). The $0 and $5 price endings are overrepresented (29% and 19%, respectively). The companies Magsphere, Spherotech, and Corpuscular use the $0 ending for over 50% of their prices, whereby Magsphere and Spherotech almost solely use $0 and $5 price endings. This overrepresentation of $0 and $5 price endings could be explained by the high cognitive accessibility of those two digits. By using the 0- and 5-ending prices, price setters can simplify the communication with their customers, which might in turn increase the opportunity that customers perceive and recall the advertised prices. In addition, one reason for the lower frequency of $5 price endings in comparison to $0 price endings might be that 5-ending prices have a lower cognitive accessibility than 0-endings prices (Schindler and Kirby, 1997). Furthermore, the $9 price ending is also comparably often used, accounting for 11%. Contrary to the other companies, Phosphorex and Cospheric apply the $9 ending most frequent (64% and 25%, respectively). Furthermore, Phosphorex solely uses $9 and $4 endings and the 95¢ ending for the last two digits of the bead prices, leading to a focus on prices which are below a round denomination (e.g. $149.95 or $199.95) in their pricing strategy (Huston and Kamdar, 1996). This prevalence of $0, $5, and $9 price endings is partially consistent with the findings of Larson et al. (2014). They found that 0- and 9-ending prices increase the demand within a B2B context, but $5 ending prices had no significant positive impact in their study.

The last frequency distribution considered concerns the last two dollar digits (table 7). Again, the last two digits of the bead prices are not equally distributed among the 100 possibilities ($\chi 2(99) = 3{,}586$; $p < 0.001$). The most frequent used price ending is $50, accounting for 5.5%. Rank 2 is occupied by the $99 ending accounting for 4.4%, while the $00 ending ranks fifth (3.7%). The company Cospheric uses the $9 ending for 25% of their prices. For the last two digits in dollar terms, almost 25% of their prices end with $99, which leads to the conclusion that nearly all $9 prices endings are simultaneously $99 price endings. Therefore, this company also has a strong tendency to use prices which are below a round denomination (e.g. $99.00) (Huston and Kamdar, 1996).

In sum, the results show that there are dominant price endings for US bead prices and that the analyzed price endings are not evenly distributed. Thus, there is strong support for hypothesis 1a and 1b. While the $0, $5, and $9 price endings were shown to be predominant for the last digit in dollar, this is only true for the 0¢ ending with regard to the last cent digit. Therefore, hypothesis 2 is only partially supported. This strong tendency to use 0-ending prices and especially the 00¢ price ending for a B2B product shows that most of the B2B price setters in this study strongly believe in the (positive) effects of round price endings (as suggested by the quality image effect theory and cognitive accessibility theory). Exceptions in this study are the companies Phosphorex and Cospheric. They focus on prices which are below a round denomination (e.g. $149.95, $99.00) and are thus rather trusting in the perceived gain effect, underestimation effect, price image effect or the rational inattention effect. All of those effects provide a possible explanation for the frequent use of the price ending 9.

Nevertheless, there are dominant price endings indicating the existence of price thresholds in B2B markets. Especially for $0, $5, and $9 ending prices, positive price threshold effects are suggested, but these findings are only partly consistent with the results of Larson et al. (2014) who found positive threshold effects for $0 and $9 ending prices within the B2B context. Because of the appearance of similar dominant price endings in B2C and B2B contexts, this study found strong support that B2C price ending theories may also be applicable to the B2B context. The observations made are strengthened as similar dominant price endings emerge when conducting the same analysis for the German market.

Table 4 Frequency distribution of the last cent digit of US bead prices.

Company	Mean price ($)	Data points	Last digit in cent (%)									
			0¢	1¢	2¢	3¢	4¢	5¢	6¢	7¢	8¢	9¢
Bangs Laboratories	783.10	1,757	**100**	0	0	0	0	0	0	0	0	0
Life Technologies	454.54	271	**21.4**	0.7	**10.0**	1.8	7.4	3.0	**21.0**	0.4	**34.3**	0
Polyscience	395.35	542	**100**	0	0	0	0	0	0	0	0	0
Magsphere	374.09	725	**100**	0	0	0	0	0	0	0	0	0
Sigma-Aldrich	351.41	124	**100**	0	0	0	0	0	0	0	0	0
Spherotech	313.46	643	**100**	0	0	0	0	0	0	0	0	0
Corpuscular	287.25	1,432	**99.2**	0	0	0	0	0.5	0.1	0	0.3	0
Phosphorex	211.21	348	0	0	0	0	0	**100**	0	0	0	0
Cospheric	143.69	882	**100**	0	0	0	0	0	0	0	0	0
Total	422.56	6,724	**91.5**	0	0.4	0.1	0.3	5.4	0.9	0	1.4	0

Note: Frequencies greater than 10% appear in bold.

Table 5 Frequency distribution of the last two digits of US bead prices in cents.

Rank	Bangs Laboratories	Life Technologies	Polyscience	Magsphere	Sigma-Aldrich	Spherotech	Corpuscular	Phosphorex	Cospheric	Total
1	00¢ 100%	48¢ 23.2%	00¢ 100%	00¢ 100%	00¢ 58.1%	00¢ 100%	00¢ 81.0%	95¢ 99.7%	00¢ 53.5%	00¢ 80.2%
2	n/a	36¢ 12.9%	n/a	n/a	50¢ 31.5%	n/a	50¢ 4.0%	99¢ 0.3%	50¢ 46.5%	50¢ 7.6%
3	n/a	00¢ 8.9%	n/a	n/a	60¢ 4.0%	n/a	90¢ 2.9%	n/a	n/a	95¢ 5.2%
4	n/a	28¢ 5.9%	n/a	n/a	70¢ 2.4%	n/a	10¢ 2.4%	n/a	n/a	48¢ 0.9%
5	n/a	24¢ 5.5%	n/a	n/a	80¢ 2.4%	n/a	60¢ 2.2%	n/a	n/a	90¢ 0.7%
Mean price ($)	783.10	454.54	395.35	374.09	351.41	313.46	287.25	211.21	143.69	422.56

Table 6 Frequency distribution of the last digits of US bead prices in dollar.

			Last digit in dollar (%)									
Company	Mean price ($)	Data points	$0	$1	$2	$3	$4	$5	$6	$7	$8	$9
Bangs Laboratories	783.10	1,757	9.3	**16.3**	1.5	**16.2**	5.9	**17.4**	**13.5**	5.5	6.1	8.3
Life Technologies	454.54	271	**12.2**	9.6	**28.0**	6.3	6.6	4.4	9.2	1.1	5.9	**16.6**
Polyscience	395.35	542	**16.4**	**14.9**	9.8	**11.1**	3.5	8.1	**12.7**	7.9	7.9	7.6
Magsphere	374.09	725	**59.6**	0	0	0	0	**38.6**	0	0	1.8	0
Sigma-Aldrich	351.41	124	4.8	**12.9**	**21.8**	8.9	**12.1**	**10.5**	5.6	9.7	8.9	4.8
Spherotech	313.46	643	**54.4**	0	0	0	0	**45.4**	0.2	0	0	0
Corpuscular	287.25	1,432	**51.3**	3.0	2.0	3.3	3.9	**12.6**	**10.6**	6.3	2.7	4.3
Phosphorex	211.21	348	0	0	0	0	**35.6**	0	0	0	0	**64.4**
Cospheric	143.69	882	**12.4**	0	3.4	0	0.6	**18.4**	0	**17.2**	**22.7**	**25.3**
Total	422.56	6,724	**28.5**	6.7	3.6	6.2	5.1	**19.2**	7.3	5.9	6.4	**11.1**

Note: Frequencies greater than 10% appear in bold.

Table 7 Frequency distribution of the last two digits of US bead prices in dollar.

Rank	Bangs Laboratories	Life Technologies	Polyscience	Magsphere	Sigma-Aldrich	Spherotech	Corpuscular	Phosphorex	Cospheric	Total
1	$55 8.2%	$72 24.4%	$33 8.7%	$50 18.1%	$32 9.7%	$40 11.0%	$10 10.1%	$09 25.9%	$99 24.8%	$50 5.7%
2	$46 5.8%	$99 8.5%	$31 6.5%	$00 13.0%	$22 8.9%	$55 10.7%	$50 7.7%	$49 16.4%	$48 22.4%	$99 4.4%
3	$31 5.7%	$71 5.9%	$40 4.8%	$25 7.4%	$51 4.8%	$35 8.6%	$00 6.1%	$74 13.5%	$97 17.1%	$55 3.8%
4	$03 5.4%	$30 5.2%	$91 4.8%	$15 7.2%	$84 4.0%	$25 8.1%	$90 6.1%	$24 11.2%	$25 14.7%	$25 3.7%
5	$11 4.7%	$24 4.8%	$65 4.2%	$75 7.0%	$03 3.2%	$00 7.9%	$56 5.7%	$69 6.6%	$50 9.4%	$00 3.7%
Mean price ($)	783.10	454.54	395.35	374.09	351.41	313.46	287.25	211.21	143.69	422.56

5 Conclusion and Outlook

This study depicted the landscape of price endings by analyzing the frequency of their occurrence on cent and dollar level for a highly complex chemical product. The results show that price setters particularly use $0, $5, $9 and 00¢ endings. Based on the assumption that price setters favor prices and price endings contributing to achieving their demand goals, this indicates positive price thresholds effects for these price endings. These price endings are similar to the dominant endings found in previous B2C studies. This finding is thus supporting the assumption that B2C price ending theories may also be applicable in the B2B context. The results particularly indicate the transferability of the cognitive accessibility theory to the B2B context. At the same time, it can be assumed that the quality image effect might be an explanation for the frequent use of the price ending 0. In addition, two companies frequently used 9-ending prices which rather support the existence of the perceived gain effect, underestimation effect, price image effect or the rational inattention effect. Thus, further research is required.

It should be noted that there are some limitations to this study. The analysis assumes that price setter favor prices that influence demand goals positively, so that the existence of positive price thresholds effects was only indirectly investigated. However, most dominant price endings are consistent with the results of Larson et al. (2014) and previous B2C studies. Furthermore, only catalog prices were investigated. Because price negotiations are common practice in B2B context (Stanton, 1981), it is unclear how far the sampled prices are true selling prices. Since this study focused on prices above $100, further research should also include cheaper B2B products as different price levels have found to lead to different frequencies in using price endings in B2C studies (Lee et al., 2009).

In managerial practice, the primary focus of B2B pricing is and will be set on the economic analysis. However, behavioral and psychological aspects should not be neglected in pricing decisions due to violations of rational choice-making principles by B2B customers (Hinterhuber, 2015). Based on this study and results of Larson et al. (2014), positive price thresholds effects may exist in B2B context. Then, specific price endings are able to increase the demand and should thus be considered in B2B pricing tactics.

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Research Paper

Critical challenges for SMEs in the UK chemical distribution industry

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The UK chemical distribution industry, despite its significant contribution to the economy and employment generation, remains largely unexplored with no academic research regarding small businesses and their success. This is the first study to investigate the challenges that SMEs operating in the specific industry are facing, arguing that only when a small business is able to cope with, adapt to and overcome these, can it be successful. Utilizing a survey strategy, qualitative data were collected from 118 SMEs, out of the 180 identified, generating a response rate of 65.5%. Regulatory compliance, supplier management, human capital and access to capital are identified as critical. Findings suggest that success is a multidimensional phenomenon where all contributing factors need to be taken into consideration and addressed simultaneously. This paper informs thinking in this field and provides guidelines to various stakeholders to improve strategy formulation and decision-making process in order to support chemical distribution SMEs.

1 Introduction

Small and medium-sized enterprises (SMEs) are in the focus of political, business and management research (Amoros et al., 2013; Dobbs and Hamilton, 2007; Lussier and Halabi, 2014) stating their benefits such as being integral to contemporary economic and social regeneration, essential for the establishment of a solid industrial base and being a key driver for innovation and R&D and above all, a significant contributors to employment generation (Franco and Haase, 2010; European Union, 2015; Halabi and Lussier, 2010; McLarty et al., 2012; Simpson et al., 2012; Smallbone et al., 2010; Unger et al., 2011).

Despite their well-established importance, there is still no universally accepted definition for SMEs with significant variations in different countries (Smallbone et al., 2010; Unger et al., 2011), no single agreed-upon definition of success (Beaver, 2002; Rogoff et al., 2000), no universally accepted model to incorporate all aspects of small business success (Chawla et al., 2010; Dobbs and Hamilton, 2007; Lampadarios et al., in press). Most importantly, SMEs tend to exhibit high failure rates and poor performance levels (Arasti et al., 2012; Franco and Haase, 2009; Gray et al., 2012; Ropega, 2011) with their success and/or survival receiving an ever-increasing attention from academia and professionals alike.

The business literature features a wide range of success factors through a number of conceptual frameworks that attempt to capture aspects of SMEs success. However, their importance appears to be relative and varies with the business environment, that is the industry and country SMEs operate in; meaning that while one success factor may be of great importance in one industry or country, it may not necessarily be of equal importance in another (Benzing et al., 2009; Kader et al., 2009; Krasniqi et al., 2008; Lin, 2006; Ogundele, 2007; Simpson et al., 2012). This inevitably creates a need for more empirical studies to investigate all aspects of success and identify critical factors in each industry and in a specific country setting.

An industry where small businesses have a particularly strong presence is the European and particularly the UK chemical distribution (BCG, 2013; Chemagility, 2012; Districonsult, 2013; FECC, 2013). However, very little is known about SMEs in the specific industry, their modus operandi and any factors contributing to their success and/or failure (Chemagility, 2008; CBA, 2015; FECC, 2015). In fact, due to the wide variety of functions performed by these companies and confusion with other types

of trading in the industry, there is still no universally agreed definition of a chemical distributor (Chemagility, 2012). Last but not least, there appears to be no official statistical and/or financial data available on SMEs operating in the UK chemical distribution industry (Chemagility, 2015).

Overall, this paper thus aims to identify and offer an insight into the challenges that SMEs in the UK chemical distribution industry are facing. Initially, SMEs, their importance, definition and characteristics are introduced, followed by an overview of the chemical distribution industry with particular focus on the UK. The rationale and methodology of this study are then elaborated on. Findings are presented and discussed offering concluding remarks and several implications for practice.

2 Small and medium-sized enterprises (SMEs)

2.1 Importance of SMEs

The importance of SMEs and their contribution to the economy and employment generation has long been established in the business literature (Dobbs and Hamilton, 2007; Galapova and McKie 2012; Halabi and Lussier, 2014; Smallbone et al., 2010). In the European Union, micro, small and medium-sized enterprises are socially and economically important as they represent 99% of all enterprises (European Union, 2015). They employ around 90m people, generate EUR 3.7tn in added value while providing 2 out of 3 jobs and contributing to entrepreneurship and innovation (European Union, 2015). In the UK, the Department for Business and Innovation (2014) reports that, at the start of 2014, small and medium-sized businesses employed 15.2m people and had a combined turnover of GPB 1.6tn; these accounted for 99.3% of all private sector businesses in the UK, 47.8% of private sector employment and 33.2% of private sector turnover. Due to the fact that SMEs are a major part in today's modern economies, an understanding of why they succeed or fail is crucial to the stability and health of the economy and research is still needed in this field (Blackburn and Kovalainen, 2009; Holmes et al., 2010; Philip, 2011; Raju et al., 2011).

2.2 Definition of SMEs

Even though SMEs is an area well researched, there is still no universally accepted definition of what constitutes a small business with variations existing in different countries. For instance, in the United States, small businesses are defined as independent businesses comprising fewer than 500 employees and are further classified according to varying industry standards on employment size, sales and annual turnover (Office of the Advocacy United States Small Business Association, 2003). In Japan, SMEs are generally businesses which employ between 4 and 299 employees but yet again definitions vary according to both sector and capital invested. In the United Kingdom, the definition of SMEs is given through the UK Companies Act of 2006 which states that if a company is to be defined as 'small', it must satisfy at least two of the following criteria: (i) have a turnover of no more than GBP 6.5mn; (ii) have a balance sheet total of no more than GBP 3.26mn; (iii) have no more than 50 employees. Similarly, a medium-sized company must satisfy at least two of the following criteria: (i) have a turnover of no more than GBP 25.9mn; (ii) have a balance sheet total of no more than GBP 12.9mn; (iii) have no more than 250 employees.

In the European Union, any enterprise that employs fewer than 250 persons and has an annual turnover not exceeding EUR 50mn and/or an annual balance sheet total not exceeding EUR 43mn qualifies as a SME (European Union, 2015). Within the SME category, a small enterprise is defined as an enterprise which employs fewer than 50 staff and whose annual turnover and/or annual balance sheet total does not exceed EUR 10m while a microenterprise is defined as an enterprise which employs fewer than 10 persons and whose annual turnover and/or annual balance sheet total does not exceed EUR 2mn. For the purpose of this study, the definition of SMEs is that of the European Union.

2.3 Characteristics of SMEs

Overall, SMEs have several features that distinguish them from larger firms. Business literature concurs that their most important characteristics are the absence of complex formal structures, the dominance of owner/managers, the lack of internal labor markets, environmental uncertainty and a limited customer base (Adams et al., 2012; Floren, 2006; Storey and Greene, 2010). According to Simpson et al. (2012), the typical SME has limited resources, limited cash flows, few customers, is often engaged in management 'fire-fighting', concentrates on current performance rather than taking a strategic focus, often has a flat organizational structure and possibly high staff turnover. Similarly, a high risk of failure makes small businesses more focused on short-term survival than long-term planning and consequently 'cash rather than profit' (Adams et al., 2012; Raju et al., 2011).

Where perhaps SMEs are more distinct compared to larger firms, is the fact that they are defined very much by the personal commitment and motivation of their owners, which, in turn, creates with-

in firms an individual and particular approach to strategic management (Bonet et al., 2011; Raju et al., 2011; Perks, 2006). This means that, as organizations, they are likely to be sustained primarily by economically significant skills along with successive knowledge claims concerning the viability of those skills. In addition, their success is likely to be dependent on combining entrepreneurial orientation with strategic action (Hitt et al., 2001; Kumar et al., 2012). It is therefore recognized that the evolution of smaller firms is likely to be influenced by the development of firm-based resources and capabilities enacted through activity rather than the accrual of resources (Unger et al., 2011). To further support the absence of formality in small businesses, Rantanen (2001) in Forsman (2008) argues that small firms are more likely to engage in informal management practices than to adopt sophisticated planning and control techniques.

Adams et al. (2012), Forsman (2008) and Raju et al. (2011) provide a good account of small businesses advantages and disadvantages compared with large organizations. Advantages include the distinct flexibility that enables them to respond quickly to environmental changes, the informal management structure and centralized decision-making, the fact that they are close to the customers, and the ability to frequently use technology and/or superior quality to gain competitive advantage. The main disadvantages are the lack of formal strategy and formulation processes, which result in implicit rather than explicit business strategies, a focus on day-to-day problems instead of longer goals, the relative lack of resources (i.e. personnel, financial, and physical facilities), which discourages management specialization as multiple responsibilities are assigned to one person, and the relatively low degree of purchasing leverage (Adams et al., 2012; Forsman, 2008; Raju et al., 2011).

3 Chemical distribution and the role of SMEs

3.1 Overview on the chemical distribution industry

Chemical distribution companies are an integral part of the European chemical industry, positioned between chemical producers and their customers (FECC, 2015). Distributors are a vital, well-established sector of the chemical industry helping manufacturers accessing local customers and markets while adding value by reducing complexity, trade-related risks and costs and providing financing and support (BCG, 2010; Chemagility, 2008; Districonsult, 2009). Manufacturers rely on distributors to ensure the safe delivery of bulk and non-bulk chemicals to downstream end-users as well as to handle logistical needs of end-users, such as custom blending and non-bulk repackaging, which are operations not primary among manufacturing operations yet met by distributors (Chemagility, 2008; Hornke, 2012). Thus, chemical distribution fills the gap between producers who wish to sell large lots without regulatory or logistical complications and customers demanding small volumes and who have very specific needs on technical, regulatory and logistical level; in essence, chemical distributors allow their principals to profitably reach smaller customers in many industries and countries (Mortelmans and Reniers, 2012). Chemical companies increasingly realize the value of chemical distributors as value chain partners and implement structured distributor management functionalities in their organizations (CEFIC, 2012; Hornke, 2012). However, genuine chemical distributors, rather than simply selling chemicals, add value through an extensive range of services to both customers and suppliers (Hornke, 2012; Mortelmans and Reniers, 2012).

Despite the importance of chemical distributors, there seems to be no universally agreed definition of what a chemical distributor is. This is mainly because of the wide variety of functions they perform and confusion with other types of trading in the industry (Chemagility, 2008). However, chemical distributors have a number of distinct characteristics. According to the Health and Safety Executive, a distributor is any natural or legal person established within the community including a retailer, who only stores and places on the market a substance, on its own or in a preparation for third parties (Health and Safety Executive, 2015). Generally, chemical distributors buy and sell chemicals from producers taking title to the goods, responsibility for stocking and warehousing before selling the products on to their customers under their own brand (Chemagility, 2008; Districonsult, 2009; NACD, 2005). There is often a formal, long-term agreement between the distributor and the chemical manufacturer whom they represent (Chemagility, 2008). Chemical distributors need to be differentiated from mere logistics companies that typically do not take ownership of products and from trading companies that typically do not repackage and assemble product portfolios according to customer needs (BCG, 2010). Also, a distributor is neither an agent nor a chemical trader; these do not take title to or stock goods, but receive a commission for their contribution in helping a manufacturer complete a sale (Chemagility, 2008; NACD, 2005).

Chemical distributors offer a wide range of services to both customers and suppliers. The typical

offering to customers incorporates a broad product portfolio with complementary products; access to reputable suppliers; competitive (and stable) pricing; stock management and Just In Time (JIT) deliveries; competent and knowledgeable sales team; technical support and problem solving skills; product expertise for formulation purposes; value-added services, for instance, custom blending, repackaging); sample management; financing and credit in line with local terms; safety training and hazardous waste removal (BCG, 2013; Burns, 2010; Chemagility, 2008 and 2015; Chemanager, 2013; Districonsult, 2009 and 2012; FECC, 2013; Hornke, 2012; Jung et al., 2014; Mortelmans and Reniers, 2012; NACD, 2005). Equally, their offering to suppliers includes services such as market share and penetration; logistics services including storage and packaging; in-depth market intelligence and assist with the implementation of marketing strategies; demand forecasting and planning; market development capabilities; new product approvals; conforming to local regulations and language; repackaging and relabeling; arrangement of import authorizations; trainable staff with good technical knowledge; modern IT infrastructure allowing automated information exchange (BCG, 2013; Burns, 2010; Chemagility, 2008; Chemanager, 2013; Districonsult, 2012; FECC, 2013; Hornke, 2012; Jung et al., 2014; Mortelmans and Reniers, 2012; NACD, 2005).

Chemical distributors form a fragmented network and it is estimated that there are about 10,000 distributors, servicing the end users for their chemical needs (Brenntag, 2010; Boston Consulting Group, 2013). Chemical distributors are often small and medium enterprises with local and regional coverage (Bee and Chelliah, 2013; Brenntag, 2010; Chemagility, 2008). According to the European Federation of Chemical distributors (FECC), FECC members - mainly SMEs - create value in the chemical supply chain by meeting the demands of over 1m downstream users who are diverse regarding needs and purchase volumes. About 9-10% of the overall output of chemical producers is distributed via independent chemical distributors. In fact, the FECC represents over 1,700 companies with over 31,000 employees at more than 1,400 sites handling six million shipments and 31mn tons shipped with an industry turnover of EUR 27bn every year (FECC, 2015). This means that there is a wide variety of organizations involved in the distribution along the value chain between chemical producing companies and the industries using chemicals. Therefore, the chemical distribution industry does not only include chemical manufacturers and their distributors, but also chemical traders, agents, export/import houses and a number of other suppliers providing these companies with added value products or services, e.g. warehousing, logistics, plant and equipment (Chemical Business Association, 2015; CEFIC, 2012). Overall, it is evident that SMEs have a strong presence in the chemical distribution industry and play an important role in its overall growth and performance (CEFIC, 2012; FECC, 2013).

3.2 The UK chemical distribution industry

Chemical distributors are an integral part of the UK chemical industry (CBA, 2015; Chemagility, 2008; FECC, 2013). Even though chemical distribution is a well-established practice in the UK, it is severely understudied both on an academic and business level with the majority of information originating from the study of the European chemical distribution industry (Burns, 2010; Chemagility, 2008; Districonsult, 2009, 2011 and 2012; Jung et al., 2014; Hornke, 2013). Similarly, there are limited statistical data available on the industry and information such as turnover, sales and margin growth, performance and future trends are drawn from the Chemagility (2008 and 2015) and Plimsoll (2013) reports.

Plimsoll (2013) reports that an average company in the UK chemical distribution industry increased sales by 6.4% in 2012. However, the larger companies grew by 8.5%, compared to the smaller companies who grew by 1.9%, meaning that SMEs are not growing as fast. As such, research in the area of small business growth and specifically in success factors seems to be necessary.

According to the latest data available from Chemagility, the UK chemical distribution market was worth GBP 4.42bn (EUR 5.44bn) in 2014, employing circa 6,800 employees and representing 10% of the total European chemical distribution market worth EUR 52bn. The total number of chemical distributors in the UK was 280 and with over 75% of them being small or micro-sized enterprises (210 companies if subsidiaries of larger international groups are excluded), it is evident that SMEs have a very strong presence in the industry. Despite major challenges due to increasing compliance costs, reduced margins, global competition and uncertainty, the UK distribution market achieved a 6% annual growth rate between 2005 and 2010, a 5% growth between 2011 (GBP 4.1bn) and 2014 (GBP 4.5bn) and is anticipated to grow further to GBP 5.6bn by 2020 at a rate of 3.6%, which is higher than expected the GDP growth (Chemagility, 2015). According to Chemagility (2008 and 2015), the UK chemical distribution industry has experienced a high rate of growth that can be attributed to globalization and international trade, the market entry of Asian producers, the reduced product and serv-

ice offerings from chemical producers and downsizing by manufacturers that led to higher utilization of distributors. However, the industry, like the rest of Europe has also experienced significant industry consolidation resulting in the overall reduction of the number of companies present and increasing even more the pressure on the survival of SMEs (Chemagility, 2008 and 2012; Key Note, 2011; Plimsoll, 2013). It is worth noting that in 2014 large enterprises and multinationals held 67% of the total UK chemical distribution market value, leaving a smaller share of 23% (GBP 1.47bn) to all other small businesses (Chemagility, 2015).

Overall, there is general agreement in the current business literature that SMEs have a strong presence in the UK chemical distribution industry, so that their performance greatly affects the industry (Plimsoll, 2013; Chemagility, 2008; Key Note, 2011; British Association of Chemical Specialties (BACS), 2014; Chemical Business Association, 2015; European Association of Chemical Distributors (FECC), 2013). Thus, it is crucial to analyze the challenges and aspects of success for SMEs operating in this industry.

4 Methodology

To date - apart from some attempts being made by industry consultants such as Districonsult and the Boston Consulting Group (BCG) -, there has been only one academic study on critical success factors for SMEs in the UK chemical distribution industry by Lampadarios (2015) and one of similar nature on a European level by Hornke (2012). Hornke's (2012) study, conducted in 2011 and based upon 62 participating companies operating in Germany, Austria and Switzerland, identifies five critical success factors: (i) employees and employer qualifications; (ii) enlargement, diversification and specialization of portfolio; (iii) enhancement of services; (iv) focusing on specific regions and (v) expansion to international sales. Lampadarios' (2015) research - a more contemporary and country specific study - establishes a positive relationship between eight factors and SMEs success in the UK chemical distribution industry. Regulatory compliance, entrepreneurial orientation, customer relations management, market and product development, prior work experience and management skills, human capital, economic environment and strategic planning are, in order of importance, the critical success factors for the industry. Findings strongly suggest that success is a multidimensional phenomenon, where both firm-internal and firm-external factors need to be optimal simultaneously. Considerable variations between SMEs in this industry based on their size are also found, suggesting that these do not form a homogeneous group and as such different strategies are needed for different sized businesses.

This paper is part of the study conducted by Lampadarios (2015). The primary aim of that study was to identify and investigate the factors critical to SMEs success and sustainable growth in the UK chemical distribution industry. However, in order to develop a more comprehensive view of the industry and cover all aspects of success, it further attempted to identify the most important challenges that small and medium-sized chemical distributors are facing. Those are reported and discussed within this paper. It is assumed that SMEs that are able to recognize, face and overcome the challenges of their business environment, have more chances of being successful and thriving. Inevitably, the challenges are related to and somehow reflected by the success factors but have the potential to offer a deeper, more qualitative insight.

To achieve the aim of the study, a survey strategy was utilized and self-administered questionnaires - incorporating open questions - were used to collect the views of owners/managers of chemical distribution SMEs. As the collection of qualitative data was based on pre-determined themes (challenges), the use of more sophisticated methods of analysis (for instance quantitative content, thematic) was not deemed necessary and thus this research drew upon the basic principles of qualitative content analysis. This is a well-established, flexible and straightforward qualitative data analysis method (Elo et al., 2014; Finfgeld-Connett, 2014; Krippendorff, 2013; Polit and Beck, 2012; Vaismoradi et al., 2013) that represents a systematic and objective means of describing and quantifying phenomena (Bloor and Wood, 2006; Gbrich, 2007; Pope et al., 2006; Powers and Knapp, 2006; Schreier, 2012). The data was collected, collated under the predetermined categories, reduced, summarized and finally reported.

All participating companies were SMEs as defined by the European Union, i.e. enterprises employing fewer than 250 people and exhibiting an annual turnover not exceeding EUR 50mn (European Union, 2003); located in the UK; not part of another organization or belonging to a larger corporation and without any manufacturing activity and capability.

Due to the fact that there was no official statistical data on the total number of SMEs operating in the UK chemical distribution industry, a combination of industry reports (by Plimsoll, Chemagility, Key Note), information provided by business associations (the British Association of Chemical Specialties, the Chemical Business Association, the European Association of Chemical Distributors, the

National Association of Chemical Distributors, the North East Process Industry cluster) and internet sources (the Chemagility online database of chemical distributors and ICIS magazine) were utilized to produce a comprehensive list and thus determine the target population for this study. Each of the identified SMEs was individually checked to ensure they fulfill the criteria of the study. However, lack of official statistical data on the target population means that allowances should be made for omissions due to human error and for the fact that the total number of SMEs operating in this industry may have changed since the time of the study.

The total number of SMEs in the UK chemical distribution industry satisfying the criteria is 180. No sampling technique has been used but instead a census was conducted. Owners and senior managers (CEOs, Managing Directors-MDs and Directors) are the key informants, an approach extensively used by other researchers as well (for instance Keskin, 2006; Lee and Cheung, 2004; O'Cass and Weerawardena, 2009; Ojala, 2009; Revell, 2007; Wilson et al., 2012). A total of 118 SMEs responded positively by returning the questionnaire, in a usable and valid form for statistical analysis, generating an overall response rate of 65.5%. Thus, it can be argued that the findings of this study offer a reliable account of the challenges faced by SMEs operating in the UK chemical distribution industry.

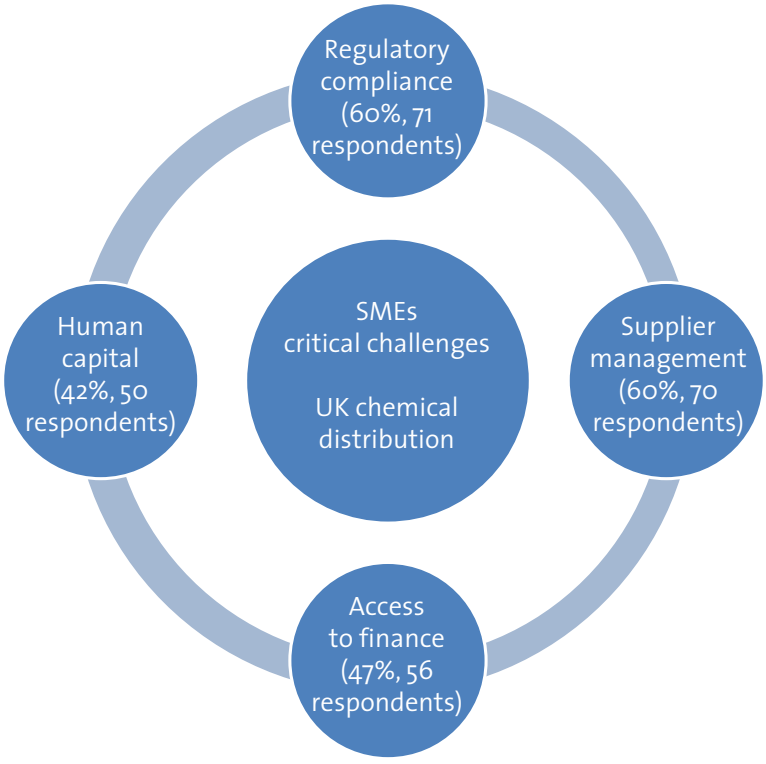
5 Findings

In an attempt to get a better insight into the UK chemical distribution industry, owners/managers were asked to express their views on the main challenges SMEs faced in the industry. The qualitative data collected contributes to a better and fuller understanding of the industry and provides a richer, deeper view on the mechanisms of the selected industry. The most important challenges identified are **regulatory compliance, supplier management, human capital** and **access to finance**. These are ranked by frequency of occurrence (% of population, number of respondents) and presented in figure 1.

5.1 Regulatory compliance

Regulatory compliance is highlighted not only as a critical success factor but also as a significant challenge for all SMEs in the UK chemical distribution industry: *'REACH is the single biggest challenge for small businesses these days'* (R70); *'...it will be interesting to see how many small compa-*

Figure 1 Critical challenges for SMEs in the UK chemical distribution industry.



nies would achieve and survive compliance...' (R110); *'...the biggest challenge would be to cope with the cost of regulatory requirements...'* (R45); *'...regulation keeps increasing in complexity...'* (R20); *'...small companies will struggle with the level of expertise required...'* (R69). The majority of owners/managers (80%, 95 respondents out of a total population of 118) identify compliance as the most important challenge.

Owners/managers consider regulatory compliance a significant drain on human and financial resources and highlight cost and resources implications with 60% of them agreeing on the matter. Complying with regulatory requirements, coping with increasing bureaucracy and offering approved, registered products in the European market alongside all other existing operations is considered a tedious task for many small businesses: *'...you have to deal with too many things at a time...'* (R71); *'(regulation) ...needs continuous monitoring that takes time off selling our products...'* (R78); *'...keeping up to date with regulations is time consuming and complex task...'* (R111); *'...you need more experienced people to deal with the regulation part...'* (R65); *'...the costs of compliance are creeping up on us...'* (R100); *'...internal costs have increased to cope with REACH...'* (R106); *'...you have to come up with the money to support registrations'* (R19). As a result, the need to recruit new people, invest in the business and allow for increased costs is considered a priority.

Similarly, many respondents (60 in total, 51%) comment that the increasing cost of compliance, as an increase of direct costs and advisory services, restricts the market and a number of distributors have to withdraw: *'...many small companies will have to leave the market; they won't be able to afford this...'* (R7); *'...many SME owners would be thinking about selling and exiting market now'* (R73). The same applies for manufacturers as they need to make a decision of whether to stay in a market or not but also for companies (e.g. from India or China) considering entering the European market: *'EU won't longer be a lucrative market anymore with such high registration costs...'* (R97); *'...the high upfront registration costs will put many manufacturers off...'* (R40); *'...entering the market will require higher costs an expertise'* (R32).

Owners/managers (35 in total, 30%) also view regulatory compliance as a further barrier to starting up a small business in the UK chemical distribution industry: *'...it is another challenge to consider if you are thinking of setting up something new...'* (R85); *'...starting up will require more initial financial capital and expertise then before...'* (R60); *'...it will affect spin offs...in the past it was easier for people to start their own business...'* (R23); *'...it makes entry more difficult'* (R26). They also express complaints about the increased bureaucracy that might eventually limit the flexibility of small businesses: *'...bureaucracy is killing the flexibility of smaller businesses'* (R1). Respondents conclude that the current regulatory requirements definitely make the start-up of a new business more challenging with 30 of them arguing the matter.

30% of the owners/managers also identify a positive side to regulatory compliance. In the words of R95: *'...if you can't do business in Europe, you might as well try your luck in other markets'*. Small distributors have the opportunity to explore other markets outside Europe that do not have such strict regulations and may be easier to do business with: *'...expand in markets that are not as heavily regulated as Europe...'* (R68); *'...promote your products (if possible) outside EU'* (R24). However, further financial and human resources challenges arise: *'...it is easier said than done...'* (R14); *'...you still need to manage the internationalization process properly'* (R74).

5.2 Supplier management

Regarding supplier management - which is highlighted by 70 respondents as a major challenge - owners/managers identified two main elements: maintaining existing suppliers and finding new ones. Based on the fact that *'...without suppliers, you have no products and thus no business...'* (R117), it becomes obvious that small distributors should *'...put a lot of effort into managing their sources'* (R41).

According to the respondents, SMEs should strive to become a reliable partner to their suppliers while building up their credibility, *'...so your suppliers can trust you and see you as a business partner'* (R2). Taking into consideration a shrinking manufacturing base in the UK and with a large proportion of global manufacturing moving to India, China and the Far East, owners/managers consider suppliers ever so important: *'...the challenge is to keep your suppliers content...'* (R56); *'...if you keep selling, they will keep supplying...'* (R84); *'...you need to maintain your good reputation or build one...'* (R37); *'...be seen as a preferred distributor...'* (R70); *'...protect your sources...others may tempt them to leave you...'* (R100); *'...get plenty of contacts in your suppliers' companies...'* (R16); *'...build good, strong relationships'* (R45). Respondents further recognize that in Europe, due to regulatory requirements, there may be a restriction in existing and new suppliers so *'...there could only be a handful of suppliers with registered products...you need to be in with one of them at least'* (R89).

A further aspect for SMEs in the UK chemical

distribution industry is the need to keep adding new suppliers. 35 owners/managers express the opinion that new suppliers are very important in growing a business and are viewed as the sole source of innovation for distributors with no R&D and manufacturing capabilities: *'...your suppliers will give you new ideas and come up with exciting products'* (R32); *'...we can't develop new products or predict market trends'* (R86). Small distributors have to keep updating their product portfolio and adjust their offering to customer requirements and market trends. Unlike larger companies with more resources, smaller companies have to rely more on their suppliers to do that: *'...suppliers can help you find new markets...'* (R61); *'...identify new applications...'* (R29); *'...provide with all data needed to sell the product...'* (R75); *'...provide the technical support you need...'* (R97); *'...do joint visits to support your business'* (R111).

5.3 Human capital

50 owners/managers (42%) also identify human capital as a challenge for small businesses in the UK chemical distribution industry. Several respondents comment that finding, attracting and retaining qualified and skilled people into their business has been getting increasingly difficult: *'...there is a lot of competition for good people'* (R42). In fact, there is general agreement that, to start with, there is a distinct lack of skilled and qualified people in the industry: *'...we need more scientists, chemists, engineers...'* (R10); *'...there aren't enough technical people educated to a degree'* (R109); *'...universities are not producing enough scientists...'* (R99); *'...we need more people with technical understanding and background...'* (R57); *'...need people with regulatory knowledge...'* (R36); *'...can't keep paying external consultants, they are too expensive...'* (R103).

In addition, 35 respondents recognize the fact that it has been getting harder for smaller businesses to attract new employees. In their opinion, this is due to two main reasons. Firstly, larger distribution companies offer better packages and career prospects: *'...we keep losing good people to the larger companies...'* (R38); *'...we can't afford to offer the same salaries and benefits...'* (R44); *'...larger distributors are very aggressive in their recruitment...'* (R23); *'...working for a global distributor is a high prestige job...'* (R66); *'...larger companies can offer many career paths...'* (R4); *'...you are part of a large machine'* (R105). Secondly, smaller companies are considered more high risk, a less stable working environment and more dependent on the market conditions: *'...young graduates think that we will go bankrupt...'* (R115); *'...difficult to see themselves working a long time for a small business...'* (R49); *'...we are seen as high risk employer'* (R19). Similarly, retaining employees is also highlighted as a challenge as: *'...large companies offer lucrative packages and prospects...'* (R71) and *'...try to poach our best people all the time'* (R64). The need to *'...keep your employees happy and content...'* (R93) and *'...give them no reason to leave your company'* (R26) was recognized.

Another aspect of human capital that 22% of the owners/managers highlight is that of succession planning and the replacement of senior management (Managing directors (MDs), directors, and owners). There is an agreement that succession planning is extremely important to small businesses as it could potentially affect their operation: *'...there is a need for a smooth transition when the MD leaves...'* (R53); *'...we will need to show that it is business as usual when I go...'* (R81). Succession planning is seen to *'...guarantee longevity...'* (R113), *'...ensure business continuity and stability...'* (R59), *'...demonstrate strategic thinking'* (R14), *'...build trust with employees but also suppliers and customers...'* (R13), *'...is a good sign of business planning...'* (R54) and *'...a way to sustainable growth...'* (R94). The fact that many small businesses did not have any business succession planning in place is stated by some respondents (10 owners/managers) and is seen as a challenge for the near future: *'...it has to be done as soon as possible'* (R88).

5.4 Access to finance

Many concerns are also voiced about access to finance especially as SMEs need funding to stay in business, *'...need to keep floating and not running out of cash...'* (R51) and *'...fuel future growth'* (R58). 56 owners/managers (47%) consider securing finance a significant challenge, especially during recession times, as financial institutions and private investors consider small businesses as high risk and do not release funds. In fact, many respondents (26 in total) feel that being refused finance has nothing to do with their company performance but due to the fact that, during recession, *'...banks will simply not lend you money'* (R74). The need to *'...have a business plan to show what you will do with the money...'* (R79), *'...maintain your profitability...'* (R106) and *'...run a tight ship on payments and payment terms...'* (R46) is also highlighted in an attempt to secure finance. Maintaining a good relationship with your lenders and building a good reputation and credit history as a business is also considered critical in attracting and securing finance from investors or banks: *'...work closely with your bank...'* (R33); *'...keep your investors interested in your business...'* (R107); *'...pay on time,*

build and maintain a good credit score' (R78).

6 Discussion and concluding remarks

This study identified regulatory compliance, supplier management, human capital and access to finance as the most critical challenges and therefore, prerequisites to the success of small businesses in the UK chemical distribution industry. Overall and in line with Lampadarios' (2015) study, it is established that only when small and medium-sized distributors address and overcome all these challenges in their business environment, can they be successful and thrive. This strongly suggests that success in the UK chemical distribution industry is a multidimensional phenomenon where a number of contributing factors need to be taken into consideration and addressed simultaneously as satisfying one or two conditions does not necessarily guarantee success.

The findings of this research strongly suggest the presence of interrelationships between the identified challenges. In specific, as regulatory compliance commands high levels of expertise, deep knowledge of the current legislation and an understanding of future trends (Eacott, 2014; Flavell-While, 2012; Whyte, 2012), human resources become an important element. People with experience and prior knowledge in the industry are fundamental in coping effectively with the regulatory requirements and financial impact of REACH compliance. The fact that small chemical distributors have to undertake the task of registrations, authorizations, implementing restrictions and communicating the results of chemical safety assessments (Flavell-While, 2012; Whyte, 2012), stresses even further the need for good management skills and careful handling. Meanwhile, access to finance also becomes a significant part of compliance as financial resources are required to cover all direct (e.g. registration costs, additional testing) and indirect costs (e.g. business consultants and agencies fees, recruitment, training and skills development). Lack of human and financial resources - which is an inherent characteristic of SMEs (Adams et al., 2012; Forsman, 2008; Simpson et al., 2012) - inevitably makes small chemical distributors turn to their suppliers/principals for information and advice. Supplier management - in terms of securing suppliers with technical, regulatory capabilities and resources - is integral to compliance and can create a competitive advantage against other distributors. Similarly, access to finance (e.g. for investments in new facilities) and human resources (e.g. for knowledge sharing) are prerequisites for a successful supplier management strategy. Lastly, any new investments in personnel and/or any training and skills development for existing employees requires financial resources and is dependent on careful planning.

6.1 Regulatory compliance

Despite the fact that SMEs, unlike their larger counterparts, are considered to be more flexible, adaptable and thus less being able to cope with the business environment more effectively (Adams et al., 2011; Forsman, 2008; Raju et al., 2011), this study concludes that regulatory compliance is unavoidable. Inevitably, all SMEs operating in the UK and European chemical distribution industry have to fully implement the measures necessary to comply with regulations otherwise face the real risk of being excluded from the market (ECHA, 2014; FECC, 2013). A compliance strategy needs to be developed and implemented while a long-term, flexible outlook on regulatory requirements, especially on REACH and competition law, has to be maintained. Keeping a low profile or adopting a 'just say yes' approach (as described in Wilson (2012)) would be meaningless.

Regulations, particularly REACH, greatly impact all other challenging factors (Chemagility, 2012; FECC, 2014). Owners/managers have to carefully manage their already limited resources and weigh potential benefits against investment. Strict financial control is essential to manage the incurring costs (direct or indirect) to the business. An investment in human resources, so as to achieve the level of expertise and regulatory competence required, is necessary. Utilizing external consultants is deemed more appropriate in the initial stages of the registration process where more expertise is required. But in the long term, permanent employees are needed to manage the process. Similarly, SMEs need to develop and adjust their product portfolio based on regulatory requirements while strengthening relationships with existing and new suppliers.

Throughout the compliance process and as part of their strategy, owners/managers are strongly advised to utilize any sources of support available to them, for instance the European Chemicals Agency (ECHA), the European Commission and the Chamber of Commerce among others. In fact, this study raises serious concerns of whether SMEs are able to cope with the regulatory requirements without the support of the government and industry organizations due to the lack of resources (Adams et al., 2011; Forsman, 2008). Thus, the government and relevant associations carry the responsibility to reach out to SMEs to offer more support and access to resources and training in order to support their business activities.

6.2 Supplier management

The fact that chemical distribution companies do not have manufacturing capabilities also makes success dependent upon providing excellent service throughout the supply chain and not just to customers. Chemical manufacturers and suppliers need to be seen as an integral part of a small business - and its success - and as such, supplier management has to be incorporated in the customer relations management (CRM) process. This research reaches the conclusion that manufacturers and suppliers are extremely important for distribution companies as they are their only source of raw materials and innovation and the ones with capabilities to develop and modify products. To that end, SMEs in chemical distribution need to develop and nurture strong, long-term relationships with their customers and suppliers alike while continuously striving to identify and satisfy their needs. Furthermore, staying close to customer and supplier base - through increased communications, participation in exhibitions, trade shows and industry related events - enables SMEs to keep in touch with the market and identify future trends. Any opportunities to become more integrated through alliances, joint ventures and any other form of cooperation should also be explored.

The importance of supplier management is further highlighted regarding market and product development (MPD). The findings of this study suggest that small chemical distributors need to obtain a good buying position and seek reliable sources and suppliers in order to implement a successful MPD strategy. SMEs can achieve sustainable growth through their existing suppliers by expanding into new product groups, new territories and extending distribution agreements. Similarly, they have the opportunity and should capitalize on suppliers' resources and capabilities such as testing, sampling, R&D and new product development (NPD) and in turn provide feedback on market trends and changes in customer preferences. The main conclusion is that there is an imperative need for owners/managers to engage more in supplier management, with the most important elements being knowledge development and sharing, development of business processes and investment in physical facilities or software in line with key suppliers' systems and processes.

6.3 Human capital

Human capital is found to be one of the most important resources for SMEs operating in the UK chemical distribution industry. This study ascertains that this is a very customer-focused and customer-facing industry with the human factor having a significant influence on business and further argues that the services offered by chemical distributors depend more on human rather than on technical or logistical resources.

This research further concludes that small businesses in the UK chemical distribution industry with a higher degree of human capital have more chances of being successful and achieving sustainable growth. Having identified a shortage of highly skilled, technically qualified employees in the industry, the findings strongly suggest that recruiting individuals with industry-specific experience, skills and qualifications has a big impact on the performance of the business. A further conclusion is the fact that SMEs in this industry, depending on their size, have a different approach for developing human capital. Smaller companies have an informal approach utilizing existing employees while larger ones prefer a formal approach. The study recognizes that a fine balance between using a combination of recruiting new individuals with high skills from the external labor market and internally developing the skills of current employees needs to be kept and further establishes the need for SMEs owners and managers to attain and develop human resource management skills. This research reveals that owners/managers often lack many skills in managing certain aspects of their businesses and acknowledges the need for further training and skills development.

Lastly, the importance of succession planning is firmly established. For reasons of stability and business continuity, formal or informal arrangements need to be made in good times and need to be communicated accordingly. This would reduce uncertainty during times of change and ensure smooth transitions.

6.4 Access to finance

Owners/managers identify access to finance (funding) as the single, most important aspect of the economic environment; a factor that could potentially be very restricting to growth. All small businesses in this industry, independent of their size and market conditions, need funding at some point in their life (whether it is to start up, grow or cope with cash flow shortages). This finding is consistent with the work of many authors who recognize the importance of the availability of financial resources in a market and argue that a lack of available cash flow or external finance hinders SMEs success and growth opportunities (Amoros et al., 2013; Calcagnini and Favaretto, 2012; Guo and Shi, 2012; Carter and Van Auken, 2005; Korunka et al., 2010; Medina et al., 2005). The importance of access

to funding becomes paramount when, especially during recession periods, financial institutions are reluctant to lend money to SMEs - because of their high risk and low collateral - and private investors similarly restrict access to funds further affecting small business growth. This research concludes that it is imperative for owners/managers and entrepreneurs to secure multiple sources of finance and fully utilize all available options in the market(s) they operate in. In detail, chemical distribution SMEs are urged to look for more perfect capital markets where more financing channels and better access to capital and credit schemes are available, especially when exporting. Similarly, it is important that owners/managers and prospective entrepreneurs seek markets where government policies (e.g. the availability of grants, loan guarantees, subsidized interest rates) and support are available for small businesses. Of course, once funding is secured, there is a still need to monitor cash flow and liquidity proactively, focus on planning and maintain a close and trustful relationship with investors and lenders.

However, even if a business has sufficient funding, it still needs to be able to deal with and manage unforeseen cash flow shortages. The findings reveal that the chemical and chemical distribution industry is largely handled on credit terms and a discrepancy between the supplier and customer payment terms is not out of the ordinary. Managing payment terms and balancing cash flow under these conditions creates a further need for finance services and flexible borrowing options. Similarly, during times of recession, an increase in bad debts is not uncommon and small business need to be prepared. This research recognizes that losses due to bad debts create cash flow shortages, put a considerable strain on SMEs and, in extreme cases, push them into bankruptcy. The latter scenario mostly applies to micro businesses depending heavily on very few customers. At this point, this study makes a further distinction between smaller and larger chemical distribution SMEs, with the first being more vulnerable and the latter being able to cope with bad debts more efficiently due to their size and funding options. Therefore, cash flow and credit terms management alongside building up a contingency fund for difficult times become crucial.

6.5 Implications for practice

This paper addresses a gap in the UK chemical distribution industry as it provides an account of the challenges small and medium-sized distributors are facing and uncovers a number of contributing factors to their success. Based on the findings, table 1 provides a summary of implications and opportunities for SMEs in the UK chemical distribution industry.

SMEs owners/managers can utilize the findings of this study to strategize, run their businesses more efficiently and effectively by concentrating their efforts and resources to the areas that really make a difference in their business, plan and prepare for the future including challenges in their planning process and addressing any issues in the very early stage, improve their decision-making process and uncover and address training needs such as strategic and financial planning skills or recruitment.

The government, policy makers and financial institutions may utilize the findings of this study to develop and implement policies directed at SMEs in the specific industry, improve and develop the necessary support infrastructure, extend the nature and the range of advice and offer training and education for SME owners, managers and employees.

Non-government, industry-specific organizations such as the FECC, the Chemical Business Association (CBA) and the British Association of Chemical Specialties (BACS), also benefit from this research as it increases their understanding of the industry, especially from a small business perspective. It also provides the knowledge for these associations to approach and recruit new members, especially SMEs that have always been difficult to approach or the ones that did not see a value in joining before.

Moreover, chemical manufacturers and suppliers are able to get a deeper, more complete understanding of the market and the SMEs operating within. Therefore, they would be in a position to evaluate, formulate and implement their distribution channel strategy in a more efficient and effective way.

Table 1 Implications and opportunities initiated by the challenges for SMEs in the UK chemical distribution industry.

Challenges	Implications	Opportunities
Regulatory compliance	▪ Need for formal 'compliance' strategy ▪ Need for financial (registration, testing) and human (recruiting experts, consultants/ advisory services) resources ▪ Restricts market for existing SMEs ▪ Instigates withdrawal from EU market ▪ Restricts entry for new suppliers/ manufacturers into the EU market ▪ Dampens entrepreneurial/start-up activity	▪ Business opportunities outside EU/ REACH ▪ Better utilization of sources of support (ECHA, Chamber of Commerce)
Supplier management	▪ Need for resources (time, people, finance) for managing existing and identifying new suppliers ▪ Need for portfolio management and dynamic product mix	▪ Utilize suppliers product development and innovation capacity ▪ Opportunity for knowledge sharing and development of joint business processes (integration)
Access to finance	▪ Regulates growth ▪ Need to secure multiple sources of finance and flexible borrowing options ▪ Good relationships with lenders/investors required ▪ Build reputation	▪ Higher utilization of available financing options ▪ Seek markets with favorable government policies and support
Human capital	▪ Need for recruitment strategy (as this is a service-based industry and SMEs present a less secure working environment) ▪ Requirement for highly skilled, industry- specific, technically qualified people ▪ Training and skills development ▪ Succession planning needs to be part for the business strategy	▪ Develop people into a competitive advantage/unique selling point (USP) ▪ Utilize available training support (e.g. through government initiatives)

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Journal of Business Chemistry

Practitioner's Section

Understanding the market dynamics of biosimilars

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Biosimilars represent an attractive market opportunity in the pharmaceutical industry. In order to understand the underlying market dynamics and to identify the success factors of the biosimilars market, a PEST (political, economic, social, technological) analysis was conducted based on desk research and expert interviews with market participants and stakeholders. The regulatory environment for biosimilars seems to be well established and both the required manufacturing technology and the necessary analytical capabilities for biosimilar development are available. The potential market is expected to grow due to the overall dynamics in the biologics market and the patent expiration of blockbuster drugs. The perspective of the scientific community towards biosimilars has changed from skeptical to rather positive in the last 10 years, probably reflecting the evolution of regulatory guidelines and technological progress. However, physicians, responsible for the prescription of drugs, are still rather skeptical about biosimilars and need to be better informed in order to increase the currently low market penetration of biosimilars. Taken together, the biosimilars industry is expected to step out of its infancy stage and now enter the growth phase.

1 Introduction

In 1982, the company Eli Lilly received approval for the first recombinant protein, i.e. human insulin, for therapeutic use in the EU. More than 30 years later, in 2015, a total of 185 biotechnologically-derived drugs has been approved (VFA, 2015). They are applied in various therapeutic areas, such as oncology (e.g., monoclonal antibodies against breast cancer), haematology (e.g., erythropoietin or epoetin against anemia), bleeding disorder (e.g., Factor VIII) or immunology (e.g., interferon alfa).

These biotechnologically-derived drugs are called "biopharmaceuticals" or "biologics". The latter term will be used in this article, following the nomenclature of de Mora (2015). As shown in table 1, biologics differ from medicinal products that are chemically synthesized such as acetylsalicylic acid, which will further be referred to as "chemically-synthesized drugs", in a number of ways (Dingermann and Zündorf, 2014; ProGenerika, 2014a, Schellekens, 2004).

Biologics are significantly larger than chemically-synthesized drugs. Their size can be up to several hundred kDa in the case of monoclonal antibodies. Due to their size, they cannot be manufactured by chemical synthesis but have to be produced by using biotechnological processes in living cells. Biologics are complex molecules with therapeutic efficiency depending on their higher-order structure, especially the tertiary structure of the protein, and the pattern of post-translational modifications such as glycosylation or disulfide bridges. Thus, biologics have to be administered parenterally as they otherwise would undergo significant structural modifications in the gastrointestinal tract. For example, a protonation of basic amino acid side chains in the acidic environment in the stomach would lead to the denaturation of the protein and thus nullifying the desired therapeutic effect. The inherent structural complexity of biologics combined with the high quality level required for intravenous administration, is one of the key differences of this class of medicinal products compared to chemical-

Table 1 Comparison of biologics and chemically-synthesized drugs.

	Biologics	Chemically-synthesized drugs
Type of molecule and size	Large polypeptide chains (molecular weight: usually more than 10 kDa)	Mostly small chemical molecules (molecular weight usually less than 1 kDa)
Production	Biotechnological synthesis	Chemical synthesis
Physico-chemical characteristics	Complex, heterogeneous and labile structure (e.g., tertiary structure is depending on pH)	Well-defined, stable structure
Analytics	Structure as well as purity difficult to determine due to structural complexitiy	Structure and purity can be determined relatively easily
Biological impurities	Elaborate measures required to prevent viral/bacterial/fungal impurities	Very rare
Immunogenicity	Potentially immunogenic	Very rare
Dosage form	Usually parenteral (e.g., via intravenous injection of a solution)	Usually oral application (e.g., pills)

ly-synthesized drugs. This is reflected by an elaborate and expensive development process as well as the high prices of biologics, which are in turn increasing therapy costs. For example, the price for five doses of Remicade® is reported to amount to EUR 4,675 (Apotheke adhoc, 2015).

As the patents of originator products, i.e. the biologics that have first entered the market, expired or are about to expire, the market is now open for generic producers to enter this seemingly attractive market. Generic manufacturers usually produce a molecular copy of the originator product and sell it at a lower price. This is also very attractive for health insurance companies in order to reduce the financial burden on the healthcare system.

However, it is not possible to produce an exact copy of the original molecule. Even minor differences in the manufacturing process will e.g. result in a different glycosylation pattern of the product and thus yield in a different molecule. The European Medical Agency (EMA) thus developed the expression "biosimilar" in their 2005 guideline (EMA, 2005). A biosimilar is a medicinal product shown to be essentially the same as the original product but not identical. The term "biogeneric" is therefore not suitable for biologics and should not be applied. In the context of this article, it is further important to distinguish between first-wave and second-wave biosimilars (Hinderer, 2012; Schellekens, 2015). The first refers to smaller and "simple" biomolecules such as insulin or the growth hormone somatropin, which are produced in E. coli or yeast cells and usually do not show post-translational modifications. The second term refers to larger biomolecules such as monoclonal antibodies that exhibit a much broader structural diversity and which are usually produced in mammalian cells giving way to different post-translational modifications.

In this work, the status quo of the market for biosimilars is analyzed along the structural framework of a PEST analysis (P: political environment, E: economic environment, S: social environment, T: technological environment) with primary focus on the following questions:

- Political environment: How far developed and reliable is the regulatory framework for the introduction of biosimilars? What is required to obtain marketing authorization for a biosimilar? Are there companies that have successfully run through the authorization process in the EU?
- Economic environment: How large is the market of biologics that have already lost or are losing patent protection? How will the competitive environment in the biosimilars market evolve – and will there be a difference to the "classical" chemically-synthesized generics?
- Social environment: What is the role of key stakeholders such as health insurance companies, physicians or patients in the biosimilars market? What is their attitude towards biosimilars and to what extent do they affect market dynamics?
- Technological environment: What are the key competencies required in biosimilars develop-

ment, especially with respect to project management? To what extent are analytical techniques (already) capable to demonstrate "similarity" between a biosimilar and its reference product?

Based on this status quo, an outlook on the biosimilars market is established and management implications for different types of market players are discussed.

2 Methods

2.1 PEST analysis

The PEST analysis was mainly based on secondary research supplemented with primary research where applicable and appropriate. Table 2 provides an overview on the sources used.

2.2 Market outlook

In order to monitor the market dynamics of the last years and to establish a sound database for a market outlook, 234 peer-reviewed scientific articles and conference contributions (referred to as "sources" in the following) containing the keyword "biosimilar" were analyzed. Those sources were selected by conducting a search for the keyword "biosimilar*" either in the title or abstract of a publication within the timeframe from 2004 to 2015 in the scientific database Sciencedirect (Sciencedirect, 2015). Each of the sources was classified in one of the three categories "skeptical", "neutral" and "positive", depending on its characteristic content. The source was classified as "sceptical" when the text rather questions the viability of biosimilars and discusses mainly problems in the context of biosimilars. A text is classified as "neutral" when it does not generally question the viability of biosimilars and discusses both problems and suggestions for solutions. The source was classified as "positive" when the text acknowledges the potential of biosimilars and discusses solutions rather than highlighting problems.

3 Results

3.1 PEST analysis

3.1.1 Political perspective

The EU was the first region to establish regulatory guidelines for the authorization of biosimilars

Table 2 Overview on methods and sources applied in the PEST analysis.

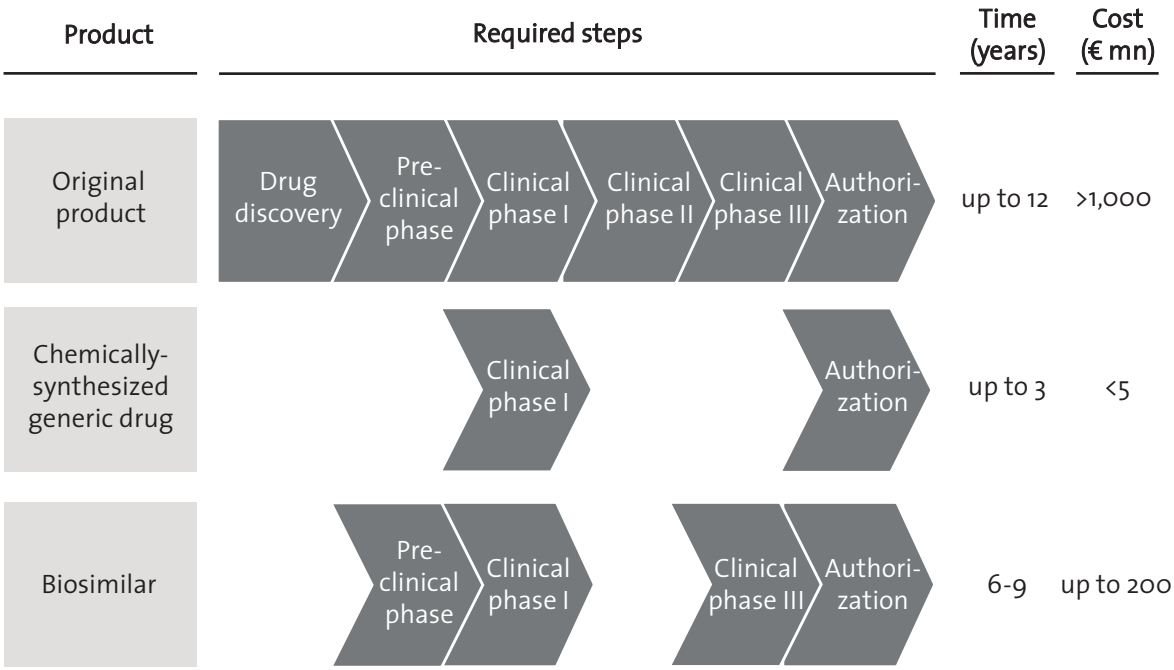
Dimension	Topic	Methods and sources	
		Secondary research	Primary research
Political	Regulatory framework for biosimilars	Peer-reviewed scientific literature EU biosimilar guidelines	-
	Authorization process for biosimilars	EU biosimilar guidelines	-
	Overview on approved biosimilars in the EU	VFA data on authorized drugs in the EU	-
Economic	Market potential	BCG/VFA annual report on biologics market IMS Health presentation (Sheppard and Di Biase, 2014)	-
	Market size	Pro Generika data on biosimilars market	-
	Competitive environment	IMS Health presentation (Sheppard and Di Biase, 2014) Company websites	-
Social	Stakeholder analysis: healthcare funds	Peer-reviewed literature	Expert interviews
	Stakeholder analysis: physicians	Peer-reviewed literature	Expert interviews
	Stakeholder analysis: patients	Peer-reviewed literature	-
Technological	Project management competencies	Peer-reviewed literature	-
	Bioanalytical know-how	Peer-reviewed literature	-

(EMA, 2005). These guidelines reflect the complexity of biologics on a regulatory level as it requires a substantial amount of pre-clinical and clinical studies before obtaining marketing authorization (figure 1). While pre-clinical studies are required in order to confirm similarity on a molecular level, clinical studies are required to confirm the therapeutic efficiency of the biosimilar.

The necessity of the clinical phase III in the development of biosimilars is required due to the fact that structural differences such as a different glycosylation pattern in the biosimilar compared to the original drug may affect the therapeutic efficiency of the medicine. Companies planning to market a biosimilar thus need to demonstrate that their product is at least as effective as the original drug. It is possible that once the effectivity of the biosimilar is established for one indication, the results can be extrapolated to other indications. For example, the biosimilar monoclonal antibody infliximab was approved in the EU in 2013 for all indications of the originator product (Remicade®, Johnson & Johnson), including rheumatoid arthritis, psoriasis arthritis, psoriasis, inflammatory bowel diseases and ankylosing spondylitis (GaBiOnline, 2013). However, in Canada, the same biosimilar was only approved for autoimmune arthritis as an extrapolation of the clinical data to inflammatory bowel diseases was not granted (GaBiOnline, 2015a). Extrapolation to other indications thus remains a subject of debate, which is also underlined by the discussion in the scientific community (Weise, 2014). The necessity of the pre-clinical phase as well as the clinical phase III in the biosimilar development marks the major difference to chemically-synthesized generic drugs which are only required to demonstrate their bioequivalence with the original drug in clinical phase I. A comprehensive discussion on the pre-clinical development of biosimilars can be found in a recently published paper by Bui et al. (2015). Additionally, after having obtained marketing authorization, companies further need to implement a pharmacovigilance plan, i.e. further studies in order to rule out potential long-term negative side effects.

This different extent in pre-clinical and clinical studies leads to significant higher development costs for biosimilars which may reach up to EUR 200 mn, representing 20% of the development costs of the original drug (ProGenerika, 2014b), compared to the development of chemically-synthesized generic drugs which require less than 1% of the development costs of the original drug (Mellstedt, 2013). This also results in a lower price reduction compared to the original drug. Prices for biosimilars are usually set 10 to 30% below the originator

Figure 1 Simplified comparison of the marketing authorization process for original pharmaceutical drugs, chemically-synthesized generic drugs and biosimilars.



price (Tsuruta et al., 2015), but there is one example of a biosimilar that was introduced at a 72% discount in Norway (GaBiOnline, 2015b). The market price for chemically-synthesized generic drugs are usually more than 80% below the price of the original product. On the other hand, both chemically-synthesized generic drugs and biosimilars do not need to run through the "drug discovery" phase as the therapeutic target of the medicinal product is already known. The clinical phase II is also not required as the dosage of the biosimilar is the same as for the original product.

As shown in table 3, a total of 18 biosimilars received marketing authorization from the EMA between 2006 and 2014 (VFA, 2015). This underlines the applicability of the EMA guidelines.

One should note that the list of biosimilars in table 3 also contains the monoclonal antibody infliximab, which received approval. This is remarkable as monoclonal antibodies represent the most complex biologics and their development as biosimilar was seen very skeptical some years ago (Schneider and Kalinke, 2008). Given the fact that the development of biosimilar monoclonal antibodies is nevertheless possible, it underlines the broad applicability of the EMA framework.

After the establishment of biosimilar guidelines in the EU, more than 30 countries worldwide have also set up their own guidelines (Heinemann et al., 2015). These countries comprise large pharmaceutical markets such as Japan, where guidelines were established in 2008, for Canada in 2009, for the US in 2010 and for India in 2011, respectively. In China, regulatory guidelines are currently in the evolution process (Heinemann et al., 2015). This evolving regulatory environment for biosimilars will continue to give companies a reliable framework for their development process.

3.1.2 Economic perspective

The market potential for biosimilars is primarily driven by the market growth of biologics which is in turn determined both by the growing number of biologics on the market as well as their high price. The market of biologics has grown significantly in recent years (figure 2). In 2006, biopharmaceuticals already represented 12% of the German pharmaceuticals market value – by 2014, the market share of biopharmaceuticals had raised to 22%. During this period, biopharmaceuticals grew with a compound annual growth rate (CAGR) of 12%, whereas chemically-synthesized drugs rather stagnated with a 1% CAGR as shown in figure 2 (BCG, 2006-2015).

Furthermore, more than ten blockbuster bio-

Table 3 Overview of biosimilars that successfully obtained marketing authorization in the EU since 2006 (VFA, 2015).

Product	Company	Active pharmaceutical ingredient	Marketing authorization
Omnitrope®	Sandoz	Somatropin	2006
Epoetin alfa Hexal®	Hexal	Epoetin alfa	2007
Abseamed®	Medice	Epoetin alfa	2007
Binocrit®	Sandoz	Epoetin alfa	2007
Retacrit®	Hospira	Epoetin zeta	2007
Silapo®	Stada	Epoetin zeta	2007
Ratiograstim®	Ratiopharm	Filgrastim	2008
Tevagrastim®	Teva	Filgrastim	2008
Filgrastim Hexal®	Hexal	Filgrastim	2009
Zarzio®	Sandoz	Filgrastim	2009
Nivestim®	Hospira	Filgrastim	2010
Grastofil®	Apotex	Filgrastim	2013
Ovaleap®	Teva	Follitropin alfa	2013
Remsima®	Celltrion	Infliximab	2013
Inflectra®	Hospira	Infliximab	2013
Accofil®	Accord	Filgrastim	2014
Bemfola®	Finox Biotech	Follitropin alfa	2014
Abasaglar®	Eli Lilly	Insulin glargin	2014

logics, i.e. drugs with annual sales of more than EUR 1bn, will lose their patent protection in the period from 2013 to 2019 (Sheppard and Di Biase, 2014) as demonstrated in table 4.

This underlines the market attractiveness from a sales perspective. As shown in section 3.1.1, companies already start to enter this market. However, as can be seen from figure 3, biosimilars demonstrate only a limited market penetration so far (ProGenerika, 2015).

Currently, biosimilars containing infliximab, somatropin, epoetin or filgrastim only represent less than one fifth of the German market for biologics that have already lost patent protection. However, there are significant differences in the market penetration depending on the product. With 8% market penetration, the market for the monoclonal antibody infliximab currently shows the lowest values. However, this biosimilar has only been introduced on the market in February 2015 and reached about 18% market share in October 2015 (ProGenerika, 2015). It remains to be seen whether this share can be increased in the upcoming months. In the case of somatropin, only one biosimilar player, i.e. Sandoz, is competing against an oligopoly of six companies producing the original product: Pfizer, Novo Nordisk, Merck, Eli Lilly, Ferring and Ipsen Pharma. This competitive environment makes market penetration for the biosimilar drug difficult to achieve. Competition based on price alone will be difficult due to the low price reduction of the biosimilar compared to the original product as discussed above. Epoetin biosimilars have achieved a somewhat larger market penetration, mainly due to the fact that epoetin therapies are mostly short-term therapies which makes it easier to switch from the original product to a biosimilar. In this context, it is important to note that a biosimilar is usually applied from the beginning of a therapy and physicians are reluctant to substitute an original biologic during an ongoing therapy. Filgrastim biosimilars have achieved the largest market penetration, probably due to the fact that seven biosimilar players have received marketing authorization (see table 3), whereas there is only one company on the market, Amgen, who markets the original product. However, given the relatively small size of the filgrastim market, this does not change the overall picture of a currently low market penetration of biosimilars.

Figure 2 Market size and growth of the German pharmaceutical market in the period 2006–2014.

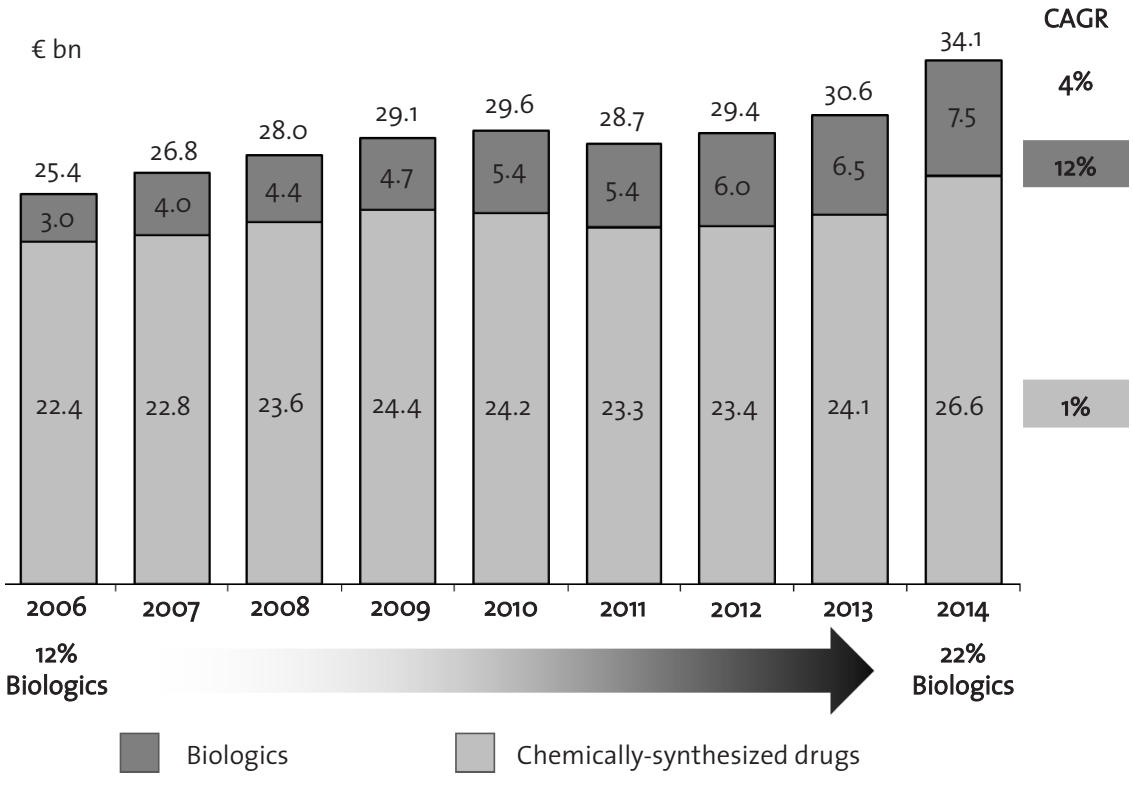
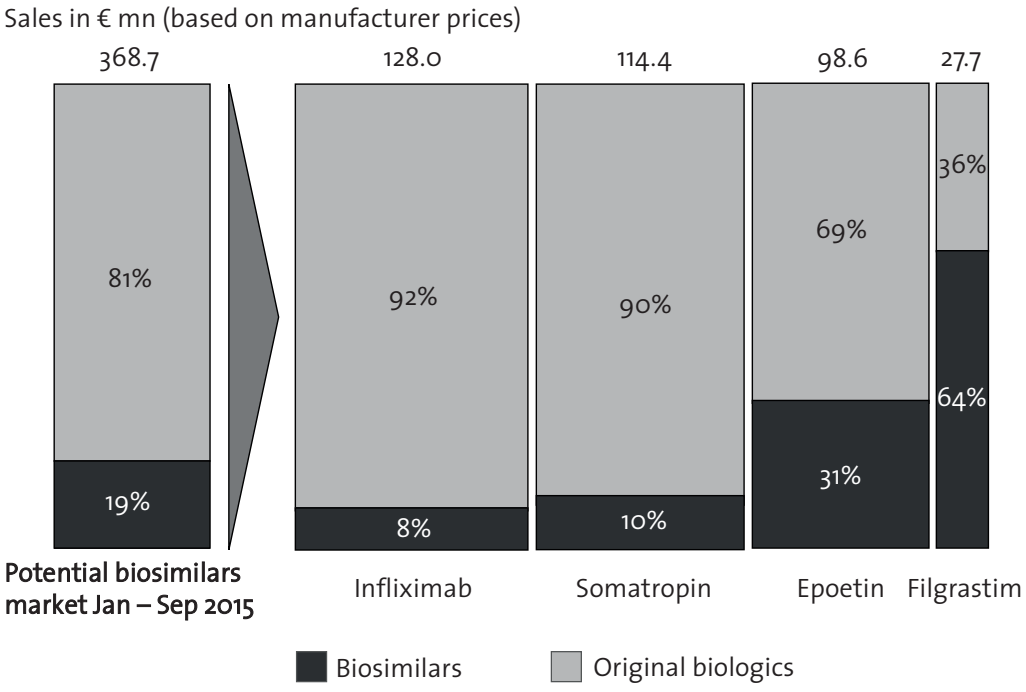


Table 4 Original blockbuster biologics that lose their patent protection in the period 2013–2019.

Year	Original biologic	Company	Global sales 2014 (€ bn)
2013	Mabthera	Roche	6.0
2014	Novomix	Novo Nordisk	5.9
	Herceptin	Roche	5.0
	Remicade	Johnson&Johnson	7.4
	Enbrel	Pfizer	7.8
2015	Lantus	Sanofi	8.6
	Avonex	Biogen Idec	5.2
	Neulasta	Amgen	4.2
2016	Lucentis	Novartis	4.2
2018	Humira	Abbvie	10.2
2019	Avastin	Roche	5.5

Figure 3 Market penetration of biosimilars in four selected biologics market segments.



The competitive environment in the biosimilars market is shaped by at least three different types of companies:

- Traditional generics manufacturer (e.g., Teva, Sandoz, Stada),
- Large pharmaceutical companies (e.g., Eli Lilly),
- New market entrants (e.g., Celltrion).

Traditional generics companies were the main driving force behind the first wave of biosimilars, such as somatropin, filgrastim and epoetin. Their development is less complex (and probably less cost intensive) compared to second-wave biosimilars, so that the entrance of some traditional generics player is not surprising. However, so far there have only been attempts but no classical generics company has successfully developed a second-wave biosimilar, which require more initial investments and bear a higher risk. The company Stada invested in a development program for the biosimilar trastuzumab, a monoclonal antibody, but canceled the project in 2010 and further decided to follow an in-licensing strategy (Stada, 2011). The company Teva, together in a joint venture with the Swiss company Lonza, stopped clinical trials on their biosimilar rituximab in 2012 (Biosimilar News, 2012).

Biosimilars also present an (additional) attractive market for large pharmaceutical companies (Ledford, 2010). As the price of a biosimilar is usually at least 70% of the originator price, it is attractive for these companies to invest in development programs of biosimilars as well. One significant advantage compared to the development of novel pharmaceutical drugs is the fact that the pharmaceutical target is already known, which means that there is no need for cost-intensive research and development in the early phase of drug development and a higher probability of success. Additionally, large pharmaceutical companies benefit from their development expertise and financial strength to approach the development of second-wave biosimilars. Indeed, looking at the development pipeline of biosimilar monoclonal antibodies, one can observe that large pharmaceutical companies such as Boehringer Ingelheim, Pfizer and Merck are currently trying to enter this market (ProGenerika, 2014b).

Another strategy for established large biopharmaceutical companies like Amgen or Sanofi is the development of so-called "biobetters", i.e. improved versions of the original product that again receive patent protection (Casey, 2015). Examples would be insulin glargin (e.g., Sanofi's human insulin analogue Lantus®) or a PEGylated form of filgrastim (e.g., Amgen's Neulasta®). The development of a biobetter can be interpreted as a strategy of original producers pursuing patent extension and will not be discussed in detail here as it was discussed elsewhere (Casey, 2015).

Most interestingly, there are also new market entrants that are stirring up the competitive environment. One of the most intriguing case examples is the company Celltrion (South Korea). Founded in 2002, the company received EU approval for the monoclonal antibody infliximab (product: Remsima) in 2013 and started to enter the market in 2015 (after patent expiration of the original product). Celltrion can be classified as a so-called "emerging market player", a company that first focuses on a certain number of regional markets (e.g., India) before attempting to enter the highly regulated pharmaceutical markets in the EU and the USA (Sheppard and Di Biase, 2014).

3.1.3 Social environment

In order to evaluate the social environment, three different stakeholders involved in the market acceptance of biosimilars are examined:

- Health insurance companies as they are responsible for refinancing the therapies,
- Physicians as they decide about the application of a biosimilar versus the original biologic,
- Patients as they are in the end the market participants who receive treatment with the biosimilar.

Pharmacies were not included in the analysis as they are not involved in the decision process about whether a biosimilar or an original drug should be used. This is a sharp contrast to chemically-synthesized generics, where automatic substitution at the pharmacy gives the pharmacist a completely different role.

Health insurance companies are generally open towards biosimilars as they represent a means to reduce the financial burden on healthcare systems. Even if the price reduction is usually only in the order of 10 to 30% compared to the original biologic drug, this still represents huge potential savings for the healthcare system. In order to create incentives for physicians to favor biosimilars during the prescription of drugs, healthcare funds introduced target agreements in some German regions (ProGenerika, 2014a). For example, the Association of Statutory Health Insurance Physicians (Kassenärztliche Vereinigung) of the federal state Bremen included specific prescription target quo-

tas in its annual agreement with the healthcare insurance companies (KV Bremen, 2015). As a result, Bremen belonged to the federal states in Germany with the highest prescription quota for biosimilars (ProGenerika, 2015).

The typical discount contracts that are usually applied after patent expiration of a drug are not seen as an instrument to improve the usage for biosimilars by healthcare insurance companies. Given the high development costs for biosimilars, discount contracts rather favor the original producer who already had the opportunity to earn their return on investment. For a biosimilar producer, discount contracts would represent a higher risk as they would be trapped between earning their investment and realizing a low price to be attractive for health insurance companies.

Physicians are the most important stakeholder group as they are responsible for prescribing the biosimilars. However, they are currently rather skeptical towards biosimilars as they are not sufficiently informed. In particular, they are concerned about the pharmaceutical quality of biosimilars, their safety (immunogenicity potential), efficacy (extrapolation in clinical studies), and interchangeability with the originator product (Cuadrado et al., 2013; Lie et al., 2015; Mellstedt, 2013; Rompas et al., 2015; Weise et al., 2012), which is also underlined by a survey among physicians (N=307) with focus on inflammatory bowel diseases (Danese et al, 2014). These results are corroborated by selected expert interviews (N = 6) that were conducted in the course of this study. Most of the interviewees (N=5) have not yet heard of biosimilars. One physician (nephrologist) who had experience with epoetin, stated:

> *"Production, quality, immunogenicity and efficacy of biosimilars are not sufficiently transparent. Clinical studies are extrapolated by using the data of the reference product, which is not suitable."*

It is interesting to note that such skepticism remains although biosimilars have to run through a thorough authorization process as outlined in section 3.1.1, and that they, to the best of our knowledge, did not yet show any adverse effects. However, in order for biosimilars to be successful on the market, companies also have to think about how to better inform physicians about the therapeutic advantages of biosimilars.

Patients, on the other hand, are nowadays better aware about their diseases and the therapeutic options. For chronological diseases such as cancer, patients seem to be rather skeptical about changing from an established original biologic to a biosimilar. They also think critical about the expression "biosimilar", as the word "similar" implies not getting the same drug. For short-term therapies such as epoetin treatment, on the contrary, substitution of the original product with a biosimilar seems less problematic.

3.1.4 Technological

Concerning the technological perspective, the literature review reveals two major topics. The first of them, the so-called quality-by-design (QbD) approach, is receiving increased attention as an approach to project management in biosimilar development and production. The QbD approach was first introduced by Juran (1992) and has been adopted by the U.S. Food and Drug Administration (FDA) for the development of pharmaceutical products (FDA, 2007). The QbD approach has also been explicitly discussed for biologics (Rathore, 2009; Scott, 2011). Essentially, the QbD approach aims at a thorough understanding as well as control of the potential influencing variables in the manufacturing process of a pharmaceutical drug from the very beginning. Thereby, the risks associated with the development process of a pharmaceutical drug, such as process changes (Schiestl, 2011) or variability of (biological) raw material quality (Rathore, 2009), should be better understood and thus already mitigated during the development phase, e.g. upon planning of the manufacturing process. The QbD approach is also reflected by the proverb "the process is the product" that is often coined in the context of biosimilars. It gives companies a higher flexibility in designing a manufacturing process for biosimilars and reflects the inherent complexity of biomolecules on a project management level as it provides companies with the flexibility to decide how to best obtain the end product. On the other hand, this flexibility may come at the cost of higher uncertainty for companies as a large number of process parameters have to be taken into account from the very beginning of a biosimilar development project.

The second important topic is the question of how to proof similarity of a biosimilar to the reference product. Again, given the large molecular size and the inherent complexity of biologics, it is obvious that a large array of state-of-the-art bioanalytical tools is required to address this question. Due to the progress in analytical science, there are now many different analytical methods available to analyze biosimilars (Kálmán-Szerekes et al., 2012; Tsuruta et al., 2015). Especially mass spectrometry has proven as an invaluable tool to analyze structural similarity, as has been highlighted e.g. by studies of epoetin biosimilars (Harazono et al., 2013) as well as complex monoclonal antibodies (Beck et

al., 2013). Even batch-to-batch structural changes or structural alterations upon variation of the manufacturing process can be monitored (Kálmán-Szerekes et al., 2012). From the perspective of innovation management, it is interesting to note that the progress of the (bio)analytical science seems to be a necessary prerequisite in order to capture the market potential of biosimilars, which is in line with the assumption of some experts that analytical science is a key driver of innovation in the chemical sciences (Franz, 2013).

3.1.5 Summary of PEST analysis

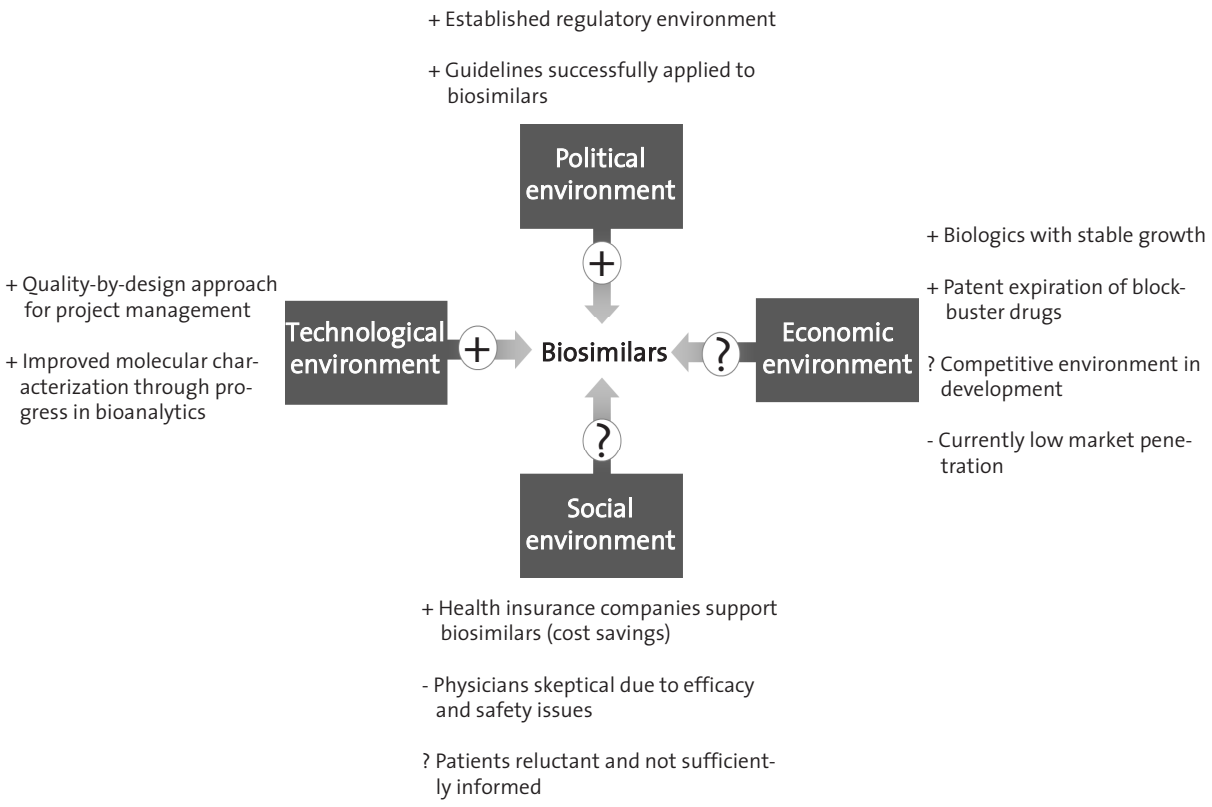
The summary of the PEST analysis of the biosimilars market is shown in figure 4.

The analysis shows that the market is economically attractive and that both the technological means to address this market as well as the regulatory environment that ensures a framework in which companies can operate to capture this market are at hand. However, the regulatory environment must be flexible enough to adapt to technological progress (Huzair and Kale, 2015). The challenges to successfully develop a biosimilar may still be high but the huge market opportunity seems to make investments worthwhile, which is in line with previous findings (Blackstone and Fuhr, 2013). The current major bottleneck for the biosimilar market development seems to be an overall skeptical attitude of physicians as they do not feel sufficiently informed about biosimilars and are rather reluctant to prescribe those drugs.

3.2 Market outlook

Due to the factors discussed in the previous section, the biosimilars market does currently not capture its full market potential. However, chemically-synthesized generics also faced a similar situation 20 years ago. In 1990, only about 30% of the potential generics market were actually served by generics (the remaining 70% were occupied by originator drugs) (BPI, 2000; PhRMA, 2015). Interviews both with a market expert of the association ProGenerika e.V. and a leading German health insurance company corroborated this finding. According to these interviews, the current market situa-

Figure 4 Summary of the key findings of the PEST analysis for the biosimilars market ("+" indicates a positive influence on the biosimilars market, "-" indicates a negative influence on the biosimilars market, "?" indicates that the factor can have both a positive or a negative influence).



tion of biosimilars can be interpreted as "starting difficulties" of an innovative market. However, it is not clear whether the biosimilar market will take a similar development as the market for chemically-synthesized generics. Given the complexity of the product and the lower number of competitors, no final conclusion concerning the comparability of these two markets can be drawn so far.

In order to better understand the perspective of different stakeholders on biosimilars in recent years, 234 peer-reviewed scientific articles and conference contributions were analyzed. The analysis revealed that the perspective of the scientific community towards biosimilars changed from a rather skeptical evaluation 10 years ago to a rather positive assessment in 2015 (figure 5).

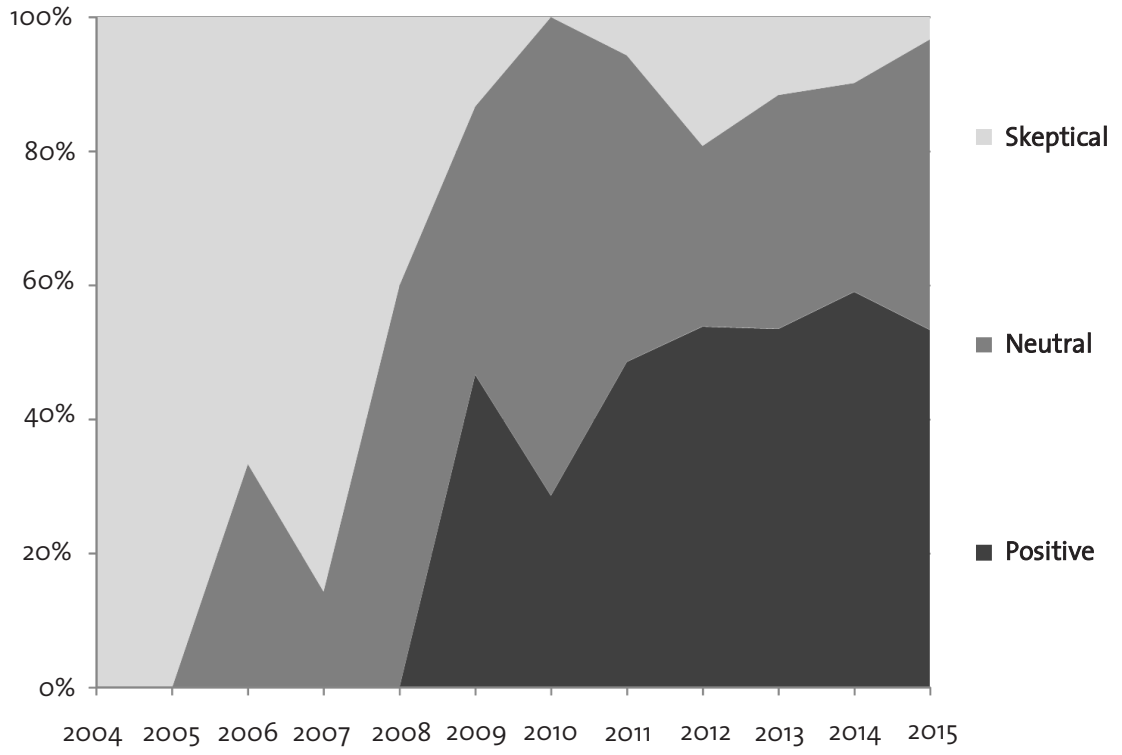
In the same period, an increasing number of countries developed guidelines on biosimilars (Heinemann et al., 2015) and significant progress in bioanalytics was made. In 2007, testing for similarity and comparability was still seen as "causes of concern" (Roger and Mikhael, 2007), whereas eight years later, Tsuruta et al. (2015) argue that *"...improved analytical methods [...] allow for the detection of even small changes [...] between lots of the reference products currently on the market"* (Tsuruta et al., 2015).

Finally, another important aspect when discussing the market outlook for biosimilars, is the demographic change in developed countries. Facing a rising life expectancy and a growing average age, access to high quality medicine without compromising the benefits of national healthcare systems already is and will become a major issue for healthcare politics. Biosimilars can play a crucial role in this context.

4 Concluding remarks

Biosimilars have successfully entered the healthcare market and broadened the access to affordable high quality medicinal products. An established regulatory environment secures the framework for companies seeking to invest in this dynamic market. The current skeptical attitude of physicians and patients should be addressed by better informing these stakeholder groups about biosimilars, e.g. by teaching medical students at universities about biosimilars in order to improve the attitude of physicians or by information

Figure 5 Assessment of the attitude towards biosimilars within the scientific literature based on the analysis of peer-reviewed articles and conference contributions (N=234).



brochures about biosimilars in order to improve the attitude of patients. Based on the comparison with chemically-synthesized generics and the changed attitude of the scientific world towards biosimilars, the market share of biosimilars in the market for biologics that already lost patent protection is expected to increase in future. The market is thus attractive for companies thinking about to enter this innovative environment.

The implication for the management depends on the type of company. For traditional generic companies, development of a second-wave biosimilar does not seem to be attractive, given the high upfront investments and the high risk. For them, seeking alliances with larger biosimilar companies would probably yield more success, e.g. if they focus on distribution, their core competency, and in-license the biosimilar from a company that focuses on biosimilar development and does not have market access. Potential partners could be, e.g., market entrants from foreign markets.

For big pharmaceutical companies, biosimilars seem to be an attractive option to fill their pipeline and to leverage their development expertise as well as their financial strength. As development of a biosimilar requires much of the expertise of new drug development, big pharma companies should be in a good starting position to address this market.

For new market entrants, the hurdles are high: regulatory know-how, expertise in quality-by-design project management and financial strength. However, as the case of Celltrion shows, given the right strategy and financial support, also those companies can enter the market.

The biosimilars market will probably develop towards an oligopolistic market, as also found in other studies (Declerck and Simoens, 2012; Rompas et al., 2015). The competitive environment will be shaped by a mix of non-classical competitors such as big pharmaceutical companies and new market entrants from foreign markets as well as a small number of classical generic players in the first-wave biosimilar market. Product competition in this market will rather occur between the biosimilar and the originator drug than between different biosimilar versions of the drug as can be observed for chemically-synthesized generics, which has also been described by Carlson (2009). But even if the competitive environment will be characterized by a lower number of players compared to the chemically-synthesized generics market, the financial burden on the healthcare system will nonetheless be reduced, which will be a major driver of the biosimilars market in the long run. Biosimilars will thus continue to become an integral part of the pharmaceutical portfolio in the future. The question will no longer be "if" but rather "when" this dynamic market will see its breakthrough.

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Journal of Business Chemistry

Practitioner's Section

PhytoGerm: Extraction of germanium from biomass - An economic pre-feasibility study

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Germanium is a metalloid with great potential for industrial use. Currently, the semiconductor is primarily recovered as a by-product during the exploitation of zinc. The global zinc mine and metal production, however, has been decreasing over the last years, which may result in a production to consumption deficit for germanium. "PhytoGerm" is part of the r³-initiative for tech metals and resource efficiency, a subsidy program of the German Federal Ministry of Education and Research. Within this context, the PhytoGerm project focuses on alternative methods to extract germanium. The suggested mining process operates with ribbon grass which is capable of accumulating germanium from soils, e.g. from mine tailings. After harvesting germanium-enriched plants, the biomass is ensiled and biogas is produced by fermentation. This study analyzes the economic pre-feasibility of this process, whereby the results reveal that germanium can be obtained economically by means of phytomining under certain preconditions (i.e. absorption of 10 ppm germanium in dry biomass, twice the current price of germanium(IV)-oxide).

1 Introduction

Phytomining is an extraction process in which metallic substances in soils or sediments are absorbed by plants. This process has become very popular in the last decades because of its low costs and environmental friendliness. "PhytoGerm" is part of the German r³-initiative for strategic tech metals and resource efficiency and focuses on a method to extract germanium from ribbon grass. This paper analyzes the economic pre-feasibility of the process introduced by the PhytoGerm project. At first, the economic importance of germanium is shown by analyzing its demand and supply. The second part deals with the plants that accumulate germanium and the boundary conditions for cultivation. The economic aspects of harvesting germanium are shown by means of a case study, whereby the necessary machinery, equipment and infrastructure for the process are demonstrated. Finally, the two major leverage factors, i.e. the accumulated amount of germanium and the market price, are examined in order to derive a conclusion concerning the economic feasibility of the PhytoGerm process.

2 Global supply and demand of germanium

The first industrial application of germanium took place in the 1960's with the invention of germanium transistors (Calder, 1958) and the usage of germanium as a semiconductor material in radar units. Nowadays, germanium is used in military applications and many industrial fields, especially in electronics and optics. In the following, the worldwide supply and demand are described in order to deduce the importance of alternative extraction methods.

2.1 Supply

Erdmann et al. (2011) estimate that the global germanium reserves range between 9,000 and 10,000 t. The distribution of the metalloid is highly dispersed, whereby the available resources are

primarily associated with certain zinc and lead-zinc-copper sulfide ores. The lion's share of the reserves is in hands of the People's Republic of China (3,650 t), followed by Russia (2,900 t) and the Democratic Republic of the Congo (1,000-2,000 t). The US (450 t) and Namibia (250-500 t) only control a small amount of the existing germanium deposits (Erdmann et al., 2011; Melcher et al., 2014).

Most of the germanium is recovered as a by-product during zinc extraction. In a few instances, the metalloid has been extracted in copper smelters and from the fly ash of coal burning power plants (Melcher et al., 2014). Over the past six years, the worldwide production of germanium increased from 118 t to 153 t in 2013 (figure 1). Following this trend, germanium supply could reach up to 200 t in 2020 with a compound annual growth rate of 4.8%.

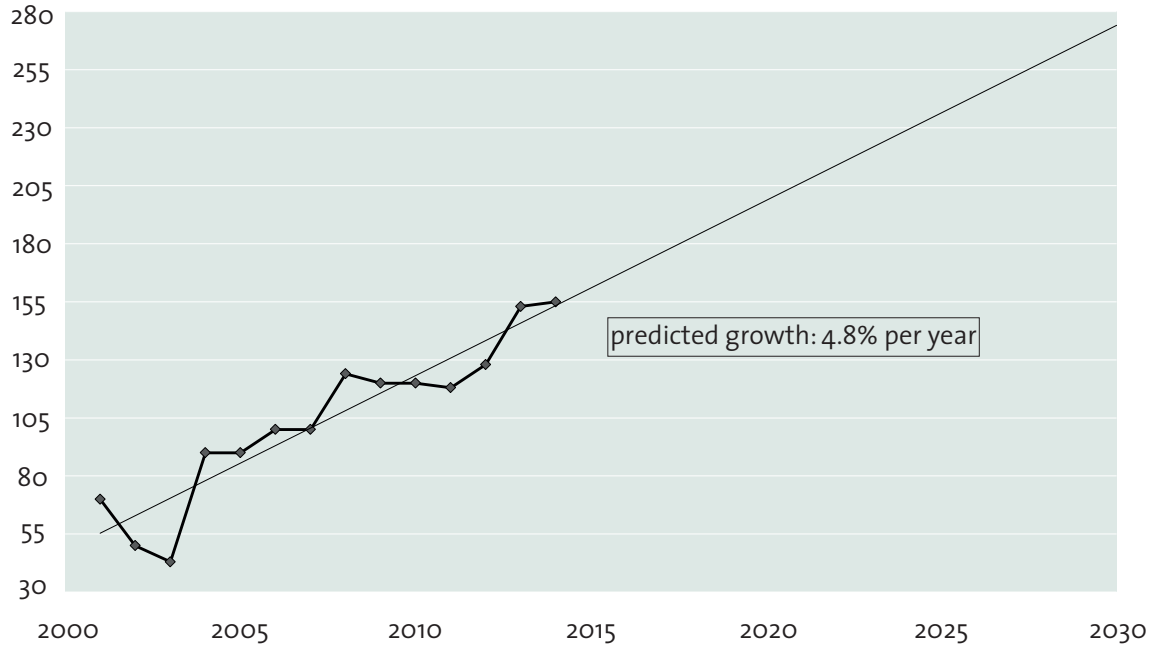
The global zinc mine and metal production, on the other hand, has decreased over the last years and leveled in 2013, which may result in a production to consumption deficit for germanium. Part of the gap can be filled by additional secondary material, especially recycled fiber optics. At the moment, the share of recycled germanium is about 30% of the annual production (Claeys and Simoen, 2011). In addition, other sources of germanium concentrate must be exploited.

2.2 Demand

According to a market study of Merchant Research & Consulting Ltd. (2014), the global demand of germanium will amount to 270 t per year in 2030. The values for the predicted germanium consumption are, however, highly diverse across different studies. The Fraunhofer Institute ISI brings up numbers of germanium consumption of 220 t to 520 t per year only limited to the fiberglass industry in 2030 (Angerer et al., 2009). Other sources like Elsner et al. (2010) estimate a composite demand of 290 t germanium per year in 2030.

The main field of application for germanium is fiber optics (40%) due to its high index of refraction and low optical dispersion (figure 2). Germanium is needed to change the optical properties inside the fiberglass. Moreover, germanium(IV)-oxide (GeO_2) is used as a polymerization catalyst (25%) during the synthesis of polyethylene terephthalate (PET), a commercially important plastic. The high brilliance of the produced polyester is particularly used in the Japanese PET bottle market. Because germanium is transparent in infrared light, it is also an important optical material, e.g. for night vision devices in cars or hot spot detection in military devices, accounting for 24% of the total germanium demand. The remaining 11% spread on

Figure 1 Trend analysis of the production of germanium for the period 2001-2030 (Erdmann et al., 2011; Merchant Research & Consulting Ltd., 2014).



semiconductors alloys, solar cells and miscellaneous usage (Erdmann et al., 2011; Europäische Kommission, 2014; Merchant Research & Consulting Ltd., 2014; Rangel et al., 2013; U.S. Geological Survey, 2000-2014). Overall, it can be said that germanium is critical in highly technical devices and processes, so that the demand is likely to remain high.

As with all strategic metals, the commercialization of sustainable resource technologies such as phytomining highly depends on the market price of germanium, which has been relatively volatile over the last decades (figure 3). The market is dominated by a few market players, with a global production volume of about 150 t per year. The price uncertainty is aggravated by the fact that germanium is to a large extent used in military applica-

Figure 2 Fields of application using germanium in 2013 (Merchant Research & Consulting Ltd., 2014).

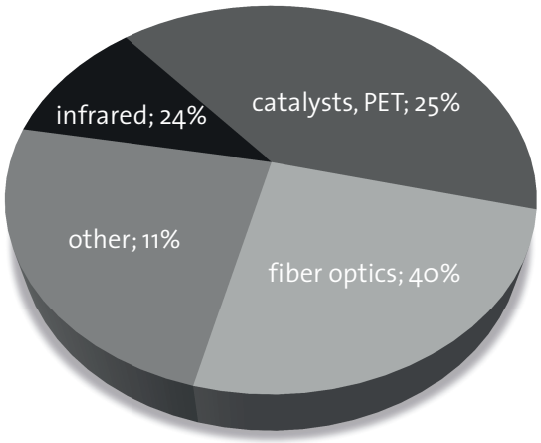
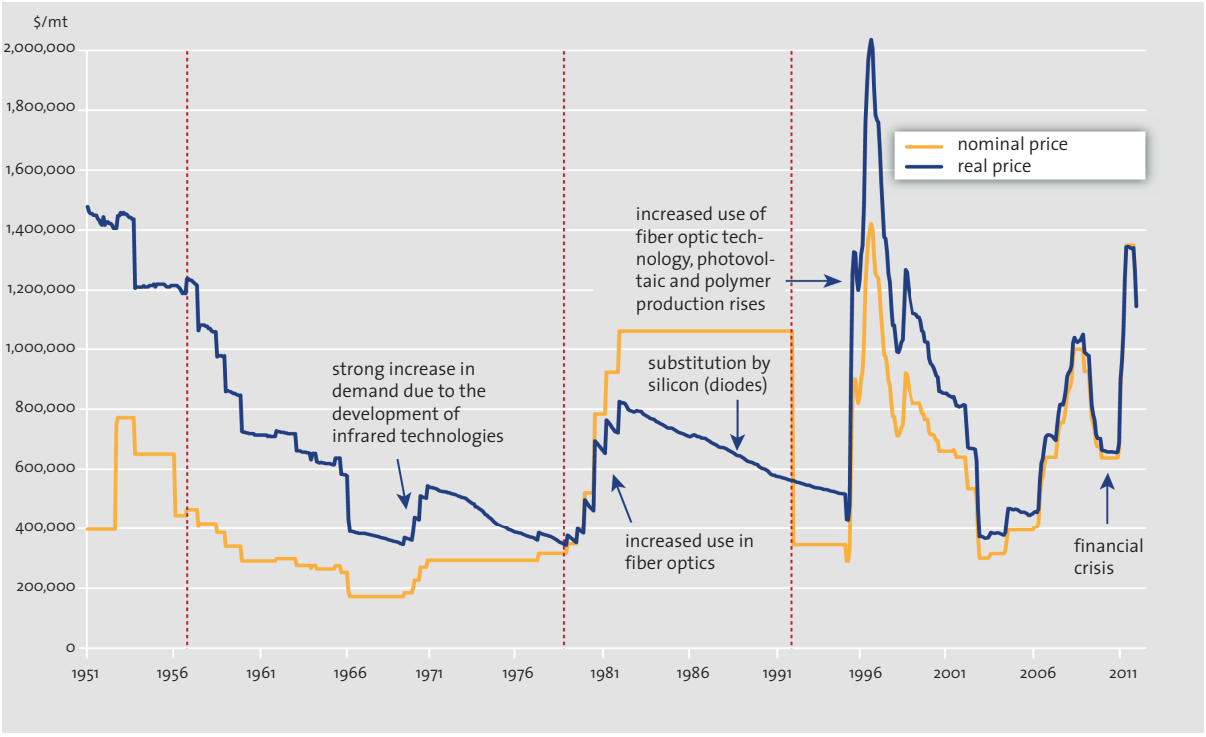


Figure 3 Germanium price development in the period 1950-2013 (Bräuninger, 2013).



tions. Hence, the U.S. and China State Reserve Bureau purchase significant amounts of germanium metal for their national stockpile on a regular basis (Bhal et al., 2013).

The erratic development of the germanium retail price is shown in figure 3. With the invention of infrared techniques in the early 1970's, the germanium metal price raised by 53% from 354,000 $/t to 540,000 $/t. Later, the price increased by another 47% up to 795,000 $/t in 1982 due to the invention of fiberglass and the usage in diodes and transistors. On top, germanium was used in the photovoltaic industry and for the chemical polymerization of PET in the period from 1985 to 1996. Overall, the fast growing demand could not be met, so that the market price climbed up to 2,039,000 $/t. Between 2000 and 2005, the price dropped by 78% to 466,000 $/t. In 2008, one ton of germanium had a price of 1,003,000 $. After the financial crisis, the price increased again by 220% from 580,000 $/t to 1,300,000 $/t, accompanying the global economic recovery (Guberman, 2015; Bräuninger, 2013).

3 Phytomining - Technology

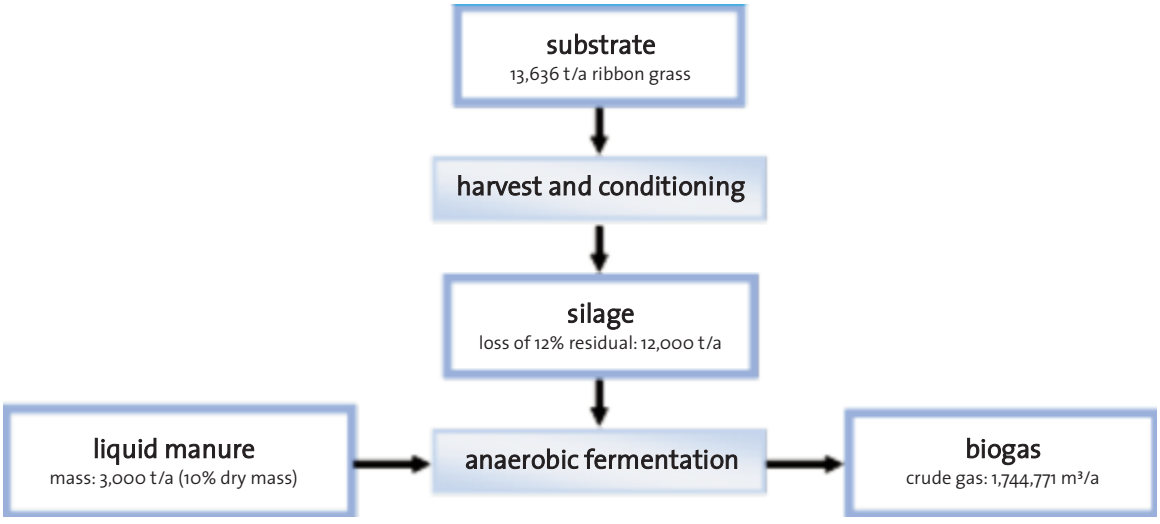
In general, phytomining refers to a process in which metallic substances in soils or sediments are absorbed by plants. Phytoextraction has been growing rapidly in popularity over the last twenty years due to its environmental friendliness. Within the PhytoGerm project, the goal is to find a plant species that concentrates germanium in aerial plant biomass, which grows well on poor soils and contaminated industrial sites. A particular suitable plant in this case, a so-called accumulator, is ribbon grass (lat. Phalaris arundinacea L.).

Ribbon grass is a persistent energy plant with a maximum height of 2.20 m, which grows on riverbanks and humid grassland, and thus on soils being humus-, clay-like or of sandy consistence (Ust'ak, 2012). Furthermore, the grass is frost and dry phase resistant. The accumulator grows well on prolific siliceous soil, providing advantages with regard to plant growth. The positive effect of silicon uptake is based on scaling up the leaf surface, thus improving light capture. Germanium and silicon largely share similar chemical properties, which is the reason why grasses incorporate the metalloid. Consequently, the concept is to make use of elevated germanium levels in soils, for instance, of tailings from zinc mining sites, and thus allowing the plants to accumulate sufficiently high amounts of germanium in order to achieve high yields during the extraction process (Heilmeier, 2010).

3.1 Process route

To analyze the economic pre-feasibility of phytomining germanium, several assumptions along the process have to be made. Figure 4 shows the investigated scenario starting with cultivating ribbon grass on germanium-rich soils, which is in turn the substrate for biogas generation. To ensure that a pilot plant for germanium extraction is sufficiently working to capacity, one will have to make use of the existing, decentralized biogas plant and mono incinerator infrastructure in Germany. In this study, we assume that 13,636 t ribbon grass per year are

Figure 4 Part 1 of the process flow diagram.

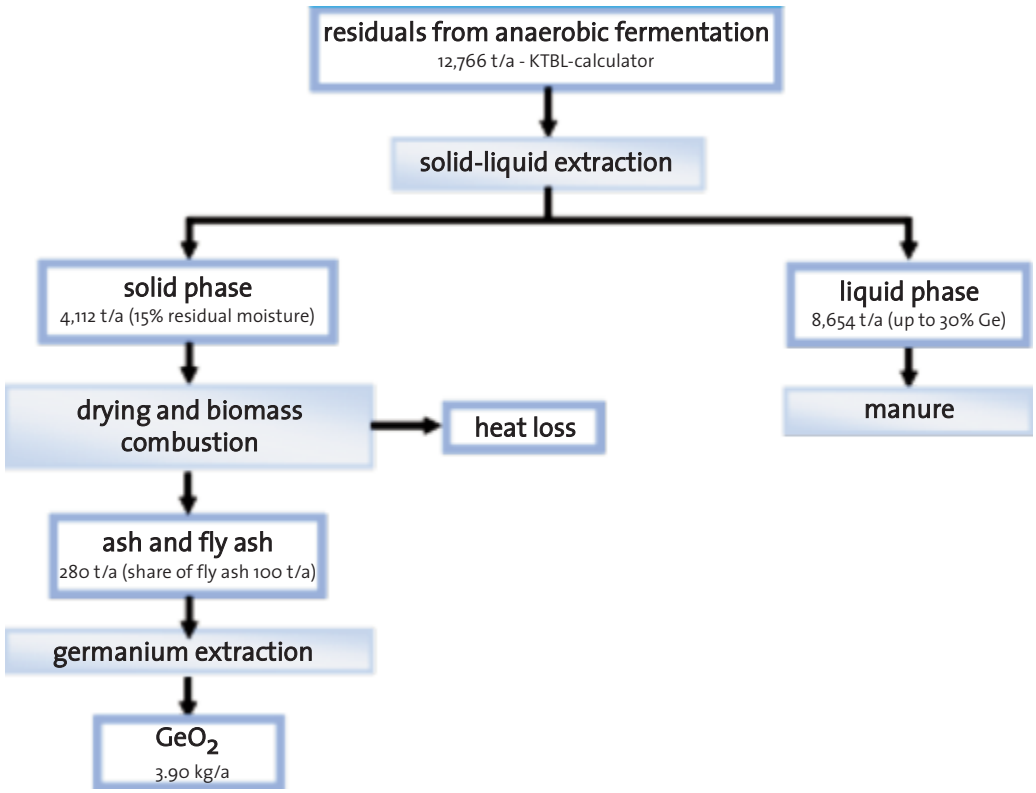


obtained from several cultivation areas, which is the amount needed to utilize an average 500KW biogas plant. In a next step, the aerial plant parts are harvested and the biomass is hackled and ensiled before it is used as raw material for further processing. During the ensiling process, acidophilic microorganisms convert glucose to lactic acid under anaerobic conditions. Ensiling causes a mass reduction of plant material by up to 12% (Heyland, 1996), whereby there is no loss of germanium detectable. In a digester, 12,000 t of the remaining biomass are mixed with 3,000 t liquid manure. The central anaerobic digestion process requires on average 60 to 70 days under constant temperature conditions between 35°C and 40°C, whereby the produced biogas can be used after purification in a gas scrubbing process (Krzack, 2013-2014).

The residual biomass needs to be separated trough solid-liquid separation, e.g. with a screw press (figure 5). After deposing the liquid phase, 4,112 t of biomass per year are available for germanium extraction. The liquid phase still contains a share of up to 30% germanium, which can be recycled through fertilizing cultivation areas with this liquid mixture. In the next cycle, the germanium will again be accumulated in ribbon grass plants. A germanium extraction of the liquid phase is economically and technically not suitable due to the high amount of liquid and its low germanium concentration. The solid biomass is at first dried and then thermally processed in a biomass power plant. The residuals of the combustion process are ashes and fly ashes, enriched with germanium, with an annual output of approximately 280 t. Studies related to the combustion process have shown that most of the germanium is accumulated within the fly ash. Bottom ashes only demonstrate a very small share of germanium. In a combustion process, the share of fly ash varies between 25% and 30% (Kröpl et al., 2013; Van Loo et al., 2012). To determine the cost-effectiveness of the process of germanium extraction, an annual volume of 100 t of pure fly ash, based on the capacity of one biogas plant, is assumed.

Typically, the soil concentration on mining dump areas varies between 3 ppm and 15 ppm (Melcher et al., 2014; Arroyo et al., 2009). Growth studies within the PhytoGerm project show a strong dependency of germanium accumulation in biomass on the germanium soil concentration and its mobility in soil, whereby certain organic acids can significantly enhance the mobility of the metal-

Figure 5 Part 2 of the process flow diagram.



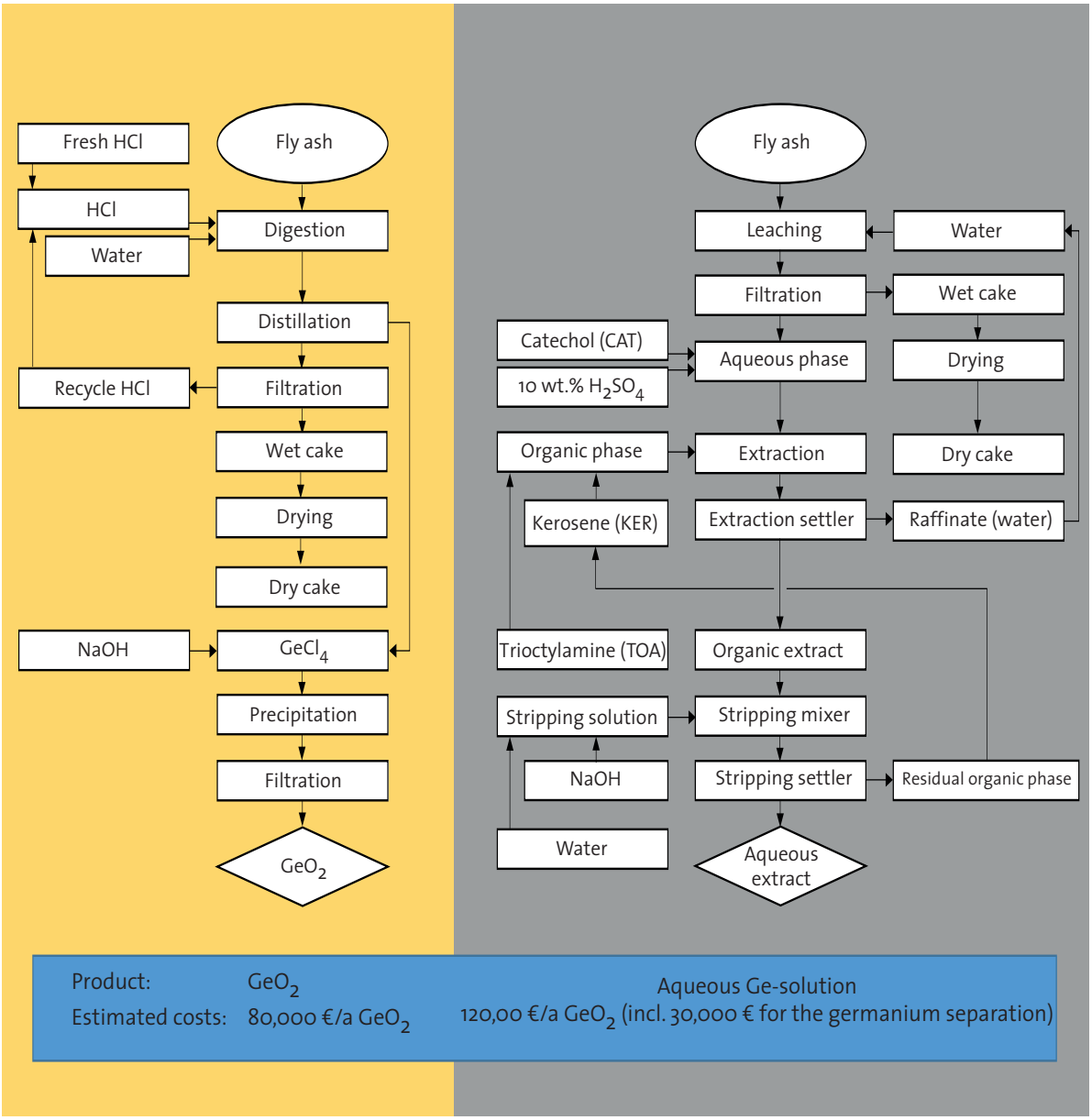
loid. Up to now, only 1 ppm of germanium can be accumulated in biomass due to the low mobility of germanium in the investigated soils within the project. The ribbon grass, however, is capable to accumulate much higher concentrations. The amount of germanium accumulated in the plants corresponds directly to the germanium content within the ash.

For the pre-feasibility study, two different processes for the germanium extraction step are investigated and subsequently introduced (figure 6): An established germanium extraction method of Arroyo et al. (2011) as well as an alternative method developed during the PhytoGerm project.

3.2 Germanium extraction process introduced by Arroyo et al. (2011)

Arroyo et al. (2011) describes a solvent extraction method for recovering germanium from coal fly ashes. The process is based on numerous steps

Figure 6 Comparison of the processes developed within the PhytoGerm project (left) and by Arroyo et al. (2011; right).



beginning with the leaching of fly ash with water. The impurities are then removed by filtration and the leachate is mixed with catechol and sulfuric acid for complexation. In the following step, the aqueous phase is extracted with an organic phase of trioctylamine and kerosene in a mixer-settler system. The organic phase is then treated with a stripping solution containing sodium hydroxide. Parts of the raffinate and the residual organic phase can be reused in the process (Arroyo et al., 2011).

3.3 Germanium extraction process developed by PhytoGerm

Within the PhytoGerm project, a germanium extraction process based on the combination of leaching and distilling germanium with hydrochloric acid was developed. At the initial stage, fly ash is mixed with a hydrochloric acid (HCl) solution and germanium is extracted in the form of germanium tetrachloride ($GeCl_4$) by distillation. Due to a solid liquid separation step, HCl can be recycled and the molarity of the solution is adjusted by a complementary feed of fresh HCl. $GeCl_4$ is injected in a second reactor with a sodium hydroxide solution for the precipitation of germanium(IV)-oxide, which is subsequently separated by filtration.

By comparing the two methods of PhytoGerm and Arroyo, it can be recognized that the PhytoGerm process requires less process steps. In addition, the Arroyo protocol ends with an aqueous germanium solution instead of isolated germanium(IV)-oxide. Moreover, the germanium extraction according to the PhytoGerm method has advantages regarding a scale-up due to less operation steps and simpler reactor systems.

The investigated process route ends with producing powdery germanium(IV)-oxide. Based on the previously stated assumptions, 3.9 kg of germanium(IV)-oxide can be obtained in total each year. If required, the oxide can be further reduced to germanium metal powder in ultra-clean graphite boats at 760 °C (Melcher et al., 2014). Finally, for producing metal bars, the powder has to be melted at 1,100 °C (Melcher et al., 2014).

4 Economic pre-feasibility of the PhytoGerm process – A case study

The PhytoGerm process can be considered as an add-on investment to the existing biogas plant and incinerator infrastructure in Germany. In the following section, the capital and operational expenditures as well as the yields of the investigated phytomining processes are assessed. The data for the PhytoGerm and Arroyo process are analyzed by conducting net present value calculations.

4.1 Economic analysis for the biogas plant

For processing 13,636 t of ribbon grass, one medium-sized biogas plant with a power of 500 kWel is necessary. We assume that the biogas plant is already in place and running, so that no additional investments are required. For the generated biogas income, we use the KTBL calculator from the German "Association for Technology and Structures in Agriculture". The KTBL calculator is a tool for planning and scaling biogas plants, so that users can select from a large number of parameters such as the type of applied biomass. Because of the high comparability with ribbon grass, and the fact that ribbon grass is not included in the KTBL-tool, values for Sudan grass are used. Overall, a biogas plant generates a revenue of about 734,523 € per year. This revenue covers the operational costs of the biogas plant of 513,928 € per year as well as the profit expectations of the owners.

To stimulate additional investments in phytomining, supplementary profits must be generated with the extraction of germanium. The same argument applies to a mono incinerator burning the dry mass, whereby an investment of approximately 4.24 mn € would be necessary for building a new furnace.

4.2 Cost analysis for the germanium extraction process

The investment and operating costs of the Arroyo and PhytoGerm process are shown in tables 1-3. The Arroyo process ends with a liquid extract, so that the germanium must still be separated from the liquid phase. Therefore, cetyltrimethylammonium bromide (CTAB) is used. The additional costs for the separation of germanium may vary and are almost completely levied. The PhytoGerm process ends with the target product GeO_2, so that no additional costs for chemicals or equipment are needed.

In order to make the process routes of PhytoGerm and Arroyo comparable, plants are scaled to an annual volume of 100 t. This corresponds to the annual amount of fly ash, which can be obtained from the biomass processed in one biogas plant. Table 1 compares the investments for the plant technology of the PhytoGerm process with an amount of 467,800 € and the expenses for the required equipment for the Arroyo process yielding a total of 674,000 €.

Based on required systems and equipment, the PhytoGerm process is much more compact because it only requires glass reactors with distillation equipment and a filter system. The infrastructure of the Arroyo process consists of different reactors and a

mixer-settler system mainly made of stainless steel.

In addition to the investments, operating expenditures contribute significantly to the efficiency of a process. Tables 2 and 3 show the operating costs for the processes according to PhytoGerm and Arroyo, respectively. Note that both processes require larger amounts of water and chemicals. Yet, parts of water and kerosene as well as hydrochloric acid can be returned to the leaching and extraction steps, therefore, only small amounts of fresh reagents must be added to the processes.

Overall, both processes are characterized by a number of necessary chemicals for germanium extraction such as petroleum, catechol, sulfuric acid, hydrochloric acid etc., causing high running costs. Furthermore, 500,000 l of water per year are needed, which have to be treated by using filters to keep the water in a closed system. The operating costs are highly dependent on the raw material costs. Figure 6 illustrates that the PhytoGerm

Table 1 Capital expenditures for the PhytoGerm and the Arroyo process infrastructure.

Apparatus	Total price* [€]	
	PhytoGerm	Arroyo
Plant for the extraction of Ge	100 t/a	
Glass reactor with distillation	412,800	-
Filtration apparatus	55,000	-
Leaching reactor	-	70,000
Filtration apparatus	-	55,000
Mixer (extraction)	-	108,000
Settler (extraction)	-	45,000
Mixer (stripping)	-	90,000
Settler (stripping)	-	54,000
Ancillary units (stripping)	-	90,000
Pumps (stripping)	-	36,000
Storage basin (stripping)	-	126,000
∑ Capital expenditures	467,800	674,000

* the presented cost values are net values.

Table 2 Operating expenditures within the PhytoGerm process.

Apparatus	Quantity	Price	Costs per year	Incl. cycle savings
Fly ash	100 t/a			
Water	500,000 l/a	0.0019 €/l	925 €	925 €
HCl (recycled share of 90%)	499,989 l/a	180 €/t	105,880 €	10,588 €
NaOH	10 t/a	700 €/t	7,000 €	7,000 €
Maintenance salaries	1,000 h/a	10 €/h	10,000 €	10,000 €
Wages	4,000 h/a	13.3 €/h	53,200 €	53,200 €
∑ Operating costs				**81,713 €**

Table 3 Operating expenditures within the Arroyo process.

Apparatus	Quantity	Price	Costs per year	Incl. cycle savings
Fly ash	100 t/a			
Water	502,500 l/a	0.00185 €/l	929 €	232 €
Catechol	320 kg/a	40 €/kg	12,800 €	12,800 €
H_2SO_4 (10%)	2,400 l/a	0.04 €/l	96 €	96 €
NaOH	751 kg/a	700 €/t	525 €	525 €
Petroleum	90,000 l/a	0.45 €/l	40,500 €	8,100 €
Trioctylamine	820 l/a	5 €/l	4,100 €	4,100 €
Maintenance salaries	1,000 h/a	10 €/h	10,000 €	10,000 €
Wages	4,000 h/a	13.3 €/h	53,200 €	53,200 €
Additional expenses			30,000 €	30,000 €
∑ Operating costs				**119,053 €**

Table 4 Comparison of the costs and revenues of the PhytoGerm and Arroyo process.

Item	PhytoGerm process [€/a]	Arroyo process [€/a]
Capital expenditures	467,800	674,000
Operating costs	81,713	119,053
Sales Revenue	5,121	5,121

process ends with filtering GeO2, while the Arroyo method produces an aqueous extract with germanium. Arroyo et al. showed that the precipitation of germanium out of the aqueous solution is not trivial due to the required pH-level as well as the remaining dissolved organic compounds from the extraction process. They stated that without any adjustments only up to 6% of the germanium can be precipitated using CTAB. Hence, the removal of germanium from the aqueous extract is only possible by introducing further process steps such as pH-regulation, filtration and removing the organic precipitation by burning of the filtration product. Therefore, add-on-costs of about 35% of the operation expenditures for chemicals, wages and other have to be considered.

Hence, in order to produce the same amount of germanium(IV)-oxide, an estimated cost difference of 30% has to be expected when comparing the PhytoGerm or the Arroyo process. These additional expenses are already included in the calculation of the operating costs. The comparison shows that the PhytoGerm approach also provides a significant advantage in terms of capital expenditures for the infrastructure and system technology of 206,200 € to process 100 t of fly ash per year.

4.3 Yields

In total, 3.9 kg of germanium(IV)-oxide can be extracted each year with the described phytomining process. The sales of germanium(IV)-oxide at a retail price of 1,313 € per kg sum up to 5,121 € per year. Table 4 summarizes the costs and revenue structure for both considered extraction methods.

Obviously, in such a setting with a discount rate of 12% and an expected plant operating time of 12 years, the net present value of both processes is highly negative. The net present value of the PhytoGerm and the Arroyo plant would amount to -942,000 € and -1,380,000 €, respectively.

The future market price as well as the expect-

ed yield are two main leverage factors for the operational efficiency. If these factors change in the right proportion, both plants could produce economically. Figures 7 and 8 show the expected cash flows to depend on the market price and the concentration of germanium that a plant is able to accumulate, whereby the Pa*-value reflects the actual price per kilogram of germanium(IV)-oxide in 2014. Accordingly, if the current retail price doubles - reaching the level of 1996 - and 10 ppm of germanium could be absorbed, a positive cash flow for the PhytoGerm process could be generated for the first time. Yet, the expected revenues would not cover the capital expenditures and the risk of the investment. Only if the market price of germanium triples and a concentration of at least 15 ppm is achieved, a sufficient cash flow and hence positive net present value can be realized. Such high market prices are only realistic if the fiberglass industry expands dramatically over the next 20 years and no substitute for germanium is found. Due to the lower capital and operational expenses, the

Figure 7 PhytoGerm process - Cash flow depending on yield and trading price.

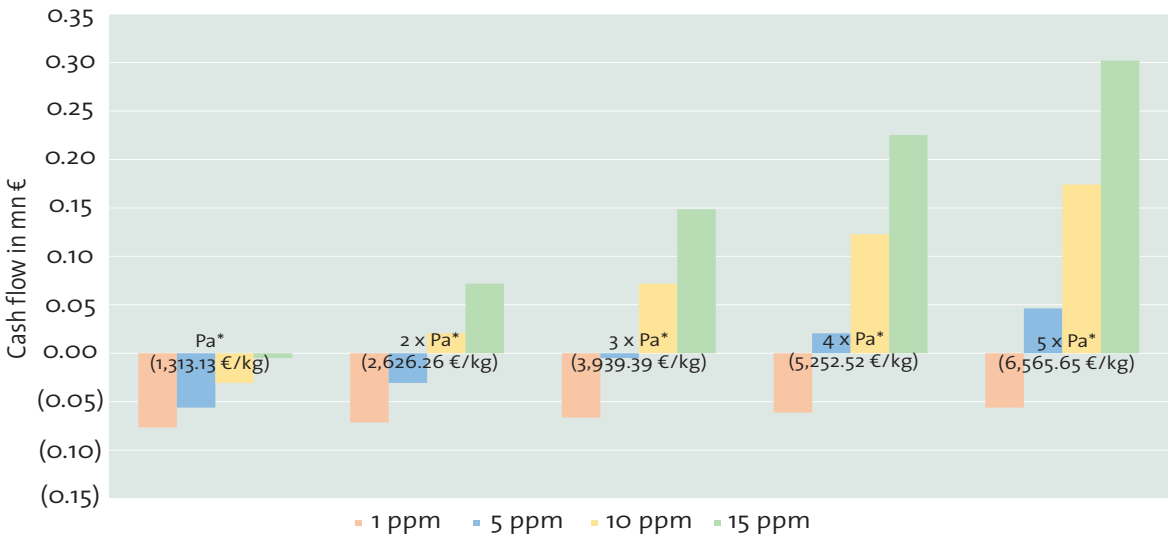
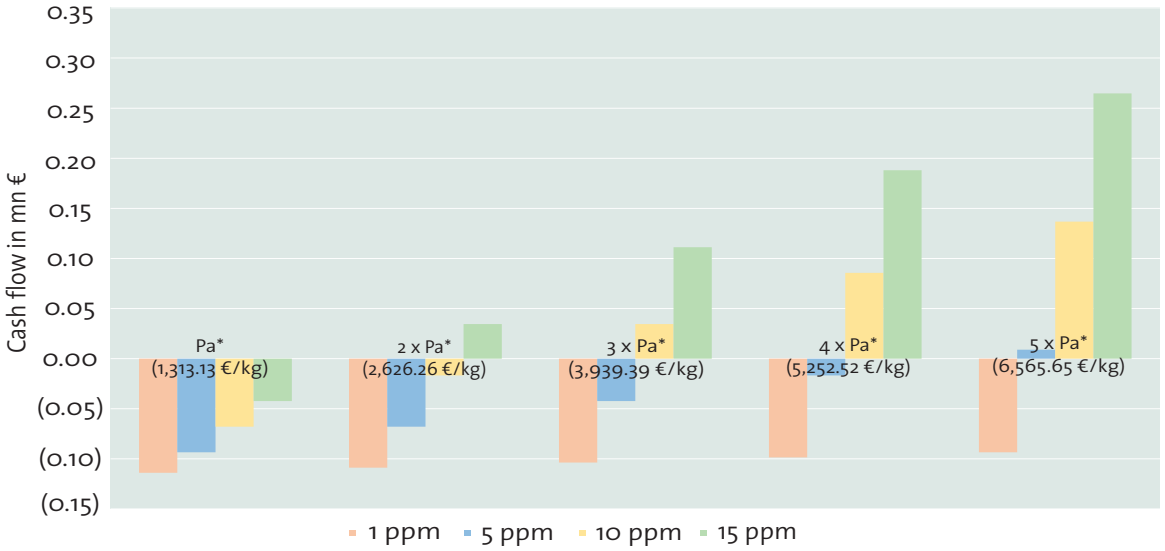


Figure 8 Arroyo process - Cash flow depending on yield and trading price.



PhytoGerm process provides the advantage that it reaches a positive net present value in just four years - assuming a germanium price of 3*Pa and a 15 ppm-concentration - and hence, it involves a considerable lower financial risk than the Arroyo process, which has a pay-off period of approximately eleven years. Further, Arroyo's method provides an internal rate of return (IRR) of 12.5%, while the IRR of the PhytoGerm process amounts to 30.5% due to the significant lower capital expenditures.

5 Conclusion

Although the PhytoGerm process presents an environmentally friendly approach to "harvest" germanium, the current market price and accumulation rate of the metalloid in plants do so far not justify add-on investments to the existing biogas plant infrastructure. Especially the last step of the value chain, i.e. the germanium extraction from fly ash, makes the process route unprofitable due to its high operational expenses. Nevertheless, germanium remains a strategic metal that is critical not only for military applications but also for several other highly technical devices and processes, so that the demand is likely to rise considerably. In order to improve the operational efficiency of the PhytoGerm process, the accumulation rates of germanium within the ribbon grass need to be intensified by methods increasing the germanium mobilization in soils. Thus far, the relatively high running costs of the germanium solvent extraction from fly ash remain the key obstacle implementing the described process route. In this paper, the two extraction approaches introduced by the PhytoGerm project and by Arroyo et al. (2011) have been investigated. From a financial point of view, the PhytoGerm method is found to be the preferred process route because it provides a higher return as soon as the market price (3xPa*) and yield (15 ppm) reach levels at which it is economically feasible to extract germanium from fly ash. Future research could e.g. focus on methods for refining germanium and other elements of the biomass. In addition, extracting further valuable substances, for example, phosphate, which is part of the bio-based ashes, has not been taken into account in this study. The co-extraction of different products might have positive effects on the economic feasibility of the PhytoGerm process, which thus has to be addressed in the further process development and studies in order to enhance the phytomining concept.

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