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Aluminum Production Costs: A Comparative Case Study of Production Strategy

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Abstract

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MSc, Yaoundé University, 2004

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Doctoral Study Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Business Administration

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Abstract

Slumping world aluminum prices have energized some aluminum producers to institute strategies to reduce product costs. This multiple comparative case study explored the strategies used by 4 aluminum producers in Western Europe: 2 companies that have successfully reduced production costs and 2 companies that have not. Wicksteed's economic theory of production and production costs was the conceptual framework for this research. Data from the companies' strategic and industry reports and from interviews with 32 senior managers were analyzed using pattern finding and clustering, a recursive approach to data gathering and analysis established by Miles, Huberman, and Saldana. Six themes emerged: (a) upstream integration, (b) energy and price efficiency, (c) carbon-manufacturing capability, (d) operational excellence and productivity, (e) technological and research developmental abilities, and (f) circular economy. The analysis of these themes indicated that the most significant opportunities for productivity improvement include (a) minimizing energy and material use, specifically alumina, cathodes, and carbon, (b) vertically integrating alumina production, (c) developing an efficient circular economic model that integrates the material properties to expand the recyclability of waste, and (d) increasing the electrolytic cell life cycle. Overall, vertical integration provides a competitive advantage and gives the producer ability to control costs. In-house carbon manufacturing capacity reduces a smelter's operating cost. Technological capabilities can minimize energy and material consumption rates. Increased productivity and reduced energy and material use can yield positive social changes, such as the preservation of natural resources, reduced emissions, and waste.

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Dedication

With God, emptiness shall be unthinkable! You have been my greatest inspiration. I dedicate this doctoral completion study to the devotedness and love of my wife, Monique, who has endured by me in affection in our union and beautiful family. Your endurance has been incomparable throughout this educational journey. You stood awake, as I did for four years; your support and belief in my ability provided me the additional strength to accomplish this remarkable achievement. My mother, Mrs. Cesarine Nloga: when I look at your face and think about your faith and trust, I am invigorated; as such, I can even withstand the strongest hurricane ever confronted by a human subject. My children—Maxime Ndejaby, Jonas Ndjebayi, Armel Ndjebayi, Honorine Ndjebayi, and Larissa Ndjebayi—each one of you, unknowingly but consciously, had a particular strategy to support me. Even in the turbulent times, you were a great stimulant to my creativity. I will be infinitely appreciative for the encouragement and patience you have granted towards the completion of this doctoral research.

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Section 1: Foundation of the Study

Since the 2008 world financial crisis, many aluminum producers have been challenged by decreased profitability, a slump in company valuations, and downswings in aluminum prices (Kvande & Drabløs, 2014; World Bank, 2013). Researchers have attempted to determine the factors that contributed to these price slumps. Factors considered have included decreasing aluminum market demand and high aluminum outputs from China (Behmiri & Manera, 2015; Blomberg & Söderholm, 2011; Radetzki, 2013). Price slumps have had a significant impact on the viability of higher cost aluminum production companies (World Bank, 2013). Reduced profitability in aluminum production has affected the return on investment some shareholders expected and the ability of some businesses to remain competitive (Blomberg & Söderholm, 2011). Given the continued profitability challenges that aluminum producers confront, reducing costs is becoming crucial to staying competitive (Behmiri & Manera, 2015; European Commission, 2013; Ping, Tang, Yao, & Chen, 2013).

The European Commission (2013) found that aluminum production costs differ from one producer to another. Additionally, World Bank (2013) found that low-cost benchmarks exist within the aluminum production sector. Dissimilarities in companies' production costs provided the motivational basis for the development of this case study.

Background of the Problem

In the European Union (EU), the primary aluminum industry represents a component of production output (Blomberg & Söderholm, 2011; Götz, 2014). Most aluminum producers must confront a changing competitive environment, including monetary policies, accelerated technological changes, and a concentrated stream of aluminum supply from China (Bianxia, Sharon, & Zesheng, 2013). Aluminum producers based in Western European are experiencing lower profitability in their production processes (European Commission, 2013; World Bank, 2013). Although worldwide aluminum demand and production have risen in the last decade, Götz, (2014) found that European-aluminum production output has declined by over 30% through plant shutdowns and production curtailments between 2007 and 2012. Aluminum production is a resource-intensive industry that requires profits to sustain business competition (Blomberg & Söderholm, 2011; Hao, Geng, & Hang, 2016; Wei-Qiang & Lei Shi, 2012).

Bianxia et al. (2013), Kvande and Drabløs (2014), and Wei-Qiang and Lei Shi (2012) have studied the profitability of aluminum producers to determine the contributing factors leading to the price slump. Bianxia et al. found that China's production output increased from 12% to 40% between 2000 and 2010, an increase that affected the equilibrium of the market's supply and demand of the raw material and aluminum commodity. Kvande and Drabløs found that raw material and energy constitute the main elements of aluminum production costs in Europe. Wei-Qiang and Lei Shi discussed how aluminum production is a resource-intensive industry that requires profits for the viability of production plants.

A limited body of literature is available about the pattern of internal cost drivers for aluminum production (Blomberg & Söderholm, 2011) and related production strategies. These drivers of production costs are found throughout the aluminum production sector. The purpose of this qualitative, multiple comparative case study was to identify the strategies some aluminum producers might implement to reduce production costs.

Problem Statement

The market prices of the primary aluminum commodity influence an aluminum producer's revenue and profitability (Behmiri & Manera, 2015). Aluminum commodity prices fell by 24% from January 2008 through January 2012, and the prices remained below marginal production costs for many producers because of persistent global aluminum outputs that continued to surpass demand (World Bank, 2013). The general business problem was that some aluminum producers experienced declining profitability because of decreasing aluminum sale prices and adverse production costs (World Bank, 2013). The specific business problem was that some aluminum producers lacked the strategies to reduce production costs.

Purpose Statement

The purpose of this qualitative, multiple comparative case study was to explore the strategies that some aluminum producers might implement to reduce production costs. The targeted population included aluminum production senior managers in Western Europe. I studied a purposeful sample of four companies to compare production strategies: two companies that were achieving sustained production costs and two that were not. I interviewed a purposeful sample of experienced senior production managers and analyzed documents to identify core themes and concepts that producers may develop into strategies to reduce production costs.

This research has implications for positive change because the findings may help companies increase their business sustainability and job security, domestically and internationally, as well as in the industrial sectors that rely on aluminum within their supply chains. Companies may also use the study findings to optimize their use of resources and energy and to contribute to environmental protection. According to the European Commission (2013), aluminum production is essential to maintaining a continuous supply of semifinished products to small- and medium-sized enterprises downstream. High-cost producers may put business sustainability and job security at risk in the local community.

Nature of the Study

Justifying the Use of the Qualitative Methods

The goal of the qualitative method is to explore insights and practices from the participant perspectives (Yilmaz, 2013) and a researcher's observations (Merriam, 2014). Pearson, Albon, and Hubball (2015) recommended that a researcher use a methodology relevant to the context of the problem under study as well as the research goals. The qualitative methodology is rooted in both the constructivist and interpretive epistemologies (Corbin & Strauss, 2014; Gläser & Laudel, 2013; Guba & Lincoln, 1994; Merriam, 2014). Researchers using the epistemological approaches to constructivism and interpretivism believe that events facing organizations are dynamic and contextually dependent (Merriam, 2014) and that the causal relationships between events are dynamic. I applied the qualitative methodology in this case study because I aimed to collect data by interviewing experienced senior managers to obtain insights and information power on the strategies that might reduce production costs.

Klein and Myers (1999) recognized that organizations are not static systems; as such, the relationships between human actions, technological capabilities, and company strategies and performances also change. Complex systems, such as aluminum production, may draw from constructivist and interpretive epistemologies to understand the driving forces underpinning production cost minimization. Because a quantitative analysis may fail to provide reliance in finding reality in a complex environment, interpretive practices were appropriate to provide an understanding of the differences between strategies companies use to reduce production costs. The importance of finding contextually related business solutions and the ability to adapt solutions to new realities aligns with the epistemological stance supported by the constructivist approach; hence, the qualitative method was appropriate for this research.

Competing Methods to Qualitative

A scholar uses the quantitative methodology to evaluate quantifiable measures of variables, test a hypothesis or a theory under a single reality (Yilmaz, 2013), or assess an intervention (Pearson et al., 2015) through a representative sample selected from a given population. A researcher uses random sampling logic in the quantitative method to generalize findings (Yilmaz, 2013). In this qualitative study, the objective was not to generalize findings beyond the business context given the contextual and unique characteristics of each case (Merriam, 2014; Morse & McEvoy, 2014). Given the purposive nature of this research, the use of a random-sampling method could have contradicted the selection of (a) qualified senior managers to answer the interview questions and (b) two categories of companies exhibiting different production-cost performance.

Positivism underlies quantitative methods (Venkatesh, Brown, & Bala, 2013). Positivist researchers have stated that a researcher can predict the future of events by assuming that patterns observed in the past will replicate in the future (Klein & Myers, 1999). Klein and Myers (1999) also mentioned that a researcher examining the relationship between factors assumes the existence of a priori fixed associations between events and outcomes. In the case under study, the forces driving the production costs were also contextually dependent; hence, the qualitative method allowed the data gathering while considering both the contextual and global cost drivers.

Mixed-methods research is a combination of qualitative and quantitative methods. A researcher uses the mixed method to investigate multiple viewpoints derived from both the qualitative and quantitative methods (Caruth, 2013). However, given the methodological difference between positivism and constructivism (Birchall, Murphy, & Milne, 2016), the use of mixed methods could have introduced a contradiction to my sampling strategy, a situation that could have jeopardized the consistency. For example, the purposive sample of qualified senior managers was essential for providing information power to answer the RQ. Similarly, the purposive samples of companies exhibiting lower production costs and those facing higher production costs were critical for the comparison.

Selecting the Research Design

A comparative case study was my choice of research design for exploring the strategies that some aluminum companies might implement to reduce production costs. A researcher can use the case study design to add to the existing body of knowledge for organizational performance (Merriam, 2014) and to describe complex events (Baškarada, 2014). A researcher may use the case study design to gather in-depth, purposive data to strengthen understanding of the problem (Yin, 2012). Stake (1995) argued that case studies may be suitable for contextual analyses that are established based on multiple sources of data.

As a company's context is often part of the business model, various intervening and causal conditions might overlap. I used two sources of data, including interviews and document analysis, to apply data triangulation for producing consistency and reducing potential biases, as recommended by Denzin (2012). Klein and Myers (1999) described principles for interpretive research such as case studies: (a) the contextualization of the analysis to the cultural and economic reality of the problem, (b) the principle of interaction between the researcher and the participants, (c) dialogical reasoning, (d) multiple interpretations, and (e) sensitivity to possible biases. In this study, interacting with aluminum production managers required understanding the context of aluminum production. The principle of contextualization implied investigating aluminum-production strategies in the companies' cultural, economic, and technological settings. Multiple interpretations necessitated the sensitivity to possible rival explanations (i.e., by comparing input efficiency to the theoretical baseline).

Several arguments motivated the decision to use the case study design in this study. First, I collected data with attention to the context of the case. Second, case study researchers can draw information from multiple sources and use data or method triangulation as a way of increasing the credibility of the findings (Denzin, 2012; Fielding, 2012; Hyett, Kenny, & Dickson-Swift, 2014; Pearson et al., 2015) and the sensitivity to rival explanations. The use of multiple data sources in production systems is essential for enhancing the quality of decisions that address industrial problems. Third, increased production costs in the aluminum production field was a contemporary industrial problem (Behmiri & Manera, 2015) requiring reflection on contextual factors such as facilities, competencies, and other capabilities that might impact production costs.

Addressing Alternative Qualitative Designs

Alternative designs to case study include grounded theory, ethnography, narrative, and phenomenology. Grounded theory is a systematic approach used to develop a new theory that arises from data gathering (Compton & Barrett, 2016). This study was applied research, and, as such, theory building was not its purpose. A researcher uses the phenomenological design to yield an understanding of a social phenomenon based on the participants' lived experiences (Blom, Gustavsson, & Sundler, 2013; Olausson, Lindahl, & Ekebergh, 2013; Sáenz, Bukoski, & Rodriguez, 2013). Investigating aluminum-production strategies to reduce production costs was neither a social phenomenon nor a meaning-making analysis. Therefore, the phenomenological design was not appropriate for use in this study.

Higginbottom, Pillay, and Boadu (2013) defined ethnography as a social science of communities, cultures, social interactions, and perceptions. An ethnographic design enables researchers to study a community and the cultural patterns that are widespread within the community (Higginbottom et al., 2013). I planned the current investigation of strategies to reduce production costs to go beyond cultural aspects and the analysis of social interactions; hence, an ethnographic design could not have provided a decisive advantage in this study because the purpose was to find solutions to industrial problems.

Baškarada (2014) and Potter (2013) characterized narrative design as being a primary method of analyzing and learning about social phenomena. Narrative design is a form of qualitative analysis associated with the theory of representation, and it can be used to explore social cognition (Lucic, Daiute, & Khan, 2015) or to portray how people derive meaning from events (Robert & Shenhav, 2014). The narrative design focuses on the structure of human knowledge (Robert & Shenhav, 2014) rather than on gathering and processing data for discovering solutions to address technical problems. Thus, the narrative design was inappropriate for use in this research.

Addressing the Typologies of Case Study

Stake (1995) identified the fundamental or intrinsic case study and the instrumental case study. The intrinsic case study is appropriate for understanding a unique case that might be longitudinal, critical, or revelatory (Yin, 2012, 2013). I selected the instrumental case study to investigate many cases with the potential to yield literal and theoretical replication (Yin, 2012). The instrumental case study design allowed gathering data from four companies and multiple sources, which might contribute a compelling understanding of the problem (Yazan, 2015) of production costs.

Because the companies selected for the study exhibited distinct production cost performance (European Commission, 2013), the multiple comparative design provided an advantage as opposed to the single case study design. The multiple comparative case study design allowed the yielding of comparable conclusions (literal replication) and discrete findings (logical replication; Yin, 2012). Literal and theoretical replications were essential paradigms for discerning strategies and concepts that affect aluminum production costs within and beyond contexts.

Research Question

Forming an appropriate RQ is fundamental to frame an inquiry and to provide adequate solutions to the problem under study (Neri de Souza, Neri, & Costa, 2016; White, 2013). The central RQ of this qualitative multiple comparative case study was the following: What strategies might aluminum managers implement to reduce production costs? The following served as a subquestion: How can a manager develop core capabilities in production units to decrease production costs? In this study, the production strategy is a set of patterned decisions that take into account stakeholders' requirements and all production factors available including operational capabilities, technology, and the raw material accessibility to yield an optimal set of changes needed to produce aluminum at an economical cost.

Interview Questions

The purpose of data collection from interviews was to provide a framework for data analysis that I could employ to identify the strategies that aluminum companies might implement to reduce production costs. Scholars have defined profit margins as follows: net profit (USD) = sales revenue (USD) - total costs (USD). Therefore, two relevant, actionable components comprise net profit: (a) sales revenue and (b) total costs (Lohri, Camenzind, & Zurbrügg, 2014; Novy-Marx, 2013).

The manager evaluates the performance of his or her production function by the way it adds to the corporate net profit, mainly by optimizing resources use. The questions outlined below served as the interview framework.

1. What are the resources of production necessary for reducing production costs?
2. How do you use the resources of production to reduce production costs?
3. What strategy of production related to production costs does your company use to minimize resource use?
4. What strategy does your company use to maximize the production output while reducing the use of resources?
5. In line with production cost minimization, by what measurement do you consider that you have reached the maximum limit attainable for resource use?
6. In line with production cost minimization, what strategy does your company use to allocate resources?
7. What material management strategy does your business use to reduce production costs?

8. What are your purchasing and procurement strategies to reduce production costs?
9. What level of technology do you use to minimize production costs?
10. What level of process engineering does your company use to reduce production costs?
11. What other production capability do you use to help your business reduce its production costs?

Theoretical Framework

The economic theory of production and production costs originates from work conducted by Wicksteed (1894), the first economist to establish the function of production in mathematical terms. The economic theory of production is the study of production focusing on converting inputs into outputs through a production function while measuring the production costs (Cobb & Douglas, 1928). The production function describes the outputs (Fx) that a company might obtain by applying inputs into production. Scholars mathematically establish the function of production in the form Fx = F (f1, f2 … fn), where Fx is a productive function and f1, f2,…, and fn are productive factors (Cobb & Douglas, 1928).

Wicksteed (1894) used the economic theory of production to identify productive factors in a production system and described how variable resources of a production system could influence production costs. Cobb and Douglas (1928) extended Wicksteed’s work and suggested that a company can adjust resources of production to improve performance. A company can develop the capabilities required to yield an efficient production system that allows minimizing production costs in the long-term.

Nevertheless, Cobb and Douglas did not consider soft capabilities—such as quality, skills, innovation, and manufacturing flexibility—as inputs that could minimize inputs and maximize outputs.

Operational Definitions

Benchmarking strategy: Hua and Lee (2014) described benchmarking as an efficient market-based learning process that uses best practice identification and its replication to a business of interest. Benchmarking is an approach by which a company identifies potential gaps between the current business performance and the desired objective to improve performance.

Data envelopment analysis (DEA): DEA is an analytical research instrument used in operational research to estimate and rank the efficiency of various decision-making units when the production process exhibits many inputs and outputs (Olesen & Petersen, 2016). Using DEA, a researcher can analyze items such as allocative and economic efficiency of decision-making units by providing adequate resources employed in a production system (Amini, Kazemi, & Marzban, 2015; Aristovnik, Seljak, & Mencinger, 2013, 2014).

Primary aluminum: Primary aluminum is a semifinished product obtained from the reduction of metallurgical aluminum oxide (alumina) through an electrolytic process (Sverdrupa, Ragnarsdottirb, & Kocac, 2015).

Production costs: Numerous definitions of production costs exist in the literature; for instance, Miltenburg (2005) defined production costs as the total expenses to the production line to acquire and convert inputs into outputs. Govindan, Khodaverdi, and

Jafarian (2013) described production costs as the final price of a product. In this definition, elements of the final price include purchasing costs, processing costs, maintenance costs, and warranty costs (Govindan et al., 2013). The European Commission (2013) identified elements of production expenses in the production of primary aluminum as comprising costs for raw materials, electricity, and conversion.

In this study, production costs refer to expenditures incurred when acquiring goods or services and processing inputs into outputs in the production of primary aluminum. Operationally, production costs included the following cost components: (a) the costs of procuring and transporting raw materials (e.g, alumina, carbon, and other additives) to production plants, (b) conversion costs that included overhead expenses to transform the raw material into semifinished products, (c) regulatory costs, and (d) electricity costs. I excluded costs for marketing and sales.

Rival explanation: In data analysis, the rival explanation is a plausible alternative that differs from the study's stipulated premises (Yin, 2012).

Strategic flexibility: Scholars have described strategic flexibility as the ability to acknowledge a change in the marketplace, allocate resources for new directions, and thereby realize higher performance (Zhang, Juan, & Xiao, 2015). Zhang et al. (2015) found that firms could generate strategic flexibility by adapting resources to an exogenous development that alters the competitive position of the business.

Assumptions, Limitations, and Delimitations

Assumptions

The assumptions made in scientific research matter, especially when a researcher makes arguments about reality. These thoughts are believed to be true, although a researcher cannot prove them along the research process (Ravenek & Rudman, 2013). Qualitative inquiries start with both the philosophical assumption about the nature of reality (ontology) and the way researchers understand and construct knowledge to discover reality (epistemology; Merriam, 2014; Schraw, 2013). Ontology and epistemology constitute the basis of research (axiology); from them, a methodology develops (Teddlie & Tashakkori, 2012). The researchers' views about reality and the production of knowledge rest on their epistemological and ontological inclinations (Yazan, 2015). The first assumption in this research was that each researcher has his or her epistemic beliefs that manifest inherently (Yazan, 2015) throughout the research process; these ideas drive the holistic perspectives of the methodology.

According to Merriam (2014), the reality is complex and context-dependent. The focus of this qualitative, multiple comparative case study was to identify production strategies that companies might use to reduce production costs in their cultural and economic contexts. The second assumption was the epistemological, ontological, axiological, and methodological approaches to this case study offered the flexibility to gather relevant data to explore the contextually developed production strategies to reduce production costs. The third assumption was, through the two intertwined philosophical stances of constructivism and interpretivism about the nature of knowing (Gorski, 2013), and through interactionist-based practices between people and their experiences, I could provide a methodological framework for discovering some elements of reality. Ritchie, Lewis, Nicholls, and Ormston (2013) advocated the principle of interpretivism as being fundamental to the qualitative research tradition; this approach allows exploring a problem through different epistemologies while working beyond empiricism.

The fourth assumption was that, based on its flexibility (Yilmaz, 2013), the qualitative research methodology allowed me to investigate diverse views of the problem under study. Because the reality is complex and not self-evident (Gorski, 2013), these industrial complex issues needed exploration and analysis beyond empiricism to include different epistemologies for discovering varying folds of reality. Yanow (as cited in Owen, 2014) found that document analysis constitutes evidence that a researcher may use for clarity and that may corroborate interview data. The fifth assumption was that using text analysis in combination with semistructured interviews permitted me to gain a rich understanding of the strategies production managers used to reduce production costs and the impact of causal conditions on businesses' efficiency.

The sixth assumption was that when individuals understand reality, they might consolidate it into an already existing context without changing it or considering new facts. Given this understanding, a participant's answers to the interview questions might have introduced unintentional bias. I reflected such a rendition of reality as being related to people's intrinsic descriptions of the constructs and their interdependency or their misinterpretations of reality. The seventh assumption was that there might be different views and ways to address strategies to reduce production costs in aluminum production.

A comprehensive interpretive approach should involve various forms of contextualization (Gorski, 2013).

Given the quantity of information required, using Computer-Assisted, Qualitative Data Analysis Software (CAQDAS) supported qualitative analytic strategies while providing a systematic approach to locating evidence and counterevidence within the text to analyze (Gläser & Laudel, 2013). Cornish, Gillespie, and Zittoun (2013) and Tummons (2014) suggested that computer-assisted programs such as Atlas.ti provide an efficient and effective way of analyzing data that a researcher had coded previously. The eighth assumption was that when compared to a manual data analysis technique, Atlas.ti provides the exactness of data analyzing and organizing techniques essential to ensure consistency throughout the propositional network of codes developed.

Limitations

All methods of inquiry have strengths, weaknesses, and limitations. Limitations are restrictions in a study and constitute threats that may affect the quality of research (Kirkwood & Price, 2013). Kirkwood and Price (2013) discussed how limitations might alter the essence of an analysis and the subsequent findings. Connelly (2013) considered that limitations concern threats to internal and external validity. Internal validity refers to the robustness of a study’s policy. External validity focuses on the generalizability of the conclusions to a different context.

McAreavey and Das (2013) recommended using gatekeepers as mediators to obtain permission for entry and conduct observations. The first limitation was that I could not negotiate the permission for entry to perform site observations because most companies were reluctant about issues of confidentiality. These restrictions limited the possibility to observe core processes and assets. Another limitation was that participants' unintentional bias might have restricted the quality of answers to the interview questions because the reality is complex and not self-evident to apprehend (Gorski, 2013). Such bias might be inherent to (a) the participants' inability to acknowledge the content, (b) their representation of reality, or (c) their failure to recall accurately historical events. Some participants had discomfort when disclosing delicate information about their company's strategies.

Delimitations

Delimitations, as defined by Merriam (2014), were the boundaries I considered in conducting this research. Operationally, delimitations specify the parameters of the investigation and the sphere of activity in conducting the study. Delimiting parameters include the RQ, the objectives of the study, the population under study, and the practical factors that a researcher decides to explore.

The central RQ of this qualitative, multiple comparative case study was What strategies might aluminum managers implement to reduce production costs? The following served as a subquestion: “How can a manager develop core capabilities in production units to decrease production costs?

Five main streams or segments constituted the value chain in the production of primary aluminum (European Commission, 2014a; Tabereaux & Peterson, 2014; U.S. Energy Information Administration, 2012). First, the upstream segment consists of the production of raw material (alumina) through bauxite ore sources. To obtain alumina, producers refine the bauxite ore through the Bayer Process. Second, alumina producers endeavor to segregate alumina into distinct grades or quality products with the objective to yield varietal purity. In the midstream segment or third stage, the raw material was procured (e.g., aluminum oxide, coke, tar pitch, and other additives) and transported by intermodal means to production facilities, where primary aluminum was produced through the Hall-Héroult electrolytic process. Producers cast the molten aluminum tapped from electrolytic cells to produce a range of semifinished commodities such as ingots, slabs, billets, and casting alloys. Next, producers supply the semifinished products to customers and the industry downstream. Finally, semifinished products are manufactured, extruded, rolled, and transformed into high-value-added goods.

In this study, I focused on the following segments: the strategies for procuring alumina and the production of primary aluminum and the supply of semifinished products to the industry downstream. These were the units of analysis. The other three steps were outside the delimiting parameters of this study.

Significance of the Study

Contribution to Business Practice

In the production and operational systems, managers often consider production cost structure and production efficiency as core indicators of the business's profitability. In this qualitative multiple comparative case study, I identified the driving forces for a sustainable aluminum business, as well as the opportunities to enhance competitiveness through productive efficiency and the circular economic model, which is the opposite of the linear model currently in use. I outlined areas of further exploration to improve material- and energy consumption efficiencies. Furthermore, I provided a portfolio of strategies that companies might use to reduce costs.

Implications for Social Change

Business uncertainty entails that under certain market conditions, existing production practices might become inadequate to meet production requirements and stakeholder expectations. Under particular pressures, stakeholder dissatisfaction might arise. Dissatisfaction can manifest in diverse ways, including altering the sustainability of job security (Bach & Bordogna, 2013) in local communities. The goal of this applied research was to produce practical knowledge, with the expectation to carry better returns for stakeholders. This study allowed me to generate concrete actions that might allow aluminum companies to lower material consumption and to contribute to a sustainable environment. The study also paved a new way of thinking about regenerative resources to enhance productivity, while enabling the continuity of the community ecosystem.

Torrie, Stone, and Layzell (2016) and Valero, Valero, and Calvo (2015) highlighted the significant role that aluminum production plays in a country's economic growth. The aluminum business occupies one of the most prominent positions in a country's economic development (European Commission, 2013, 2014b; Götz, 2014). As such, the EU's aluminum industry directly represents a workforce of approximately 255,000 people (European Commission, 2014b). Aluminum production's durability, which depends in part on the sustainability of its production costs, becomes prominent when considering the downstream, upstream, small-, and medium-sized companies that are all connected to the production of primary aluminum.

A Review of the Professional and Academic Literature

Discussion Summary

Three streams of literature were available for this study. In papers from the first stream, I explored aluminum production from a historical perspective and outlined production cost drivers using Porters' five competitive forces that shape an industry. I discussed some strategies for addressing production system performance from a production cost perspective. The concepts covered were economies of scale and forward and backward integration. The second stream of literature derived from the economic theory of production and was connected to the current study's RQ. In some of the relevant papers from this stream, I focused on critical performance determinants of production cost minimization. These determinants involved technical efficiency, production flexibility, innovation, and allocative efficiency. I also discussed the conditions under which factors of production can be used to minimize production costs and maximize outputs. The minimization of resources to reduce production costs may be grouped into five main strategies: (a) technology-based, (b) resources-based, (c) energy-use-based, (d) innovative-based, and (e) operational-flexibility-based. The third stream of literature focused on developing the capabilities required to yield an efficient production system that can allow minimizing production costs in the long-term.

In the current market context, production companies endeavor to customize production strategies that help meet internal performance to gain competitive advantage (Jean-François, Boiral, Marie-Josee, & Roy, 2016). Internal production functions should exhibit both the quality (Cant, Wiid, & Kallier, 2015) and the efficiency required to reduce production costs within the design and technological limits (Herrmann & Kayasa, 2012; Miltenburg, 2005). Numerous factors affect production costs, including machine capability, labor skills (Chauhan & Singh, 2013), quality (Herrmann & Kayasa, 2012), processing efficiency (Farrell, 1957), and resource allocation and use (Bartelsman, Haltiwanger, & Scarpetta, 2013; Cobb & Douglass, 1928).

Herrmann and Kayasa (2012), Miltenburg (2005), and Oke (2013) found that a production system provides many outputs against which to measure performance. Bartelsman et al. (2013) and Farrell (1957) showed that when optimally designed, a production function could exhibit the efficiency required to reduce production costs. Productive efficiency is a system's financial contingency in which a company realizes the maximum possible outputs from its resources (Farrell, 1957).

Restuccia and Rogerson (2013) and Jones (2011) noted that the optimal combination of production factors depends on the efficiency of the allocative resources at each operational level and the alignment between organizational units. With this understanding, a complete analysis of a production-function efficiency to reduce costs includes two principal-efficiency components: allocative and technical (Haelermans & Ruggiero, 2013; Jones, 2011; Restuccia & Rogerson, 2013). Farrell (1957) further decoupled technical efficiency into two constituents: input and output. Input-output efficiency is the ratio of the total value of the products and services obtained from a production process to the set of resources used given technological capabilities (Fang, Guan, Lu, Zhou, & Deng, 2013). Jones (2011), Farrell (1957), and Fang et al. (2013) found that a higher input-output efficiency refers to an efficient allocation and a rational use of inputs. Tovar and Wall (2015) conceptualized productive efficiency as the capacity inherent in a production function to allow a manager to increasing production outputs and decreasing variable inputs while sustaining quasi-fixed resources.

Farrell (1957) and Yang, Shi, Qiao, Shao, and Wang (2016) defined the maximum output realizable, given a set of inputs as a production frontier. The frontier technique, which is also termed the "directional distance function" (Tovar & Wall, 2015), can be suitable for comparing the production performance of different companies. The frontier analysis helps to determine the extent to which a production manager can stretch inputs and yield allocative resources to reduce production costs. Baik, Chae, Choi, and Farber (2013) found that managers could use the production function analysis to monitor the firm's efficiency. Researchers can use production costs as a variable to analyze and compare the performance of different activities within and between companies. Govindan et al. (2013) defined production costs as the total price for the production line to acquire and convert inputs into outputs.

As Porter (1980) and Miltenburg (2005) outlined, different strategies exist for lowering production costs, including upstream and downstream integration, economies of scale, innovation, and flexible production and operational modes (Ajmal, Hussain, Kristianto, & Tenkorang, 2012). Tukker (2015) mentioned that the circular economy allows improving the productivity of resources, which contributes to business productivity and reduced resource depletion. Liu, Dong, Lohse, Petrovic, and Gindy (2014); Dockendorf and Paxson (2013); and Lucio, Wendell de Queiroz, and Rubens de Camargo (2013) found that strategic energy management in production systems could reduce production costs. Strategic energy management in a production system contributes to improving electricity consumption and cost through flexible operations and option-pricing methods (Liu et al., 2014).

Based on the real options model for value developed by Dockendorf and Paxson (2013), and given the complexity of the aluminum electrolytic process, the interruption of energy input might involve significant structural and infrastructural costs. Interrupting power in an aluminum smelter for an extended period can be financially prohibitive for both the aluminum producer and the power provider. Finances are not the only risk involved in curtailing a production line and restarting it; operational risks to people and assets also exist (Bastian-Pinto, Brandão, & Ozório, 2015). Park, Simar, and Zelenyuk (2015) found that data envelopment analysis could allow an assessment of the technical efficiency in using the real options practice. Managers must consider asymmetric costs in switching from the full production mode to the partial interruption of outputs and vice versa.

Ozorio, Bastian-Pinto, Baidya, and Brandão (2013) also mentioned the application of switching between production options. Ozorio et al. evaluated the possibility of switching the output option from full production mode to the partial interruption of outputs and vice versa in the steel industry for reducing production costs under uncertain conditions. Ozorio et al. considered the different prices of the steel produced and the production expenses incurred as inputs to evaluate the opportunity of curtailing the production of steel and trading the available energy.

Cobb and Douglas (1928) and Wicksteed (1894) provided a methodology for analyzing production system performance depending on a company's cost structure and profitability behavior. In the body of research, the scholars outlined three main stages of production. These steps will be detailed in the subsection entitled “Economic Theory of Production and Production Costs.”

Blomberg and Söderholm (2011) discussed how resource-processing firms, such as aluminum production companies, face challenges in their production strategies owing to the complexity of the business. First, the production of primary aluminum is the mass production of standardized products. Second, aluminum production is classified as an electro-intensive and capital-intensive industry (Bastian-Pinto et al., 2015; Blomberg & Söderholm, 2011; Shrouf, Ordieres-Meré, García-Sánchez, & Ortega-Mier 2014; Wei-Qiang & Lei Shi, 2012). These characteristics render the process challenging to adapt to changing market environments.

I have organized the remainder of this literature review around four central themes. First, I discussed aluminum production from a historical viewpoint. Second, I outlined the dominant economic drivers underlying the aluminum production sector. Third, based on Porter’s (1980) model of an industrial structural analysis, I described in detail the five competitive forces affecting the aluminum production industry and its core segments. Finally, I reviewed the economic theory of production (ETP) and production costs.

Strategy for Searching the Literature

In the literature review, I analyzed 131 references. Of these references, 117 (89%) were from peer-reviewed journals, and I sourced the remainder from seminal scholarly works and authoritative reports. The most commonly used journals included periodicals such as the *International Journal of Strategic Change Management, Technological Forecasting and Social Change,* the *International Journal of Operations and Production Management*, *Organizational Dynamics*, *Resources, Conservation and Recycling*, *Journal of Cleaner Production, Environmental Progress and Sustainable Energy,* the *International Journal of Production Economics*, *Global Business and Organizational Excellence, European Journal of Production Research,* and *Energy Policy*. I compiled the research list by using the following initial search keywords: *aluminum production costs, production strategy*, *production function*, *production costs*, *marginal productivity, technical efficiency, productive efficiency*, *environmental protection,* and *data envelopment analysis*. Scholars published most of these articles between 1894 and 2016, with roughly 91.6% published from 2013 onward. Searching articles using the above terms yielded more than 550 results in numerous business and academic databases, such as Science Direct, ABI/INFORM Complete, Emerald Management, Google Books, and ProQuest Central. Table 1 outlines the distribution of the peer-reviewed and authoritative references.

Table 1

Overview of References Used

	< =5 years	> 5 years	Authoritative and books	Peer-Reviewed references	Total
Number of references used for the literature review	120	11	14	117	131
Percentage of references used for the literature review	91.6%	8.4%	11%	89%	100%
Total references	241	33	32	242	274
Overall ratios of references used	88%	12%	11.7%	88.3%	100%

I reviewed the abstract to determine the appropriateness and eligibility of a source. Mainly, I considered how the article explained to the topics of production efficiency, production function, and production cost minimization. I found 131 articles that met the selected inclusion criteria. I chose these authors because they discussed contemporary views for the economic theory of production, capabilities development paradigms, and strategies to reduce production costs. These multiple perspectives provided insight into identifying strategies some aluminum production managers might implement to reduce production costs.

Analysis and Synthesis of the Literature

The purpose of this qualitative, multiple comparative case study was to identify strategies some aluminum producers might implement to reduce production costs. The central RQ of the study was the following: What strategies might aluminum producers implement to reduce production costs? The following served as a secondary question: How can a manager develop core capabilities in the production units to reduce production costs?

The historical perspective of the primary aluminum production. Oersted first isolated metallic aluminum in 1825 (Bray, 2013). Scientists considered aluminum a semiprecious metal because its retail price in the early 19th century was high compared to other minerals (Bray, 2013). Sverdrupa et al. (2015) reported that the production levels of primary aluminum in the early 19th century were insignificant because scientists had not yet learned ways to process it efficiently. In 1886, however, electrolytic reduction—also known as the Hall-Héroult process—led to increased production (Bray, 2013). The market demand for aluminum worldwide expanded further in the 1920s because the automotive industry was growing and aluminum had new construction applications.

In 1939, the demand and production of aluminum grew significantly, spurred on by extensive preparation for World War II, especially in the building of military aircraft (Bray, 2013). The aluminum industry benefited from the metal's price advantage over other minerals (Bray, 2013). Bray (2013) also noted that the Korean War increased demand for aluminum.

In the late 1970s, the price of aluminum was the result of balance in the market between supply and demand in the absence of governmental regulation and allocation (U.S. Geological Survey [USGS], 2013). According to Bray (2013), the industry at that time faced high inventories, surplus capacities, and limited demand across the world, conditions that led to falling prices worldwide. Another consideration that influenced the market was the introduction of aluminum to futures markets that affected its price (Blomberg & Söderholm, 2011). According to Blomberg and Söderholm (2011), companies needed to adjust their production policies to the complex realities of the market. Such strategies included production cutbacks to promote decreased inventories, the creation of a deficit that could enhance demand, and a rebound in prices (Bray, 2013). Blomberg and Söderholm highlighted that production cuts tended to reduce short-term revenues and cash flows.

In addition to the market supply-demand pattern for the aluminum commodity, the USGS (2014) also found that money supply was a determining factor influencing aluminum commodity prices. Countries exhibiting high economic deposits and growth affected the supply-demand distribution of the aluminum product (USGS, 2014). Because only a few dominant countries across the world share a significant proportion of aluminum commodity consumption, the USGS claimed that significant events in such countries could have an impact on the product's supply-demand and its global commodity price (USGS, 2014).

The USGS (2014) found that the Chinese and the U.S. aluminum commodity consumption account for 22% and 18%, respectively, of worldwide consumption. The other primary consumers of the aluminum product include Japan and Germany, whose aggregated consumption accounts for approximately 15% of the global consumption (USGS, 2014). A significant change in Chinese or U.S. economic deposits or growth may affect aluminum commodity prices worldwide. The USGS found that factors that influenced aluminum commodity prices in the last century included such international events as world wars, recessions, the dissolution of the Soviet Union in 1991, and economic growth or recession in China.

In the last decade, aluminum has become essential because of new applications for aluminum alloys in construction, automobile and airplane manufacturing, electrical transmission, the generation of energy, and packaging (Pogue & Lukiw, 2014; Sverdrupa et al., 2015). The overall global output of primary aluminum has grown in the last 2 decades because of the electrolytic technological improvement in aluminum production (European Commission, 2013). The primary aluminum production sector is now confronting issues of competition and profitability deterioration (Blomberg & Söderholm, 2011; European Commission, 2013).

Understanding the Economic Drivers in the Primary Aluminum Business The production of primary aluminum is the process by which raw material (alumina) is electrolyzed into the molten electrolyte to yield pure metallic aluminum in a liquid form (European Commission, 2014b). Aluminum companies produce the liquid form of aluminum in steps: first, bauxite must be refined into alumina (primary raw material). Then, the alumina obtained is reduced electrodynamically into molten aluminum through the Hall–Héroult electrolytic reduction process. An aluminum plant consists of electrolytic cells connected through a circuit series in which the electrolysis takes place. Plants vary widely, composed of 100–450 cells, through which the current is passed to create electrolysis.

A plant’s productivity depends, among other things, on the size of its cells (capacity) and its production efficiency. The production of primary aluminum uses a batch process for its production flow, in which the molten aluminum deposited at the cathode is tapped periodically and sent to the casting plant. Depending on the design, electrolytic-cell cathodes are composed of anthracite or graphitized materials and petroleum coke. These materials are mixed with coal-tar pitch to form a homogenous and long-lasting cathode. Carbon cathodes and their lifecycles are critical components of the electrolytic cell because the economic costs related to their acquisition account for a significant portion of capital expenses. The material used must possess the necessary attributes—such as strength, electrical conductivity, heat capacity, and high resistance to both wear and sodium penetration—to maximize energy efficiency and minimize the early failure rates that increase operating costs.

Cathodic carbon is not the only critical component of the electrolytic cell. Carbon anodes, which also are made of petroleum coke mixed with coal-tar pitch, are elements of interest in the analysis of production costs. The manufacturing quality of anodes has significant environmental, and economic impacts on aluminum production performance (Chevarin et al., 2016). For instance, the energy efficiency of a manufacturing plant depends, in part, on the quality of anodes and the constituent materials. On the other hand, based on the bauxite grade and the stoichiometric coefficients of the chemical reaction governing the Hall–Héroult process, for every four tons of bauxite ore extracted from the earth's crust, producers obtain 50% alumina and 25% molten aluminum. Thus, raw material efficiency is a primary driver in the analysis of production costs.

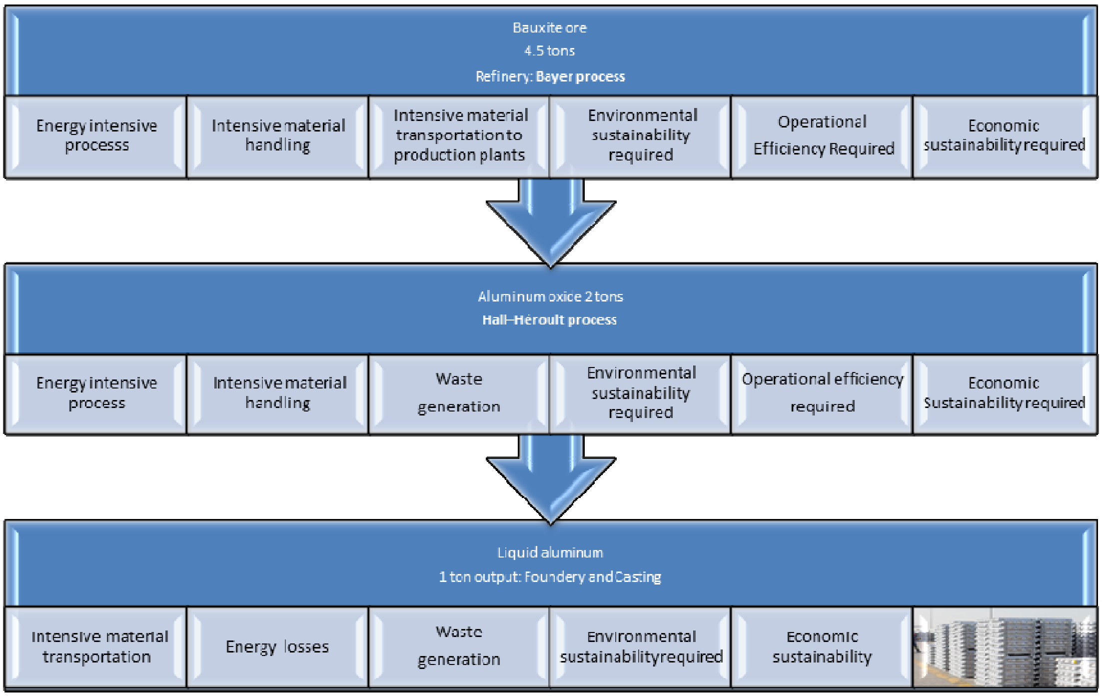


Figure 1. Aluminum production stages. Adapted from interviews (Participants 1A, 3B, 4C, March 2017).

In the Hall–Héroult process, aluminum oxide is dissolved in a bulk of molten cryolite at approximately 17–19 cm depth, depending on the technological design. Anodes made of carbon, which, from a cost perspective, are the second-most valuable raw materials, are immersed into molten cryolite. High direct electric current, ranging from 200–500KA is passed through the molten cryolite via carbon anodes to electrolyze the aluminum oxide. The molten aluminum is siphoned periodically from electrolytic cells and transferred to casting facilities, where operators mold it into semi-finished products.

During the electrolysis process, oxygen atoms are dissociated from aluminum ions and react with the carbon anodes to generate carbon dioxide. Occasionally, the lack of dissolved alumina into the molten electrolyte will cause greenhouse gases that are sources of energy consumption as well as environmental costs that companies must pay to sovereign governments and neighboring communities. The alumina electrolysis process uses direct current (DC) and consumes energy at the scale of 12.5–15 DC kWh/kg Al depending on the plant's technological and operational capabilities (Gutowski et al., 2013). DC measures the energy use of the electrolysis that occurs after rectification; it does not include the power required for casting.

The theoretical power consumption required, based on the enthalpy of the reaction of the chemical elements, and heating, is approximately 9.03 MWh/ton Al (U.S. Energy Information Administration, 2012). Because the annual aluminum production capacity for most smelters ranges from 150,000–500,000 tons, energy efficiency becomes a significant economic and cost driver for sustainability. The European Commission (2014) found that energy represents approximately 23–43% of aluminum production costs. Other costs include management, labor, and environmental costs. Freight and intermodal transportation costs of materials, which depend on the geographic location of the production plant, are also significant cost drivers.

Worldwide, energy consumption by aluminum production companies ranges from DC 12.5–15MWh per ton of material produced (Gutowski et al., 2013). The difference between the upper and lower energy consumption levels equals 2 MWh/ton of material output, equivalent to a potential cost avoidance of USD90/ton produced. By studying the energy-efficiency distribution curve, production managers might understand discrepancies in production costs and pinpoint energy consumption difference between companies.

The European Commission (2013) has analyzed the cost structure in the production of primary aluminum and found that the competitiveness of producers in Europe differs widely. The European Commission found that electricity and labor, together with raw materials, constitute the primary components of production costs in aluminum production. In Europe, direct operating expenditures are distributed as follow: energy accounts for 36% of the production costs; alumina, 30%; other raw materials, 9%; labor, more than 12%; and other expenses, 7% (European Commission, 2013; Kvande & Drabløs, 2014). As of 2013, the European Commission found that the EU's regulatory and environmental policies constituted 8% of the total aluminum production costs. Other cost elements include transportation, storage, marketing expenses, administration costs, and taxes. According to the European Commission, the global production cost structures are in the range of USD1300–1900 per metric ton aluminum produced (Al). At the same time, latest aluminum electrolysis technologies deliver the industry's most comprehensive efficiency than the old ones do (Gutowski, Sahni, Allwood, Ashby, & Worrell, 2013).

Table 2 is a summary of differences in production costs among the companies observed. Figure 2 outlines the primary drivers of production costs and the ratio of each component in the production cost structure. Data indicated that the cumulative difference between the regional benchmark and the highest cost producer could reach USD723 per ton Al (see Figure 2). This gap is high, given the relatively reduced returns on investment observed in recent years.

Table 2

Production Cost Differences Among Companies per Ton of Aluminum

	Percentage Range	Minimum Observed (USD/Ton Al)	Average Costs (USD/Ton Al)	Maximum Observed USD/Ton Al
Alumina	23—29	371	419	467
Electricity	23—45	371	548	725
Carbon Anodes	11—17	177	226	274
Management and Labor	8—11	129	153	177
Chemicals and Additives	8—10	129	145	161
Maintenance and Overhead Cost	8—10	129	145	161
Environmental Costs	8—12	129	161	193
Cumulative Difference				**723***
Cost/Ton				
Total Costs		1435	1797	2158

Note. The symbol * represents the cumulative difference between the regional benchmark and the highest cost producer (USD per ton Al). Census data derived from the participants interviewed.

As shown in Figure 2, electricity prices drive aluminum production costs, followed by raw material. Whereas electricity is one significant component of an aluminum producer's business economic sustainability, most smelters depend entirely on the supply and efficiency of carbon and alumina, often from different parts of the world. Transportation, raw material, and environmental costs require similar attention from aluminum producers. Some companies, such as Ma'aden Aluminium (MAA), the joint venture between the Saudi Arabian Mining Company and Alcoa, have taken proactive steps to integrate all activities along the aluminum production chain, according to participants interviewed (Participants 5A, 4C, 1D, March 2017). MAA is located on the

Gulf Coast of Saudi Arabia and is one of the lowest cost aluminum producers in the world.

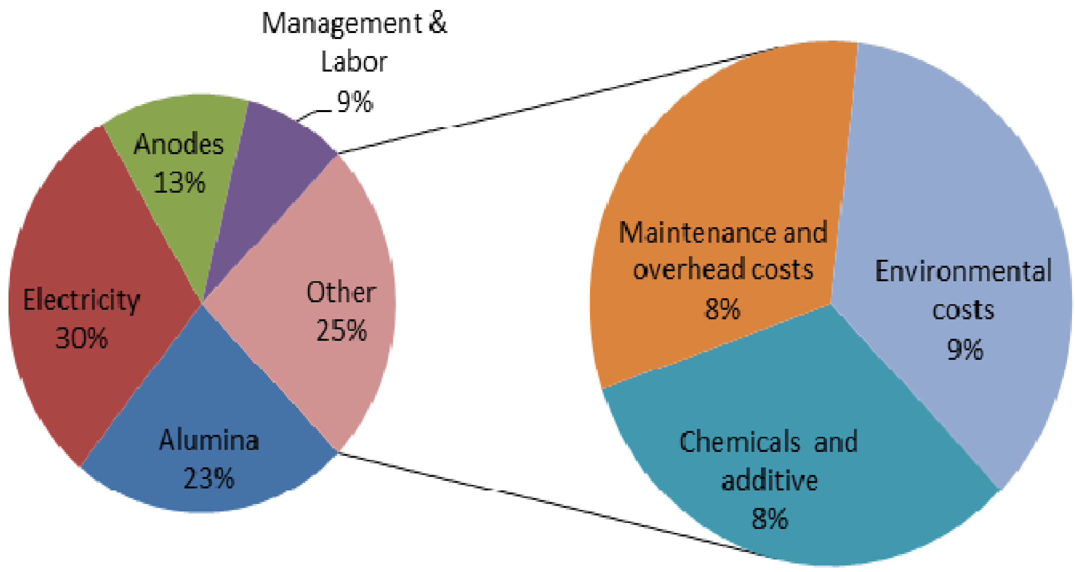


Figure 2. Production cost distribution, according to participants interviewed.

The raw materials used to manufacture anodic and cathodic elements (e.g., carbon and coal) are exposed to global oil prices, which might be related to the world economic environment (World Bank, 2013). The energy use in aluminum production requires significant amounts of fuel, which generates carbon dioxide (Gutowski et al., 2013), adding costs due to environmental taxes. According to technical efficiency paradigms (Farrell, 1957), companies may adjust their energy and raw material usages to minimize the costs of inputs.

Both the fluctuations in aluminum prices and the production costs influence production outputs and strategies for aluminum production. Casadesus and Zhu (2013) found that technological superiority and innovative business models are critical business performance factors to reduce production costs. Innovative companies are equipped with the necessary capabilities for long-term survival and business profitability (Helm & Conrad, 2015). Gutowski et al. (2013) recommended that companies should develop technology roadmaps that identify key energy challenges to taking breakthrough energy-efficiency steps to reduce production costs.

Structural Analysis of the Production of Primary Aluminum Sector

Using Porter's (1980) concept of five competitive forces, the industry's structure and a competitor's strengths and weaknesses can be analyzed to build a foundation for a production strategy. The five competitive forces are interpreted through the framework of the sector's structural analysis. A manager uses the industry's structural analysis to (a) determine competition within an industry, (b) plan the future strategic position of the business units (e.g., the production system), and (c) distinguish fundamental processes and capabilities for achieving critical goals. For this qualitative, multiple comparative case study, I did not analyze all industry forces at a granular level; instead, I focused on identifying the underlying strengths of efficiency that production managers may use to reduce production costs. Figure 3 is a philosophical summary of the five competitive forces shaping an industry in the aluminum production sector.

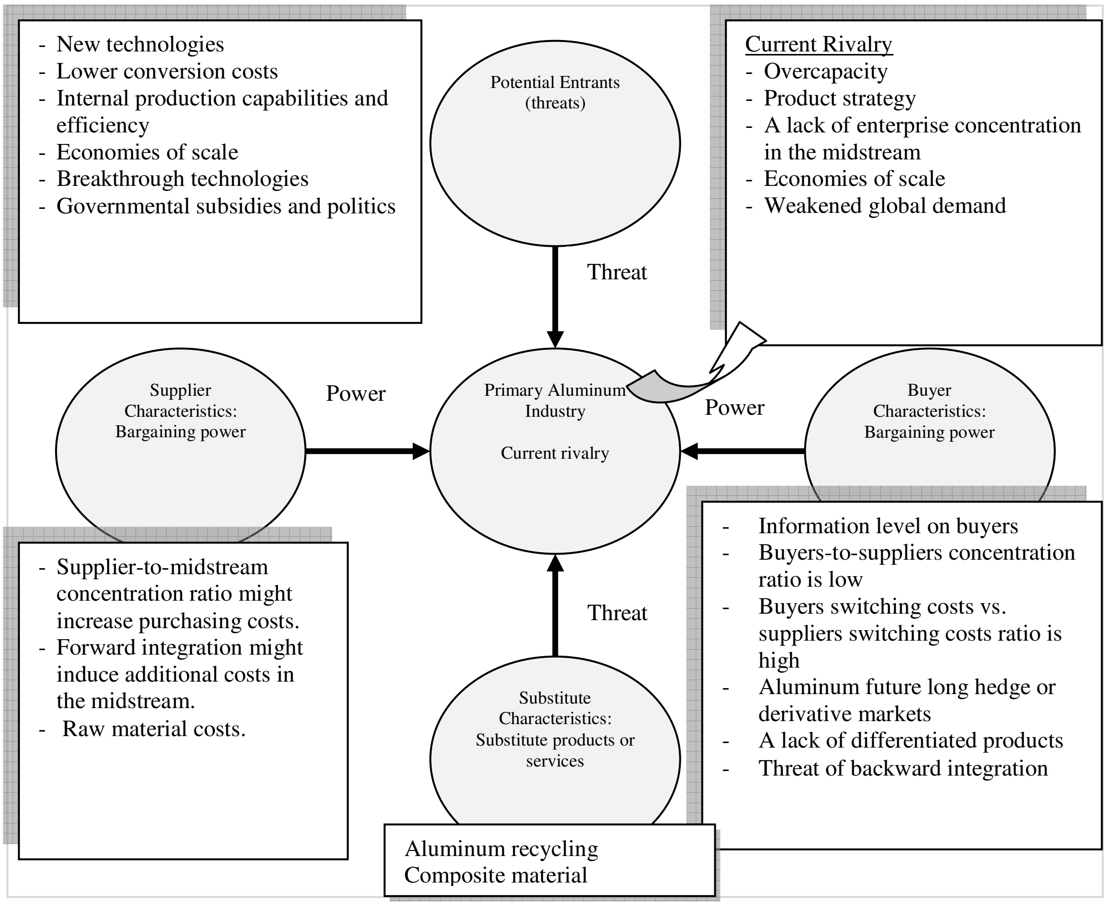


Figure 3. Systemic structures in the aluminum production sector adapted from Porter, M. E. (1980). Competitive Strategy: Techniques for analyzing industries and competitors. New York, NY: The Free Press.

The threat from new entrants. New entrants may change the competitive environment and influence the profitability behavior of companies in an industry (Porter, 1980; Ray, 2015). Porter (1980) found that new entrants to an industry or the market tend to diversify their production strategies through the introduction of new technologies that can reduce production costs. Porter showed that both economies of scale and product strategies could allow companies to neutralize additional production costs that a new entrant might have induced. An economy of scale refers to decreased per-unit costs of an operation when production volumes increase (Carvalho & Marques, 2014). Porter found that a company could rationalize activities and increase production capacity to gain cost benefits. Porter also found that rational businesses should combine functions to streamline and achieve operational efficiency.

Miltenburg (2005) found that a company that vertically integrates activities along the value chain could acquire economies of scale with upstream and downstream businesses by operating in the successive stages of its production chain. For example, removing redundancy and reordering functions can reduce production costs. Economies of scale might also lower production costs if a company purchases products in more significant quantities (Porter, 1980). Notwithstanding, producers must weigh the benefits gained from economies of scale against the storage costs incurred. Excessive inventories may be a source of additional expenses (Esmaeilikia et al., 2014).

Economies of scale can provide a production manager the cost advantage through large-contract purchases, resulting in a better purchase price. Economies of scale in a production system can also increase the production rate-per-unit of time and reduce the marginal costs of production. An analysis of the value chain provides a distinction between unproductive assets and the sources of low-cost advantage. A company can derive a cost-benefit by integrating, revamping, and reorganizing critical activities in the value chain.

Bargaining power of suppliers, relationship to production costs. In a value chain, suppliers can exert power by increasing material prices or by reducing the quality of the material (Miltenburg, 2005; Porter, 1980). An increased raw material price affects the buying costs. Porter (1980) discussed that in an industry with intense competition, dominant suppliers often are more concentrated than their buyers are; such an industry structure (discrepancy in concentration ratio) may affect the profitability of purchasing companies.

Miltenburg (2005), Radetzki (2013), and Porter (1980) identified conditions under which the power of suppliers may affect the production costs of buying companies. First, the industry downstream is disintegrated—that is, the supplier-to-downstream concentration ratio is high (Radetzki, 2013). Second, no substitute products are available for the buyers. Third, the supplier product is critical for the downstream industry. Finally, the provider may decide to perform forward integration with a company downstream. Forward integration occurs when a vendor decides to absorb a business operating downstream in the same industry (Glock & Kim, 2015). Glock and Kim (2015) found that forward integration affects vertical and horizontal competition as well as the price structure of the product under consideration. Notwithstanding, vertical integration provides such benefits as enhanced planning, improved forecasting predictability, and the quality of replenishment (Glock & Kim, 2015; Jin, Amydee, & Fawcett, 2013). Planning, forecasting, and replenishing influence production costs.

Jin et al. (2013) found that integration enhances a company's productivity and improves operational performance. Ping et al. (2013) reported that because prices of raw materials for nonferrous metals have been rising worldwide, upstream integration in the aluminum industry would make sense. Nevertheless, Lin, Parlaktürk, and Swaminathan (2014) found that upstream and downstream integrations tend to intensify competition.

Backward integration occurs when a company in the downstream of a given supply chain decides to integrate upstream activities in its business (Lin et al., 2014). Backward integration can allow convenient access to the strategic raw material while improving purchasing activities and production coordination (Miltenburg, 2005; Porter, 1980). Lin et al. (2014) found that a company that vertically integrates functions might capture a premium by internalizing its supplies of high-quality resources.

Some drawbacks exist in highly vertically integrated businesses. For instance, Lahiri and Narayanan (2013); Adamczak, Domanski, Hadas, and Cyplik (2016); and Cardoso, Ana Paula, Barbosa-Povoa, and Relvas (2013) found that highly vertically integrated companies exhibited limited profits in leveraging innovation compared with their vertically specialized competitors. Adamczak et al. (2016) and Hadas, Cyplik, and Adamczak (2014) found that the highest level of integration might lead to excessive costs incurred under stable market conditions when contrasted with potential profits. Conversely, cost and profitability levels followed a reverse pattern under uncertainty (Adamczak et al., 2016).

Rivalry among competitors and relationship to production costs. Porter (1980) found that factors that may intensify the competition include slow growth in the industry (e.g., companies across the industry exhibit weak earnings), high fixed costs, and small profit margins. As Porter outlined, some production strategies companies may use to absorb fixed costs in the long-term include proprietary technology and outsourcing strategies. A company may outsource non-core activities or functions in which it demonstrates an inability to reduce costs. Outsourcing may involve both domestic and international activities.

According to Ma, Chang, and Hung (2013), proprietary technology may be a strategic resource or input in a production system and can provide an advantage in a highly competitive environment. Porter (1980) argued that technological capability might provide a production cost advantage in the long-term if it is inimitable, rare, and involves some costs to access it. Gutowski et al. (2013) found that implementing low-cost capacity machines or replacing high-cost technologies could provide high-energy efficiency. Where production systems can provide the flexibility for differentiated products or modes of production, Eckel, Iacovone, Javorcik, and Neary (2015) found that companies could gain quality premium and lower production costs.

Structural analysis of an industry allows distinguishing fundamental strengths and weaknesses in the face of competitive forces (Porter, 1980). A production strategy requires the consideration of all options and the development of production capabilities to reduce costs. Critical enablers for reducing costs include human competencies, facilities strategy, material-based strategies, process technologies, sourcing, and production planning (Miltenburg, 2005).

Economic Theory of Production and Production Costs

Stages of the production function and business profitability. Shepherd (2015) and Wicksteed (1894) defined the production function as a combination of factors used in a process to yield outputs. Cobb and Douglas (1928) and Wicksteed (1894) found that each production function consists of different stages. Producers can increase or decrease outputs by adjusting the inputs. Nevertheless, a manager may face increasing returns to scale (IRS), constant returns to scale (CRS), or diminishing returns to scale (DRS; Restuccia & Rogerson, 2013). CRS and DRS may arise in cases where input levels are not controlled adequately—in such circumstances, production costs might increase (Cook, Tone, & Zhu, 2014).

Cobb and Douglas (1928) and Wicksteed (1894) outlined three main stages of production depending on production cost structure and profitability behavior. In stage one, producers obtain maximum outputs proportional to increased inputs. At this point, the production function exhibits increasing marginal returns to scale (Restuccia & Rogerson, 2013). In production companies, however, economic considerations often exist, as well as the quest for business growth and cost efficiency, both of which imply that a firm cannot limit its performance or increase the use of resources indefinitely (Jones, 2011). As a company increases inputs, production outputs change and follow a different behavior in stage two. Outputs may not vary proportionally with the resources used. Instead, the rate of production remains constant despite the level of the resources used; then, the firm faces CRS. In addition, one characteristic of this stage of production is that marginal returns and profitability continue to decrease (Cobb & Douglas, 1928; Wicksteed, 1894) compared to stage one. An inflection point may occur, given the convex nature of the model, for which the outputs stagnate despite increasing inputs (Jones, 2011; Restuccia & Rogerson; 2013).

In stage three, the production cost structure changes, despite an intensifying use of inputs—outputs decrease, while marginal costs increase (Cobb & Douglas, 1928). A company faces the DRS. Production companies may overuse some resources in the DRS if production managers fail to conduct adequate net present value analysis of choices. In sum, companies need to know the boundaries of each production phase so they can analyze production costs and identify when to start allocating resources (Jones, 2011; Restuccia & Rogerson, 2013).

Factors of production and production costs. When a production manager creates core activities for a firm, production is a central consideration. A method for analyzing the performance of a decision-making unit (DMU) is monitoring the ratio of outputs to inputs (Cobb & Douglas, 1928; Wicksteed, 1894). Cobb and Douglas (1928) and Wicksteed (1894) analyzed aggregate factors of production and their influence on production costs. Cobb and Douglas found that a manager might adjust inputs or resources used in production to optimize the cost efficiency.

In economics, inputs are termed factors of production. Modern companies such as aluminum plants often include raw material, energy, labor, technology, and financial capital as inputs. Energy plays a critical role in aluminum production costs (Sverdrupa et al., 2015). Chauhan and Singh (2013), Porter (1980), and Latham (2013) found that skilled labor could be a source of competitive advantage for reducing costs and may provide adaptability in a changing business context. Porter (1980) considered that experienced R&D staff could be a source of creativity, simplicity, and reliability in the quest for differentiation and cost minimization. Kvande (2015) found that production costs for many aluminum production companies depend on their operational efficiency. Resource utilization, technological capability, and processes design are variables of production cost. Investments in technical capabilities provide the standard of efficiency in production systems (Dosi, Grazzi, & Moschella, 2015).

The concept of efficiency. In aluminum production, economics refers to the analysis of choices a manager makes under insufficient resources. A key measure of any production system is its efficiency (Farrell, 1957). Miltenburg (2005) found that efficiency in a production system requires high-quality facilities, process innovativeness and flexibility, and technological capacity. Cobb and Douglas (1928) described the production function in mathematical form as $P = f(L, K, R)$, where P is the amount of output; and L, K, and R represent the resources employed (e.g., energy, material, labor skills, technologies). Production managers define the factors' efficiency through their respective ratios: L/P, K/P, and R/P. A manager can also measure the production performance by tracking changes in the marginal product of operation (MPO). The MPO is the rate at which total factor outputs change as a company modifies its inputs. In mathematical terms, the MPO can be calculated as $MPO = \Delta P/\Delta I$, where ΔP is a change in total outputs and ΔI is a change in overall factors used.

Ding (2014) found a curvilinear relationship between the production efficiency and a firm's cumulative experience. A curvilinear relationship indicates that not all input combinations could yield cost efficiency. Notwithstanding, some managers have difficulty finding the optimal mix of resources for lowering production costs. Porter (1980) indicated that the experience curve concept could allow estimating the optimal mix of resources. Candelise, Winskel, and Gross (2013) found that production costs decreased in systems in which the production doubled given the technology and quasi-fixed inputs. The experience curve view was supported elsewhere by MacGillivray, Jeffrey, Winskel, and Bryden (2014) and Shepherd (2015) regarding the roles of dynamic learning and allocative efficiency.

Weak productivity growth is the cause of poor economic performance in many companies (Crespi & Zuniga, 2012). Innovative firms have higher labor productivity when compared with noncreative companies (Crespi & Zuniga, 2012). Developing economic and technological capabilities may allow producers using resources efficiently, providing an economic advantage (Crespi & Zuniga, 2012; Dosi et al., 2015). Allocative efficiency is the responsibility of a company's leadership (Haelermans & Ruggiero, 2013) and might be a determinant for reducing production costs.

Designing efficient systems for aluminum production. Production companies endeavor to gain a competitive advantage by creating customized production strategies to meet market requirements and profitability goals. In production companies, a manager makes decisions about the production strategy while evaluating the economic cost of his/her options. According to Cobb and Douglas (1928), these decisions are complicated because they involve various steps. First, producers should consider the design of the production process, given its technical capability and expected outputs. The second step consists of evaluating the technical efficiency and adapting inputs to promote low-production costs for the long-term (Herrmann & Kayasa, 2012). Finally, a production system provides various criteria against which to measure performance. Such criteria include production costs, flexibility, delivery, quality, efficiency, and innovativeness (Herrmann & Kayasa, 2012; Miltenburg, 2005; Oke, 2013).

Critical infrastructural and structural components to a product strategy include business vision and direction (Burian & Maffei, 2013) as well as capacity, facility, product technology, and process technology strategies (Alborzi, Khalili, Nazemi, & Salimian, 2013). Herrmann and Kayasa (2012) and Reinartz and Schmid (2015) recognized the need for production function flexibility, innovativeness, and efficiency to minimize production costs. Marsillac and Jungbae (2014) found that innovation and flexibility constitute moderating factors for reducing production costs.

Ballot, Fakhfakh, Galia, and Salter (2014) identified the complementarity between innovativeness and process flexibility and the impact of both on cost minimization. Ballot et al. (2014) found that innovation and flexibility could alter the use of inputs through process engineering and technological capability, thereby allowing production cost minimization. For instance, process design can allow energy and material management through new production modes of reducing, recycling, and reusing (RRR) energy and materials; methods that might generate cost benefits in waste disposal. Reh (2013) idealized the concept of RRR as a circular economy, a practice that can affect production outputs as well as material inputs use.

Davenport (2013) defined process innovativeness as the ability to redesign a process to maximize quality, reduce costs, and provide additional flexibility to a production function. Stanko, Molina-Castillo, and Harmancioglu (2015) found that innovation reduces production costs. Singh, Oberoi, and Ahuja (2014) and Miltenburg

(2005) concluded that the development of operational flexibility provides a superior capacity to act appropriately and economically while satisfying variable markets. In aluminum production, Liu et al. (2014) and Shrouf, Ordieres-Meré, García-Sánchez, and Ortega-Mier (2014) found that energy efficiency could be achieved by optimizing energy consumption and through the strategic and flexible energy management options, an approach that can allow reducing costs. Caniëls and Rietzschel (2015) advocated innovation as a determinant of competitiveness in production systems, particularly in a business environment facing prices uncertainty.

Technical efficiency and allocative efficiency for reducing production costs. In production systems, technical competence derives from the extent to which a manager can operate a production function with the maximum achievable outputs (Bartelsman et al., 2013; Farrell, 1957). Technical efficiency is a concept that describes the ability of a production manager to reduce the level of the input use while maximizing outputs at the lowest possible cost. Technical efficiency is also termed “productive efficiency” (Bartelsman et al., 2013; Farrell, 1957; Tovar & Wall, 2015), which occurs when the production function could not produce any more of one output without using another input or altering another output (Koopmans, 1951). A technically efficient company operates its production function close to the limits of the capacity of the resource (Bartelsman et al., 2013; Farrell, 1957). Restuccia and Rogerson (2013) found that productive efficiency in a production system could be achieved by implementing best technological capabilities, material management capabilities, and strengthening manufacturing processes and allocative efficiencies.

The difference in companies' technical efficiencies is delineated in three ways. First, the technical ability for mitigating production costs may be different due to different technological capabilities (Moll, 2014; Restuccia & Rogerson, 2013). According to Restuccia and Rogerson (2013), both the slow adoption of technology and its inefficient use will influence production costs. Second, shortcomings in technological capabilities may derive from the misallocation of resources and the lack of financial capital. Furthermore, Restuccia and Rogerson found that failure to adopt appropriate technical capabilities could affect a company's ability to innovate, which might have implications on production costs. Finally, structural and infrastructural systems may have strategic implications on the characteristics and cost of production.

The measurement of technical efficiency in a production system. Researchers estimated the technical efficiency of a production unit through the data-envelopment-analysis model. For instance, Farrell (1957) provided a model consisting of two approaches for measuring technical efficiency: input and output. The former is relative to the ability to reduce inputs while maintaining fixed outputs unchanged. Some strategies to cut resources of production include reducing waste, recycling, applying lean manufacturing principles, reducing no-quality costs (Polansky, 2014), and analyzing value (Bastič, Ivanišević, Leber, & Mavrič, 2014).

The output approach is the opposite of the input approach; in the former, a manager aims to maximize outputs while maintaining fixed production factors (Farrell, 1957). These approaches are not mutually exclusive. Factors affecting technical efficiency are considered from several angles, such as economies of scale, input utilization, the geographic location of a production unit (Yang et al., 2016), and the return to scale (Aristovnik et al., 2013; 2014).

From the analysis outlined above, practical reasons exist for considering that some aluminum production companies have been inefficient given the difference in companies' production cost structures, as discussed by the European Commission (2014b) and Gutowski et al. (2013). According to the European Commission (2014b), global production cost structures currently range from USD1300–1900 /ton Al.

Although scholars provided some guidelines for evaluating the production efficiency, only a few studies have provided the methodological framework for measuring and analyzing the technical efficiency (Farrell, 1957). Because of such deficiencies, many production companies lack qualitative and quantitative knowledge about their technical efficiency and production frontier. Notwithstanding, industries, such as steel, have made progress in this area (Yang et al., 2016). The methods used in those industries could be transferred to aluminum.

Farrell (1957) emphasized the lack of suitable data as the cause of the technical efficiency research insufficiency. Park et al. (2015) and Yang et al. (2016) recommended performing technical efficiency analyses using nonparametric techniques, such as data envelopment analysis (DEA). DEA is an analytical research instrument used in operational research for estimating and ranking the efficiency of various DMUs when the production process contains many inputs and outputs (Olesen & Petersen, 2016; Park et al., 2015). DEA analysis can provide reports such as the allocative and economic efficiency of DMUs by identifying the optimal combination of resources used in a production system (Amini et al., 2015; Aristovnik et al., 2013, 2014). DEA allows the simultaneous consideration of multiple inputs and outputs and requires no a priori presuppositions to interpret the production frontier (Varabyova & Schreyögg, 2013; Yang et al., 2016).

By using the DEA method, a production manager aims to identify cost-benefit opportunities (Sherman & Zhu, 2013). Given that DEA is established based on production assumptions, these assumptions must hold true (Park et al., 2015) to avoid under- or overestimating a company's level of efficiency. For example, the timeframe and parameters of the analysis in relating outputs to inputs must be defined accurately (Amini et al., 2015; Atici & Podinovski, 2015; Chian, 2013). Amini et al. (2015) suggested that the unit of measure for a given parameter must be similar. Park et al. (2015) also suggested the use of ratios to enhance the interpretation quality.

Technological capability to decrease production costs. Technology is a determinant of success in a production system (Miltenburg, 2005). Shepherd (2015) defined production techniques as additional arrangements distinct from traditional factors of production that enable a manager to adapt production systems and fulfill critical production requirements. Miltenburg (2005) and Shepherd (2015) found that inadequate selection of production technology might increase production costs. In addition, the adequate selection of technological capabilities, which is part of a manager's responsibility, involves allocative efficiency (Moll, 2014; Restuccia & Rogerson, 2013).

Challenges in production systems. Producers need to explore all available options and ascertain the adequate combination of inputs given the changing business context. Farrell (1957) and Zelenyuk (2015) found that the optimal combination of resources depends on aggregate resources that a manager applies to a production system. Farrell further stated that the optimal combination of resources refers to the desired technical efficiency that a company expects to attain given technical considerations and the production frontier within an industry. For example, Farrell found that long-term cost performance could be compromised if a decision was made to increase or diminish inputs to increase revenues without considering relative frontiers and marginal production costs.

The law of diminishing marginal returns and loss of profitability. According to Cobb and Douglas (1928), under certain conditions, a production function can reach the point of diminishing returns, a state that has a direct implication on a firm's production cost structure. Diminishing marginal returns in a production system is a state in which the production function yields high production costs and decreased profitability (Ellington, Dierdorff, & Rubin, 2014). Diminishing returns in a production system may lead to diseconomies of scale, which refers to business circumstances in which economies of scale no longer provide the benefits expected in a production system (Ellington et al., 2014; Ray, 2015).

Farrell (1957) and Ellington et al. (2014) explored issues of optimization in modern companies. As companies face market pressure, annual budgets often become restricted (Caniëls & Rietzschel, 2015). On the other hand, questions about the use of resources and the need for cost optimization emerge. Some managers evaluate the production cost efficiency by comparing with the industry benchmark or the production frontier (Farrell, 1957). Farrell found the production frontier outlines the marginal rate of factor substitution, the resource allocation, or the adoption of sourcing capabilities. The Law of Diminishing Marginal Returns (LDMR) becomes relevant when a manager seeks to maximize outputs by adding resources to fixed factors (Ellington et al., 2014). Yao and Liu (1998) found that diminishing marginal returns manifest in both rising marginal and production costs (see Figure 4).

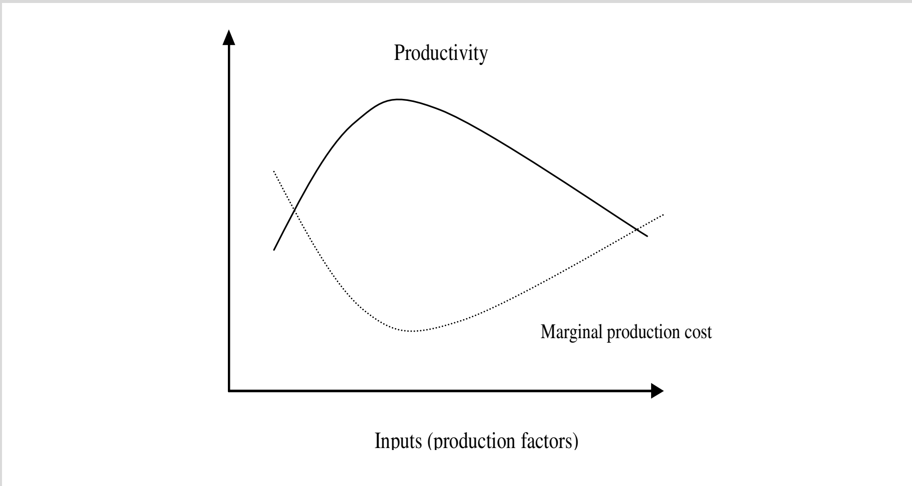


Figure 4. Diminishing marginal productivity, adapted from Yao, S., & Liu, Z. (1998). Determinants of grain production and technical efficiency in China. *Journal of Agricultural Economics*, 49, 171-184. doi:10.1111/j.1477-9552.1998.tb01262.x.

For a given combination of inputs, depreciating efficiency and profitability constrain most optimization processes (Ellington et al., 2014). Ellington et al. (2014) found that when a production unit nears maximum, its profitability decreases because production costs increase with the level of inputs used. An increase or decrease of one factor may require a company to trade off the direct and indirect costs of other inputs. Researchers use the LDMR to analyze the productivity of a production function when inputs change (Bennett & Vedder, 2014; Ellington et al., 2014).

Price inclusion in efficiency analysis. Although prices are considered exogenous factors in the production performance analysis, managers should always consider options offered in the market to reduce overall production costs (Farrell, 1957). For example, in an electro-intensive industry such as aluminum production, Bastian-Pinto et al. (2015) and Shrouf et al. (2014) considered improving production costs by reducing non-production models. Shrouf et al. found that constant changes in energy prices had become a constituent of output costs, requiring companies to adjust their production models.

Efficient and inefficient firms differ. Bertelsmann et al. (2013) stated that the differences between companies' technical efficiencies stem from their business models, internal distortions, and the ability to minimize input usage. Dissimilarities might also reflect a firm's ability to innovate and develop efficient resource allocation with minimal trade-offs among options. Price input could improve by combining materials purchases to gain economies of scale. Notwithstanding, a production manager should evaluate the storage costs to select the adequate approach. Price efficiency differs from low-quality options that can have long-term bottom-line consequences.

The effect of misallocation on production costs. Jones (2011) found that the misallocation of core resources leads to revenue differences among companies. For example, companies adopting breakthrough technologies in production systems may develop a competitive edge more swiftly than their rivals (Jones, 2011). Restuccia and Rogerson (2013) also showed that many companies lose money because they fail to operate their production function at the optimum level of efficiency. Miltenburg (2005) found that the extent to which production efficiency differs across firms might explain the size of internal distortions and managerial decisions.

Quality strategy to minimize excessive use of production factors. Quality is the extent to which products or processes conform to a customer's specifications and expectations (Cant et al., 2015; Polansky, 2014). Polansky (2014) found that the capability of a process to yield quality products within specification helps mitigate the product fall-out rate and the production costs inherent to poor quality. Silva, Abellán-Nebot, Siller, and Guedea-Elizalde (2014) proposed an adaptive control optimization system for minimizing production costs. Selective and adaptive production systems allow achieving technically efficient production (Herrmann & Kayasa, 2012; Silva et al., 2014). Waste increases production costs. The zero-defect strategy for mitigating the costs of poor quality is recommended by Herrmann and Kayasa (2012) through adaptive production systems.

Taheri, Moghaddam, and Arami (2015) found that when applying the Taguchi quality-loss function, producers could evaluate the costs of poor quality and thus undertake actions to reduce production costs. According to Taheri et al., implementing such an analysis requires assessing four fundamental parameters: (a) the process variance, (b) the quantity output, (c) the target a manager intends to achieve, and (d) the production costs per unit. Polansky (2014) indicated that companies might decrease production costs through quality and by specializing in a particular business process. The specialization guarantees that processes and products delivered would meet customer specifications, no matter how much inputs might change. When quality improves, production costs decrease (Polansky, 2014).

Some drawbacks of productive efficiency. Theoretical considerations suggest that productive efficiency operates in tandem with technical efficiency (Huang, Ho, & Chiu, 2014). Productive efficiency refers to the production of outputs at the lowest point on the average cost curve in a given industry (Huang et al., 2014). Farrell (1957) found that profit-maximizing companies attempt to operate their production function at the lowest possible point on the cost curve by minimizing investments through budgetary restrictions.

Budgetary limitations often manifest in downsizing labor, outsourcing non-core activities, and disinvesting (Gallegos, Giskes, Ramsey, & Turrell, 2012). Miltenburg (2005) cautioned that budgetary constraints influence long-term decision-making and lead to a trade-off among options. Gallegos et al. (2012) discussed that inappropriate budgets are a risk for businesses. Limited investments in production systems may lead to insufficient production initiatives (Miltenburg, 2005). Gallegos et al. (2012) found that although disinvestments can produce financial benefits in the short-term, the adverse consequences may be overwhelming if a manager fails to integrate market potential and variations to long-term production strategies. Contrary to the view of budgetary limitations expressed by Gallegos et al. (2012), Scopelliti, Cillo, Busacca, and Mazursky (2014) found that constrained financial resources might be beneficial to ideation and creativity because they may lead to cost reduction. In practice, tension and perplexity often occur between the short-term savings of budgetary restriction and the potential long-term gains realized from financing innovative projects (Caniëls & Rietzschel, 2015).

Budgetary limitations may produce mixed effects on production costs. Production companies should use such practices sparingly. Budgetary restrictions can limit a company's ability to respond to the variety of strategic options that may contribute to increased profitability. Productive efficiency necessitates allocative efficiency of inputs to meet production cost requirements (Chiang, Li, Choi, & Man, 2012; Haelermans & Ruggiero, 2013). Managerial capability influences productive efficiency (Chiang et al., 2012; Fu et al., 2012). Finally, Novy-Marx (2013) found that firms with productive assets return on average greater profits when compared with companies whose assets are unproductive.

Raising Technical Capabilities

Theorists of the RBV emphasize that some resources within an organization contribute to business performance (Ahmed, Kristal, & Pagell, 2014; Kortmann, Gelhard, Zimmermann, & Pillier, 2014; Wiengarten, Humphreys, Cao, & McHugh, 2013). According to the RBV, a company might increase its profitability if it undertakes actions that create value. Ahmed et al. (2014) expanded the analysis of the RBV to the study of production systems. Ahmed et al. mentioned that companies create competitive advantage by finding adequate ways to manage and operate their production systems. Ahmed et al. and Kortmann et al. (2014) found that the degree to which managers generate strategic capabilities drives the development of production efficiency by minimizing production costs. Capability refers to any source of high levels of competitiveness or expertise or to those processes or practices that can serve as an advantage for performing core activities efficiently (Ahmed et al., 2014).

In production systems, misalignment in or shortage of resources can produce unbalanced performance and a trade-off among functions (Achtenhagen, Melin, & Naldi, 2013; Camuffo & Wilhelm, 2013). Resource complementarity is critical in production systems for developing efficiency that can affect production costs (Porter, 1980). Porter found that complementarity could allow developing a holistic approach, as opposed to strengthening a single unit in isolation.

Miltenburg (2005) found that most businesses in a given production field compete using similar production systems and manufacturing capabilities. Top-performing companies nevertheless are those that identify the value from the marketplace and leverage their manufacturing capabilities to fulfill such value (Alborzi et al., 2013; Allen, Fontaine, Pope, & Garmestani, 2011). Camuffo and Wilhelm (2013) found that the lack of investment in a production system affects production abilities if a manager allows trade-offs in core capabilities. This view corroborates the discussion about budgetary limitations and potential trade-offs between production options. Miltenburg (2005) explained that the higher a company's operational capability is, the higher its overall production function capacity will be to reduce production costs. In sum, researchers found that companies balance cost efficiency and profitability through the proper arrangement of their production function.

Summary

In this literature review, I outlined emerging developments and paradigms in the economy of production and related them to aluminum production. In a competitive business environment, reducing production costs is required to sustain business performance. Researchers found that production cost differences among production companies result from internal distortions, technical inefficiencies (Farrell, 1957; Koopmans, 1951), managerial decisions, and production strategies (Miltenburg, 2005).

Scholars recommend various strategies that influence production function performance including upstream and downstream integration, product differentiation, economies of scale (Miltenburg, 2005; Porter, 1980), and flexible production capabilities (Ajmal et al., 2012). Blair and Kaserman (2014) found that variations in prices to acquire resources affect a company’s production cost structure; however, the impact of price variation is reduced when such resources are integrated. Five overall strategies are identified to improve performance in aluminum production: (a) technology-based strategies, (b) resources-based strategies, (c) energy-efficiency-based strategies, (d) innovative-based strategies, and (e) operational-flexibility-based strategies.

These strategies are not actions that production managers can implement routinely in day-to-day production practices. Fundamental barriers to production cost minimization exist, given the technical challenges involved and the characteristics of the aluminum electrolytic process. Reducing production costs requires that a company be technically efficient—a state of production that necessitates efficient allocation of resources at distinct levels of production (Baik et al., 2013; Jones, 2011; Miltenburg, 2005) and a full exploitation of economies of scale in a production system (Porter, 1980; Ray, 2015). Scholars agreed that differences in firms' production cost efficiency emerge from resources usage (Farrell, 1957), misallocation of core resources at distinct functional levels, and insufficiencies in the adoption of technology (Baik et al., 2013; Jones, 2011). Selecting appropriate technical functions and procedures for a production system is essential for minimizing production costs and input utilization (Herrmann & Kayasa, 2012).

Yang et al. (2016) recommended analyzing technical efficiency using nonparametric techniques, such as DEA. DEA is an analytical research instrument used in operational research to estimate the effectiveness of various DMUs when the production process exhibits an arrangement of many inputs and outputs (Farrell, 1957; Park et al., 2015). DEA can allow evaluation of capacity utilization, the minimum long-run average costs, and the expected level of outputs (Ray, 2015); furthermore, it can compare the performance of different companies within an industry.

A firms' technical ability has implications for production costs. Efficient resource allocation tends to minimize production costs (Miltenburg, 2005). Inefficient resource allocation often leads to lower levels of production outputs, resulting in lower productivity (Jones, 2011; Miltenburg, 2005; Shepherd, 2015). Camuffo and Wilhelm (2013) found that misalignment in or shortage of resources can produce unbalanced performance and a trade-off among functions in a production system. Resource complementarity is critical in production systems for developing production efficiency (Porter, 1985).

Transition

In Section 1, I provided the background to this qualitative comparative case study. The purpose of the research was to identify the strategies some aluminum production managers might implement to reduce production costs. I also outlined the conceptual framework and provided insights about the lens through which I viewed the connection between the economic theory of production and primary-aluminum-production strategies. According to this literature review, strategies for reducing production costs are upstream and downstream activity exploration; innovative production processes; and productive, technical, and allocative efficiency. Innovation can contribute to the economy of production by reducing costs. Creative leadership, change-oriented practices, external monitoring, and workforce expertise are moderators of success (Latham, 2013) for improving the production performance.

In the next section, I restated the purpose statement and outlined the role of the researcher in the data collection process. I also discussed procedures for contacting participants and gaining their consent with the aim of building a working connection with the senior managers. Additionally, I identified measures to consider for guaranteeing the ethical inclusion and protection of human subjects. In the remainder of the section, I addressed the research method and design and provided a rationale for the data collection procedure used throughout the collection process. Other components discussed included the description of the population and the sampling strategy, data collection instruments, and the data analysis technique recommended for this qualitative multiple comparative case study. Because the participants and I might have induced bias in the data collection and data interpretation processes, I outlined strategies for addressing potential threats to reliability and validity.

In Section 3, I covered the results of the study with a thorough summary and interpretation of the findings and evidence. I also illustrated the results by demonstrating the evidence and linking the results to the conceptual framework because they all relate to the RQ under study. Additionally, I provided a framework for the discussion, researcher reflections, recommendations, and implications for business and social change.

Section 2: The Project

The purpose of this qualitative, comparative case study was to identify the strategies some aluminum producers might use to reduce production costs. Mainstream economic theoriests of production agree that most decisions in production management are concerned with profit maximization by minimizing the inputs used to produce a given amount of outputs. Reducing production costs requires that a company be technically efficient—a state of production that necessitates both the efficient use of inputs (Farrell, 1957) and the allocative efficiency of resources at distinct levels of production (Baik et al., 2013). Firms' technical abilities have implications on production costs. Selecting appropriate technical functions and procedures for a production system is essential for cost minimization and resource consumption.

The preparation for data collection in developing a case study is challenging because data gathering and analysis require the use of appropriate procedures for producing ethical research. Should a researcher fail to address threats to reliability and validity, the entire case study may be jeopardized (Yin, 2012). To develop this case study, I ensured that the human participants engaged in the research were protected. After guaranteeing that this research was ethical, I sought approval from the institutional review board (IRB). Second, informed consent was administered from all research participants, and I developed a case study protocol that provided a model for conducting ethical research.

Additional policies I included in the data collection subsection comprised the data collection plan, strategies for producing information saturation, the selection criteria for both the participants and the sites under study, and the ethical research strategy I used to protect human subjects. Finally, I provided the procedure for gathering and analyzing data and for detailing the quality research criteria employed in this study. These quality measures constituted the basis for guaranteeing the reliability and validity of the findings as well as the researcher's steps to preserve a high level of integrity.

Purpose Statement

The purpose of this qualitative, multiple comparative case study was to explore the strategies that some aluminum producers might implement to reduce production costs. The targeted population included aluminum production senior managers in Western Europe. I studied a purposeful sample of four companies for comparing the production strategies: two companies that were achieving sustained production costs and two that were not. I interviewed experienced senior production managers and used documentary analysis to identify core themes and concepts that producers may develop into strategies for reducing production costs.

This research has implications for positive change because the findings may help companies increase their business sustainability and job security, both domestically and internationally, as well as helping other industries that rely on aluminum within the supply chain. Companies may also use the findings of the study to optimize their use of resources and contribute to protecting the environment. According to the European Commission (2013), aluminum production is essential to maintaining a continuous supply of semifinished products to small- and medium-sized enterprises downstream.

Aluminum companies that continue to yield high production costs and lower profitability may put the job security of the local community at risk.

Role of the Researcher

My relationship with the subject of aluminum production strategies for reducing production costs derived from the experience I have in the aluminum field, an experience that has been at midstream for more than 2 decades. I understand that my knowledge and my epistemological insights can help shed light on the selection of the theoretical frameworks and methods that could lead to ethical research as well as to potential implications for the aluminum production business. Hook (2015) stated that epistemology, as a core ingredient of qualitative research, is at the forefront of the theoretical direction of research. An adequate connection between my epistemological insights, the conceptual orientation of this analysis, and the RQ was critical in this research because this case study was applied research in a sector that was facing contemporary industrial issues.

It was essential to write the correct RQ, select the appropriate theoretical frameworks, and adopt an adequate approach to data gathering and analysis. The epistemological wisdom for which I advocated could produce outcomes that were trustworthy, reliable, and ethical, given their theoretical foundation. I ensured credibility and validity in this case study so that the findings could result in conceptual and literal replication. My goal in conducting this study was to seek to close the existing industrial gap between the present state in which aluminum production companies are facing high production costs, and the desired future business managers expect.

I aimed to maintain ethical research by ensuring that the four commonly used qualitative criteria for rigor—trustworthiness (Perkins, Burton, Dray, & Elcock, 2013), credibility (Guba & Lincoln, 1994), transferability (Houghton, Casey, Shaw, & Murphy, 2013), and confirmability (Noble & Smith, 2015) —were met throughout the research process. The paradigmatic view I selected for gathering and analyzing data was constructivism, and the type of data analysis and reporting was interpretivism. Interpretivism and constructivism are two intertwined epistemological stances (Gorski, 2013) that acknowledge reality as contextually based and by which researchers seek to understand phenomena by constructing meaning through interactionism and interpretation (Huberman & Miles, 1994; Merriam, 2014; Onwuegbuzie & Byers, 2014).

During my professional life, I have experienced several commodity price cycles in the production of primary aluminum, moving within explicit price upturns and downturns (USGS, 2014). During these cyclical movements of aluminum commodity prices, many companies have experienced profitability losses that led to smelter closing or curtailments (Götz, 2014) as producers struggled to manage plunging prices. This doctoral study stemmed from my frustration in searching for how some aluminum managers might have failed to implement strategies to reduce production costs. Therefore, I sought to explore strategic practices that might allow production expenses to reduce in the production of primary aluminum.

I promoted an anticipatory method in this study, preferably to reactive responses (Palmer, Fam, Smith, & Kilham, 2014) to manage potential ethical difficulties that may arise. This approach was to read recently published peer-reviewed case studies to learn from the experience of others. Learning from experience is fundamental to adaptation (KC, Staats, & Gino, 2013). Prior successes and failures can help people overcome their weaknesses (KC et al., 2013) and might provide a wealth of information.

Data Collection Program

Most scientific research involving human subjects have risks, particularly when a researcher gathers information from companies and human subjects. The Council on Population, Social Sciences, and National Research (2014) identified informational, physical and psychological, and data protection among the many risks facing human subjects in scientific research. Building on this premise, I took appropriate steps to address the risks thereof.

Stake (1995) recommended a useful preparation method that requires writing a protocol and developing a plan of action before data collection. The premise in conducting ethical research was to raise my awareness and sensitivity about ethical issues that might arise. I went through a training about protecting human subjects, as well as reacting to unexpected situations and acting in a sound ethical manner.

CAQDAS capability provided a systematic approach to locating evidence and counter-evidence within the text that was analyzed (Gläser & Laudel, 2013). I used Atlas.ti software, which provided an efficient methodology of coding and linking information (Cornish et al., 2013; Tummons, 2014) as well as extracting and analyzing data from within and across cases.

Challenges in Data Collection

The main difficulties I encountered included the reluctance of the companies selected to sign the letter of cooperation, creating a productive relationship with participants, obtaining the quality of participants who fulfilled the qualitative criteria I selected in the research and complying with the interview planning given the diverse geographic locations of the participants. Rimando et al. (2015) also reported these numerous data collection challenges in qualitative studies. The most commonly reported problems were addressing the participants' reluctance to participate, selecting the suitable environment for the interview, a lack of experience in conducting interviews, and obtaining informed consent.

This research was planned to follow ethical criteria from inception; I only proceeded after I received approval from the IRB. I took appropriate steps to select neutral locations for interviewing participants. Ashton (2014), Namageyo-Funa et al. (2014), and Rimando et al. (2015) stated that the lack of neutrality in a place of a meeting could influence the quality of details provided by a human subject. For example, participants may provide biased responses to the interview questions if the location is not neutral (Namageyo-Funa et al., 2014).

A researcher needs to protect the identity of the participants throughout the study (Council on Population, Social Sciences, and National Research, 2014). The interview protocol (see Appendix A) included the interview questions, the procedural nature of interviewing, and the policies about maintaining the independence of the participants in developing their thoughts (Van Wijk, 2014). Hannes and Parylo (2014) and Hall, Prichard, Voogt, and Zuccato (2014) emphasized that a researcher must use a form to obtain participant consent. Through this approach, I described the steps I used to assure confidentiality.

Although Graham, Powell, and Taylor (2014) recommended that participants must be guaranteed fair compensation, no ascertainable financial earnings were expected in this study; therefore, no compensation was offered for participation. Furthermore, in conformity with the suggestions proffered by Chan, Fung, and Chien (2013) about eliminating personal judgment, I mitigated my potentially preconceived notions to temper deleterious effects that might have influenced the analysis quality. Cruz (2015) argued that failure to overcome personal belief in scientific research might foreground the researcher's subjectivity and undermine decisions made in a study.

Gaining Access to Participants

The sample population was senior managers in aluminum production from Western Europe. I included four aluminum producers: two companies that are achieving sustainable production costs and two that are not. Cleary, Horsfall, and Hayter (2014) and the OHRP (2005) recommended selecting participants who meet ethical criteria of the research. I selected senior managers who complied with the criteria for producing ethical research. The Office for Human Research Protections (OHRP, 2005) stated that participants must possess both the adequate age and the legal capacity to negotiate consent as well as an appropriate understanding of the impact of engaging in the research.

Participant Selection

The U.S. Department of Health (2014) stressed that vulnerable populations who may be coerced should not participate in research. Cleary et al. (2014) emphasized that inappropriate participant selection could lead to decreased precision in explanations. Cleary et al. commended the selection of participants according to their capacity to inform the RQ and to illuminate the researcher's understanding of the topic under study. These authors acknowledged the richness and depth of analysis that experienced participants might provide.

Before the data collection, I fulfilled the IRB's requirements for conducting ethical research and protecting human subjects. To enhance my knowledge on conducting ethical research and to demonstrate my intent to comply with the IRB's requirements, I passed Human Research Protections training at the National Institutes of Health. I obtained a completion certificate, which I presented to the IRB along with all the drafted letters of confidentiality. These documents included the initial letter of contact addressed to participants, the consent form, and the privacy agreement sent to the transcription services that had access to the raw data. I described reasonable and foreseeable risks or discomfort that the participants and sites might face. One of the eligibility criteria I selected was that participants should be senior managers who had 10 years of experience in the production of primary aluminum. I assumed that this population category had the psychological, intellectual, and physical ability to understand, accept, or reject arguments. I planned to provide additional protection to vulnerable populations that I might have included unintentionally.

Apart from the doctoral graduation, there was no foreseeable benefit from the researcher's perspective; therefore, I disclosed in the consent form that no anticipated benefits to subjects were planned. I had no conflicts of interest about the subject under study or the participants; also, I included a statement that participation was voluntary so discontinuing participation involved no penalty. I began recruiting participants (e.g., contacting senior managers, obtaining signed consent forms) only after the IRB approval. Participants exhibited high responsiveness to the initial e-mails.

Because I encountered difficulties obtaining cooperation letters from companies, I submitted a request for a change in procedures form to the IRB to drop site observations because the companies I selected were stringent in confidentiality issues. Yin (2012) advised that a researcher must stay adaptive if unanticipated events occur, and the researcher should make minor changes when required. The IRB treated the request as an expedited review because the proposed changes did not increase the level of minimal risks identified in the initial application.

Data collection and analysis occurred concurrently. The data sources used in this doctoral research included semistructured interviews, comprised of open-ended questions, and documentary review. For the interviews, the first step was to select participants based on the purposive eligibility criteria I had decided. For example, the subject should be knowledgeable about aluminum production and operational practices and should have a minimum of 10 years of experience in the field. These criteria were challenging to meet given the number of participants required to attain data saturation.

More specifically, I read no less than 100 senior manager profiles in the network from which I recruited the participants.

The purposeful sampling is justifiable in a study to yield substantial information quality (Palinkas et al., 2015) in answering the RQ under study. After I had identified eligible participants, I sent the initial letter of contact, which the IRB had approved. The acceptance rate was approximately 85%. Upon acceptance, I planned the interviews in agreement with the participants based on their availability.

Initially, it was arduous to establish the relationship with some senior managers as a novice researcher for several reasons. For instance, some senior managers lacked the motivation to provide data to a transient person. Potential cultural differences could justify this reluctance. Nevertheless, the cultural susceptibilities needed cultural competencies (e.g., developing awareness, knowledge, skills, and adaptability to each personality) to overcoming reluctance within the same interview. Hoskins and White (2013) recognized that new researchers might face challenges convincing potential participants and putting them in a comfortable situation to converse openly. Bonevski et al. (2014) argued that participants often have a concern about disclosing details to a researcher. Nevertheless, the method of interviewing was managed as a collaborative process in which I aimed to use the knowledge and positionality of the participant to maintain the conversation active and exhaustive. Although I had the impression of facing challenges connecting with some of the participants, the competencies I used to convince one person did not necessarily succeed with another one; a quick adaptability to personality was a decisive factor.

Addressing Issues of Risks and Discomfort

The first step in addressing potential risk and discomfort was to inform each participant that there was no foreseeable risk or discomfort involved in this research. The IRB approved this study (see approval # 01-06-17-0395650); as such, I took the necessary steps for producing ethical research by guaranteeing trust and confidentiality. I also informed the participants that I would protect their identifying details, if any, and those of their company through anonymization of raw data.

The second step was to convince the participants to allow audio taping of the interview. The argument I used to convince participants was that I needed to avoid losing valuable information because each interview was vital in this process to capturing contextual and intervening conditions to reduce production cost. Most senior managers accepted the audio taping method. The relationship with the senior manager became more open and trustful when I clarified these details and presented the purpose of the study as well as how I would address issues of confidentiality. I appreciated the senior managers for their experience in the aluminum production field. In using this approach, I assumed that every individual might be grateful to receive a positive testimony, which demonstrates sensitivity and respect as an evidence of a distinguished accomplishment. I also discussed how I based the participant selection on their intensive experience in the production area; therefore, I expected them to add significant value to the research findings.

I was committed to protecting the identities of the human subjects. All written information gathered from the interviews has been secured and will remain for at least five years in a personal combination safe. Mitchell and Wellings (2013) recommended that the researcher should be the only person to access participant details. I secured the digital and electronic data by assigning specific codes to the companies' names (e.g., Company A, B, C, or D), aliases to participants' names (e.g., Participant #1A, #2A), and by a personal password-protected computer flash drive.

Benefits, Voluntary Participation, and Informed Consent

Ethical issues may emerge when there is lack of trust and reciprocity regarding benefits between the researcher and participants (Graham et al., 2014). Graham et al. maintained that all members must profit from the research. Furthermore, Graham et al. recommended ethical principles of fairness and respect among research members.

I discussed with each participant that apart from the doctoral graduation, I do not expect financial benefits from this research; therefore, I will provide no compensation for their participation. Conversely, there will be no costs incurred due to their engagement in the study. Any refusal to answer questions will involve no objection of mine. I provided the Walden University telephone number in case participants would like to talk privately about their rights or have a further referral.

The process of obtaining informed consent. Participants who agree to engage in the study must sign a consent form before interviews begin (Brown et al., 2012; Hannes & Parylo, 2014). Gaining informed consent can be difficult should a researcher fail to explain the purpose and content of the research to the participants (Wirshing, Wirshing, Marder, Liberman, & Mintz, 2014). I informed the subjects about (a) the purpose of the study, (b) their freedom to abandon the study, (c) the respect of their confidentiality, (d) the length of time required for the interviews, and (e) the implied impact of the study. I treated each participant decently. Wirshing et al. (2014) proposed conducting the process of obtaining informed consent in steps. Before the interview, I provided by e-mail information about the purpose of the study, its significance, and implied risks to participants. I also took steps to choose a neutral location for the conversation in such a way to guarantee the participants' confidentiality. The location and its environment were planned to remain neutral because they can affect the quality of communication (Ashton, 2014; Namageyo-Funa et al., 2014; Rimando et al., 2015). At the beginning of the interviews, every participant had to acknowledge that he or she understood all of the potential risks involved.

Research Method and Design

Researchers use three types of research methods including quantitative, qualitative, and mixed methods (Earley, 2014). This study was exploratory given the contextual factors and the multiple variables that influenced production. A qualitative methodology allowed identifying intervening and causal conditions that affected the production cost. The use of the qualitative method was critical because of the complex processes involved (Hoon, 2013) and the dynamic forces that affected production costs in aluminum production (World Bank, 2013). Given these dynamic forces and complex processes, I discovered diverse views in response to the RQ. I used the data saturation principle to determine the adequate sample size.

Research Method

Qualitative researchers focus on the way a researcher and the participant interact to understand the research problem (Holloway & Wheeler, 2013) in an economic, social, and cultural context (Hazzan & Nutov, 2014). Merriam (2014) discussed that qualitative studies also contribute to evidence-based practices, and through this contribution, business people, among others, can make sense of their experiences. Qualitative studies constitute an opportunity for scholars to interact, explore, understand, and interpret research problems as lived by individuals in their business settings (Gioia, Corley, & Hamilton, 2013; Holloway & Wheeler, 2013). Holloway and Wheeler (2013) explained that the qualitative method is comprehensive and flexible for exploring information at a granular level. Denzen (2012) concurred that qualitative researchers could draw on distinct sources of information to triangulate data and to increase the credibility of the findings.

Given this understanding, several benefits motivated the choice of the qualitative method. First, based on its flexibility as discussed by Ritchie et al. (2013) and Yilmaz (2013), the qualitative method was used to understand and answer this complex industrial question by considering many views and epistemologies to address the problem of production costs facing some companies. Second, I had the opportunity to interact with experienced senior managers in the production of primary aluminum to gather relevant data locally. Third, interactionist-based research emphasizes the value of investigating events in their natural settings (Merriam, 2014), a method that has permitted aluminum managers and the researcher to explore many views of the strategies that might reduce costs.

Fourth, contrary to quantitative data collection methods, qualitative data gathering is not restrained to a formal set of a questionnaire (Yilmaz, 2013). For instance, to shed light on ambiguous and inconclusive answers of participants, I was able to reorient questions in real time to capture granular details as the study unfolded. One concrete example of the flexibility of the qualitative method was that I did not plan to use the quantitative information; however, the flexibility of the method allowed collecting some quantitative data on production costs and energy efficiencies. These quantitative data permitted comparisons between companies' performances. Klein and Myers (1999) advocated interpretivism, which allows disambiguating complexity by delving into an investigation with different prospects. Interpretive research is based on the hermeneutics' underlying principles, which intimate that a researcher may learn to understand a complex phenomenon by analyzing the meanings of its constituents and their interdependence (Klein & Myers, 1999). Because multiple interconnected subunits and processes were involved, disambiguating in this study increased the sensitivity to unique details and differences in the companies' business practices.

Alternative methods to qualitative research include quantitative and mixed methods. The quantitative method neither offers the flexibility to interact with people (Frels & Onwuegbuzie, 2013) nor allows reviewing documents to bring to light the answers to this RQ. Quantitative and qualitative studies on the aluminum production process are scarce (Blomberg & Söderholm, 2011; Boulamanti & Moya, 2016). Mollick

(2014) characterized exploratory studies as the studies conducted on problems exhibiting a limited knowledge foundation of causes and effects. Quantitative analysis, applied in an exploratory study, could be limited because the researchers could evaluate only the relationships between or among variables, quantify the magnitude of the issue, or test a theory (Yilmaz, 2013). As Frels and Onwuegbuzie (2013) and by Yilmaz (2013) stated, the quantitative method is appropriate for correlational analysis, to test hypotheses and theories, and to perform numerical modeling. My audience expected the answers to why and how questions. A quantitative method could not provide these characteristics.

The use of mixed-methods research was inadequate given the likelihood of the conflicting paradigms that might arise (Venkatesh et al., 2013). For example, the purposeful sample of companies exhibiting high production costs and those that were not, was essential to gather relevant data for comparing different strategies used in aluminum production. Mixed-methods research is a combination of quantitative and qualitative analyses in either a concurrent or a sequential scheme (Venkatesh et al., 2013). The Mixed-methods could allow developing insights into complex phenomena that a researcher might not be able to explain using a single method (Venkatesh et al., 2013). In this case, mixed-methods research could have been challenging for many different reasons.

First, given the potential conflicting paradigms between qualitative and quantitative methods (Birchall et al., 2016), the use of mixed methods could have led to a contradiction, a situation that might reduce the consistency and the rigor of the procedures used to collect data. For example, senior production managers were sampled purposefully, as were companies exhibiting high production costs and those that were not. The purposeful sample enhanced information depth and increased the comparability power of different strategies used in low- and high-cost production companies. The use of mixed methods in this qualitative, multiple comparative case study involving a purposeful sampling logic was inadequate. Second, from a practical point of view, Venkatesh et al. (2013) affirmed that the time and costs involved in data collection could be significant when using mixed-methods research. As a result, fewer practical benefits were forthcoming from mixed-methods research.

Research Design

Yin (2012) suggested that a researcher should choose the case study design when (a) the central RQ driving the study is exploratory, (b) the inquirer has limited power over behavioral issues, (c) the focal point of the research is a contemporary problem, and (d) the problem explored is complex. Aluminum production costs depended on numerous constituents including external factors, intervening conditions, technological capabilities, environmental and material consumption intensity. Few studies only referred to production cost minimization in the primary aluminum production. Given that complex and interrelated-cost components have not been studied explicitly to establish cause-effect relationships, this research exhibits the exploratory characteristics. Stake (1995) argued that case studies may be suitable for contextual analyses that are established based on the observational conversion of implicit knowledge into explicit knowledge. Case study design was used to understand and answer this complex industrial question by considering many views and epistemologies to address the problem of high production costs. Pearson et al. (2015), Hoon (2013), and Hyett et al. (2014) considered that one crucial characteristic in a case study is the application of multiple data collection strategies to permit in-depth inquiry of a complex phenomenon. The case study attributes highlighted previously; and the evidence that high production cost in the aluminum production field was a contemporary industrial problem (Behmiri & Manera, 2015), made the case study an ideal design for investigation in this research.

Alternative designs to case study include grounded theory, ethnography, narrative, and phenomenology. Grounded theory is a systematic approach used to develop a new theory arising from data gathering (Compton & Barrett, 2016). This study is applied research; as such, theory-building was not the purpose of the investigation. A researcher uses the phenomenological design to yield some understanding of a social phenomenon based on a participant's lived experience (Blom et al., 2013; Olausson et al., 2013; Sáenz et al., 2013). Investigating aluminum strategies to reduce production costs is neither a social phenomenon nor a meaning-making analysis; instead, it is applied research of an acute industrial problem. Thus, the phenomenological design was inadequate in this research.

Higginbottom et al. (2013) defined ethnographic design as the social science research of communities, cultures, and social interactions. The ethnographic design is focused on a community and the cultural patterns that are widespread within the community (Higginbottom et al., 2013). This investigation went beyond cultural aspects and the analysis of social interactions. The ethnographic design could not provide a decisive advantage in this study because the purpose was to identify strategies used by some senior managers to reduce production costs, not to investigate social issues.

Baškarada (2014) and Potter (2013) characterized narrative design as being the structural method for analysis that is appropriate for learning about social phenomena. The narrative design is a form of qualitative analysis associated with the theory of representation. It can be used as a research design to explore social cognition (Lucic et al., 2015), to portray a group of people, and learn how people organize and derive meaning from events (Robert & Shenhav, 2014). Thus, the qualitative narrative design focuses on the structure of human knowledge (Robert & Shenhav, 2014) rather than gathering and processing data for discovering solutions to address complex industrial problems, such as high aluminum production costs. Thus, the narrative design was inappropriate for use in this research.

Benefits of using a comparative case study design. The case study can take the form of a single or comparative design (Yin, 2012), depending on the intent of the researcher. I selected the comparative case study design to produce data richness by comparing the practices of two sets of aluminum companies, paired because they use similar production processes with distinct production cost structures. A comparative case study design can provide insights into both the historical perspective and the contemporary view of the RQ (Yin, 2012) by looking at the problem from all angles in different contexts. The comparative case study design provided both literal and theoretical replications when addressing different aspects of the production cost study. The single case study design could not provide sufficient knowledge of the business problem under study because of the singularity of each case study and the uniqueness of each context (Merriam, 2014).

Data and thematic saturation. Denzen (2012), O'Reilly and Parker (2012), and Glaser and Strauss (1967) interpreted the concept of data saturation as being the point in the data-gathering process when the researcher finds no new theme to develop different aspects of the RQ. No commonly recognized formula exists for determining the point of data saturation. Researchers have proposed some fundamental rules regarding the argumentation driving to the data saturation point, nevertheless. For instance, Guest, Bunce, and Johnson (2006) conducted semistructured interviews about socially desirable behavior and the accuracy of self-reported sexual behavior. Guest et al. identified 97% of the key codes after just 12 of their 61 interviews. Tribedy and Venugopalan (2012) provided a statistical analysis of the number of interviews and Google Scholar annual citations for single case studies. Tribedy and Venugopalan found that of the top Google performers, the highest average impacts ranged from 15–30 interviews. Further, Tribedy and Venugopalan showed that the Cronbach's alpha rating for thematic prevalence was higher than .75 in the 13-to-18 interview range. In an extensive analysis of the literature regarding case studies, I found that a range of 8–20 interviews could yield a high Cronbach's alpha. This information was essential in planning the data collection program and cost.

I conducted in-depth semistructured interviews, documents review, and member checking to generate data saturation. The data collection and analysis were conducted concurrently. After each interview or document collection, the material was transcribed verbatim and uploaded to Atlas.ti for coding. The Atlas.ti query tool allowed exporting the codes as well as the thematic frequencies to a spreadsheet. I outlined the number of new codes and themes using the graphics method.

When all documents were coded, I assigned a similar prefix to the codes that were similar semantically in meaning. Data grouping was an essential step to understand the differences between various code-families. Besides, I achieved connectivity between the families through using the Atlas.ti functionalities. For example, recycling material was associated with the circular economy. The category, in this case, was the best fitting concept from all codes in a given data set of a single case study. Primary categories were those introduced by the greatest number of participants (high groundedness), secondary themes were discussed by the next most significant number of individuals, and the leftover themes were introduced by the least number of participants and documents. Categories are the codes exhibiting similar meaning. Axial coding allowed reassembling subcategories into essential concepts. From a hermeneutic standpoint, the aim of conceptualizing data was to construct a reality from the interpretation of the text provided by participants and the documents review. The RQ and the conceptual framework guided the categorization scheme.

I sought saturation at two levels including interviews (data saturation) and member checking (thematic saturation). These two approaches to data and thematic saturation were used concurrently to maximize benefits from the synergy. In the first level, I continued interviewing participants until there was a point where the information from many participants started repeating and providing no new insights. Notwithstanding, I assumed that participants might provide only surface level information in the interview stage and, adding the researcher self-reporting bias (Stake,1995), I endeavored to solicit member checking. In the second level, thematic saturation was sought from member checking. I reviewed, interpreted the data, and synthesized the findings, which were sent to participants via e-mails to corroborate and to add or remove information. I continued this repeated and cross-verification process until there were no new themes to answer the RQ and subquestion. Before the point of data saturation, most data (94.5% of the codes) were similar repeatedly; this persistent similarity and negligible variability between interviews provided reasonable confidence that the codes identified were saturated and the description that the participants provided regarding the strategies to reduce production costs were thick. Similarly, I stopped the member-checking process as I noticed that no new intervening concepts or causal conditions emerged to answer the RQ and the subquestion.

Given the multiple case study design, I sought data and thematic saturation for each case, rather than the holistic saturation. I assumed that the holistic saturation of the multiple cases could be achieved based on individual saturations. This characteristic was of paramount importance from a qualitative interpretation perspective because I assumed that each case study could exhibit a different business context, operational capabilities, and intervening and causal conditions of the aluminum production strategy. The literature review, the RQ, and the conceptual framework permitted the interconnection between elements of the data analysis.

As the data analysis unfolded, I identified consensus of viewpoints on aluminum production strategies to reduce cost among most participants interviewed and documents reviewed. The consensus of views was measured based on the similarity and frequency of codes from the two datasets. For instance, I considered the convergence of two similar themes from different datasets when the aggregate frequency of codes composing each theme was higher than 50%. This criterion was based on the homogeneity and quality of participants I had selected in premises. By these rules, the alignment provided some confidence that the minimal discrepancy of views observed in the data might not obscure the saturation point.

Table 3 encapsulates the original codes isolated at a particular stage in the data-gathering process to produce the saturation. I identified 94.5% of the primary themes after six conducted semistructured interviews in each case. At this stage, I gathered an aggregate of 24 interviews and 16 reports. I decided to carry out additional interviews and member checking. The eight subsequent-conducted interviews yielded less than 5.5% new codes, and 94.5% repeated answers. I achieved data saturation after 32 interviews (eight in each case).

Table 3

Total Number of Interviews Conducted to Attain Data Saturation

	Number of semi-structured interviews	Number of documents collected	Percentage of new codes identified	Subsequent interviews
Company A	6	4	97.2	2
Company B	6	4	95.7	2
Company C	6	4	92.9	2
Company D	6	4	94.1	2

Population and Sampling

The population for this case study consisted of senior production managers of aluminum production companies in Western Europe. These companies all use similar production processes, the production of primary aluminum through the Hall-Héroult electrolytic process by electrolyzing the raw material (aluminum oxide) into semi-finished products (European Commission, 2014b). Semistructured, open-ended interviews provided rich information in addition to document review.

Sampling Site Participants

I used a purposeful sample of two companies employing production processes that achieved sustained production costs and two companies that did not, to investigate the strategies some aluminum producers might implement to reduce production costs. This sampling procedure followed a nonprobability sampling logic because the objective was not to generalize findings in a statistical sense. The purposeful sampling was suitable for this case study to yield information-rich cases as suggested by (Palinkas et al., 2015). The quality of sampling allowed identifying contextual, intervening, and causal conditions to answer the RQ. These two groups of companies were different because they used distinct strategies of aluminum production although the aluminum electrolytic process is similar. This heterogeneous group was selected to capture a wide range of perspectives relating to RQ of interest. Yin (2012) further recommended that sites should be selected if they are expected to yield either a comparable or an opposite result.

In light of the criteria described thereof, I selected four companies paired into two categories that could yield literal and theoretical replications along two theoretical dimensions: (a) production costs and (b) production strategies (see Figure 5). In pairing the samples, I sought to reduce variability (within subgroup variability) to make a more comprehensive comparison. The choice of production strategies and production costs was understandable because the two constructs were intervening and outcome of intervening concepts, respectively. Production strategies and costs were also critical components of the RQ. Finally, in choosing these cases, I intended to discover and report findings to highlight disparities and leading to a maximum knowledge gain.

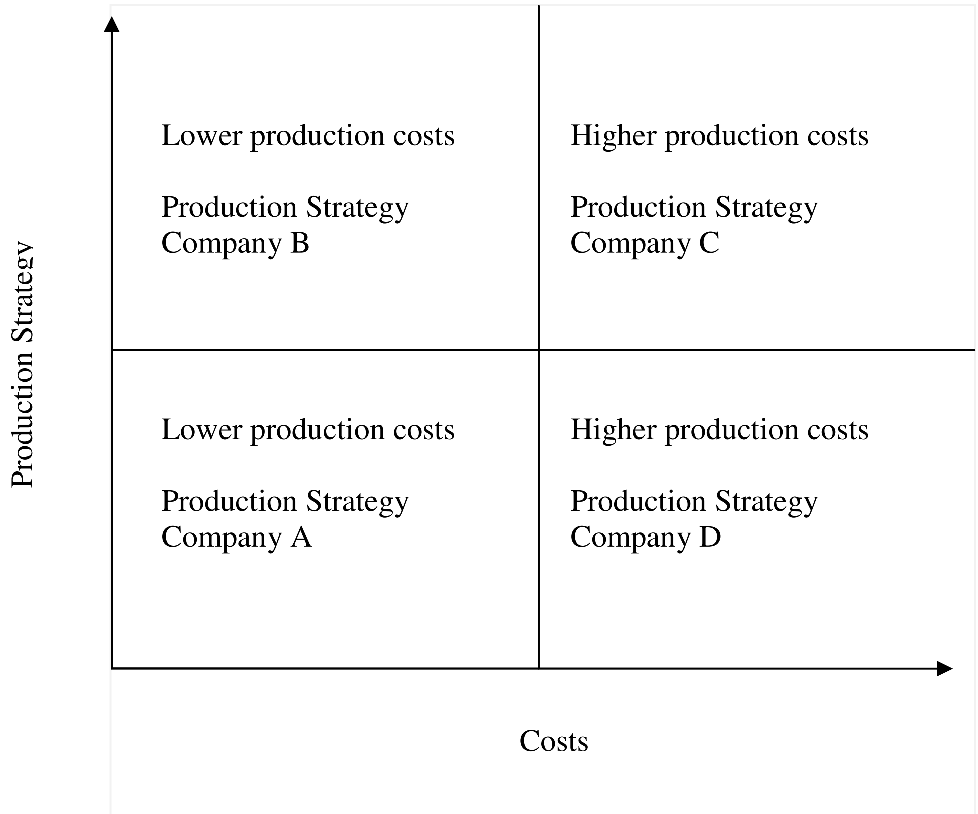


Figure 5. The conceptual sampling structure of the site participants.

The sample size was limited to four companies for technical and economic motives. First, a larger sample size could involve a significant, even a staggering, amount of time to complete data collection. Second, the quantity of data collected in such circumstances could be excessive, and the time and costs for transcribing and analyzing the data could have surpassed the level one independent researcher could reasonably sustain. A sample size of four companies was adequate in this study to provide sound business implications and capture a broad range of perspectives.

Shortcomings to purposeful sampling exist. For example, a purposeful sampling lacks statistical generalizability. A purposive sampling may also introduce the self-selection bias (Lucas, 2014). For instance, the sample might be thought to represent a broad population when in fact, it does not. Addington et al. (2014) maintained that the purposive sample strengthens the data quality. The data I collected were drawn from experienced-senior managers in the aluminum production field, who faced the problem firsthand. The purposive sample in this respect strengthened the data quality. As mentioned by Cleary et al. (2014), a researcher must select the most productive sample to answer the RQ adequately.

Sampling Participants

In qualitative research, the accuracy of the data sampling is a quality criterion and the premise for credibility because the researcher intends to uncover conditions associated with the problem and the context (Stake, 1995). The Council on Population, Social Sciences, and National Research (2014) described how the participant population is recognized, conceivably to manifest decisional vulnerabilities; hence, researchers must take appropriate steps to produce informed consent before conducting the study. McAreavey and Das (2013) maintained that there is no one way of gaining access to participants, but a researcher needs to respond appropriately to ethical issues that may arise. In this study, I used a professional network to identify senior managers (SMs). Furthermore, I invited the SMs to participate by way of an initial personal e-mail. I used a purposeful sample of senior production managers to gain information quality based on their position in each company's hierarchy.

For the sake of consistency, the targeted participants met uniform socio-professional criteria. Homogeneous criteria allowed eliminating variations in responses that might otherwise arise because of cognitive or social desirability bias (Bornstein, Jager, & Putnick, 2013). Participant selection depended on socio-professional criteria regarding (a) the participant's level of responsibility in the aluminum production, (b) the participant's experience, and (c) the participant's knowledge about aluminum production strategies. All participants had at least 10 years of experience in the aluminum production.

Rimando et al. (2015) indicated that low-literate participants might exhibit difficulty understanding complex questions and answering questions adequately. A cognitive bias pertains to a systematic deviation from rationality in understanding—a situation in which judgments on a phenomenon might be illustrated illogically (Croskerry, 2013; Williams, Blackwell, Mackenzie, Holmes, & Andrews, 2013). Croskerry (2013) discussed how some individuals tend to provide particular information based on perceptions, especially when the analysis involves ambiguous and complex situations. In this study, cognitive bias might occur from limited understanding (e.g., a lack of knowledge or experience) of the concepts of interest. Social desirability bias also may influence a participant's ability to answer with honesty and may be a significant threat to the validity of data-self reporting (Kelly, Soler-Hampejsek, Mensch, & Hewett, 2013; Nolte, Elsworth, & Osborne, 2013). Both the cognitive bias (Croskerry, 2013) and the social desirability bias (Kelly et al., 2013) may influence data integrity and validity.

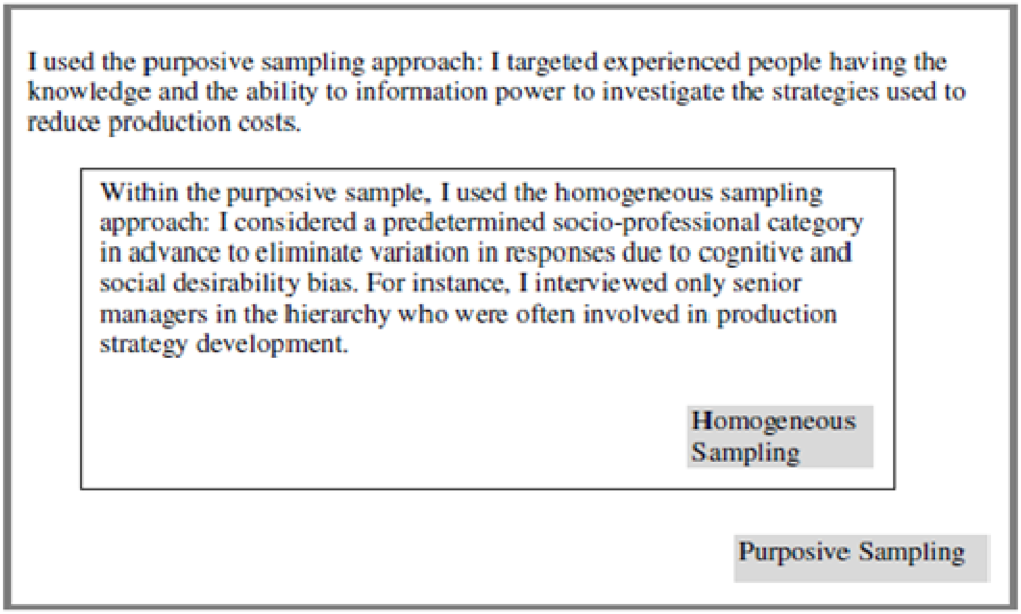


Figure 6. Sampling strategy for selecting participants. Adapted from Bornstein et al. (2013). Adapted from “Sampling in developmental science: Situations, shortcomings, solutions, and standards,” by Bornstein, M. H., Jager, J., and Putnick, D. L., 2013. Developmental Review, 33, 357–370. doi:10.1016/j.dr.2013.08.003

The quality of responses is critical to allow a researcher discover patterns within and across cases and for searching connections across emerging themes (Jeong & Othman, 2016). Given the wide range of purposive sampling techniques, it was critical to select the variant that best fit the goal of this study. The integration of the two criteria—purposive and homogeneous characteristics (see Figure 5), supported mitigating responses bias. Palinkas et al. (2015) also considered the importance of a purposeful sampling and the benefits of considering the sampling strategy by integrating its variants in selecting participants.

Interviewing and Location

The environment and locations selected for the interview were neutral. In most cases, the participant selected a restaurant or a public park to enhance the neutrality and the quality of the conversation. A meeting's location influences the quality of both the answers to the questions and the conversation (Bonevski et al., 2014; Bourne & Robson, 2015; Namageyo-Funa et al., 2014). In addition, the neutral location must be safe to protect a participant’s details and his or her confidentiality (Rimando et al., 2015). The locations selected were safe to provide confidence in protecting the participants’ details as Rimando et al. (2015) recommended. The neutral locations for the interview also allowed me to avoid the intimacy of the family. Haahr, Norlyk, and Hall (2014) found that the closeness of a family is a situation that may disturb the conversation or the concentration of a participant.

Given the geographically dispersed distance of the participants’ locations and the timing of the interviews, I used a technology-mediated communication tool (Skype) in some cases for higher efficiency. The use of Skype allowed overcoming availability limitations. Hanna (2012) also supported that online-interviewing electronic device might allow eliminating the costs of traveling without reducing the quality of the data-gathering process. Bonevski et al. (2014) advocated the benefits of technology-based interviews when collecting data from participants who are not readily available. Nevertheless, all participants had to sign informant consent and send a scanned copy. Skype allowed gathering information rapidly and to closing the availability gap between the participants and the researcher.

Duration of the Interview

The length of the interview and the interview-question structure can influence the data collection quality (Namageyo-Funa et al., 2014). Rosenthal (2016) found that carefully constructed interview questions and the quality of participants might enhance the quality of answers. The duration of the interview was limited to a maximum of 50 minutes, and the number of interviews in a day was limited to two due to the possibility of fatigue. I found that some participants were interested and motivated to provide answers to some topics more than others were. In some cases, I proposed a break for five minutes and suggested having snacks or placing the commands to the restaurant's waitstaff. Participants proved their knowledge about the topic, and they suggested areas of exploration. For example, some senior managers placed a significant emphasis on the circular economy as a source of competitive advantage.

Developing the Interviewing Scheme Based on the Flexibility of the Qualitative Method

Gibbins, Bhatia, Forbes, and Reid (2014) reported that semistructured, face-to-face interviews are the most original interview setting for enriching the conversation and generating qualitative data. Semistructured interviews can offer the flexibility to have a provisional list of predetermined concepts or propositions to explore while allowing the participants to communicate freely within topics (Irvine, Drew, & Sainsbury, 2012). Face-to-face contacts promote an active exchange of ideas between a researcher and the participants (Gibbins et al., 2014). As Irvine et al. (2012) discussed, a semistructured interview is extensive; it allows the person interviewed producing new thoughts during the interview.

The semistructured interview format was used to administer 10 initially planned questions. In this open-ended interview format, I asked similar questions to all participants. This approach allowed collecting answers efficiently, analyzing, and comparing outcomes. I based the decision to use the semistructured interview format on its flexibility and adaptability to new insights, which are characteristics of the exploratory study. Furthermore, this interview format provided a degree of freedom and the flexibility by adding ideas that produced a direct connection to the RQ. Semistructured interviews also facilitated adding follow-up questions to seek convergent information (literal replication) by probing interesting responses or completely different outcomes (theoretical replication).

To maximize the quality of answers to the RQ, I organized the interview questions in such a way to start the conversation with issues that participants could respond with simplicity, followed by the ones that were more complex. The objective of using this approach was to allow raising their level of self-confidence of the participants. One week before the follow-up one-on-one semistructured interview, I sent the list of questions to all potential participants along with the initial contact letter. I found that most participants appreciated the format because they were allowed expanding and exemplifying based on their experience, seldom from the perspectives that I might not have considered highly influential.

After three interviews, I discovered that three of the 10 interview questions I initially planned tended to produce redundant answers. Additionally, upon discussion with a few participants, I observed that some quantitative information was needed for comparing production costs between companies. I decided in agreement with the doctoral chair to merge some questions into a single question focusing on providing substantive information to answer the RQ. In the subsequent interviews, I requested the participants to provide the quantitative numbers to allow differentiating the performance between companies. As Ritchie et al. (2013) and Yilmaz (2013) discussed, the qualitative method offered the flexibility to interact with people and to refine interview questions as the interview unfolded.

Throughout the interviews, the ability to listen carefully to what participants were saying without interrupting was essential for a constructive interaction. Doody and Noonan (2013) suggested that a researcher must show understanding and remain an active listener by maintaining eye contact during the interview. I maintained eye contact and showed passion and respect to what the participants were saying while allowing the conversation to flow without interruptions.

Although I wanted to remain attentive, the modest approach was not systematic, because some probing or follow-up questions were needed to enhance consistency or convergence or to establish clear divergence of viewpoints when required. Some examples of follow-up questions included, “Could you clarify how operational excellence allowed to reduce production costs?” Another probing question was, “When you mentioned that cutting costs through capital expenses have saved USD150, 000,000, could you identify some operational risks or quality issues that could have been induced by cutting these costs and how did your company address them?"

Ethical Research

I attained a high level of integrity by protecting participant information and maintaining trustworthiness throughout the data gathering and analysis. Oquendo, Stanley, Ellis, and Mann (2014) suggested paying attention to both general and specific ethical considerations. The OHRP (2005) recommended that the voluntary consent of the research participants was of paramount importance for meeting the ethical criteria of research. Besides, the participants should possess the adequate understanding of the impact of their participation (OHRP, 2005).

Before accessing the participants, I obtained the research approval from the IRB at Walden University and included the authorization code in the final manuscript. The IRB provided guidance about how to manage ethical research and minimize the risks involved. Criteria to yield ethical research covered (a) the ethically responsible management of private information through new technologies, (b) handling informational risk, (c) the general typologies of risk, and (d) the conventional solutions for managing and minimizing risk (45 C.F.R. § 46.111). Furthermore, according to the U.S. Department of Health and Human Services, mentioned in the Council on Population (2014), the minimal risk implies that the likelihood and magnitude of the anticipated discomfort in the study are less than or similar to quotidian risks. The characteristics of minimal risk provided thereof, derived from regular, physical, and psychological activities that a human subject might face during quotidian actions (Council on

Population, 2014). With this understanding, I considered the human subject protection beyond those cited-minimal risks to ensure that I induced no discomforts (physical and psychological) in the case study procedures, or if any exist, that they would be less than typical minimal risks.

Wirshing et al. (2014) and Oquendo et al. (2014) suggested that a researcher should administer informed consent properly. I applied this process in two stages. In stage one, I provided information about the study's significance and the risks to potential participants. I wrote a letter inviting potential SMs to engage in the study. In this letter, I included information such as (a) the purpose of the study, (b) a statement that participants were free to quit the study at any time, (c) the potential risks involved, (d) the length of time needed, and (e) the intended impact. In stage two, I prepared the data-gathering plan, with the contingencies to dealing with any issues that may arise. At the outset of each interview, I ensured that the participant understood the information detailed thereof and that he or she has signed the consent form before data collection.

I also assured the participants that no physical or psychological harm from their participation was expected. Stacey and Stacey (2012) stressed the need for a researcher to produce accurate, honest, and reliable reporting of data as well as to maintain high-quality relationships with all participants. I kept a high level of trust throughout the research process by building genuine relationships with all SMs.

Stacey and Stacey (2012) maintained that the researcher should avoid any cultural bias and unfair practices as well as conflicts of interest between the interpretations of evidence and organizational goals. There was no discrimination toward human subjects based on ethnicity, age, gender, race, national culture, sexual orientation, disability, or socioeconomic status. Finally, I maintained the privacy, confidentiality, and anonymity of the participants as recommended by Oquendo et al. (2014) and Stacey and Stacey (2012). As suggested by Yin (2012), I have planned to store the raw data for at least five years so that other scholars may retrieve them efficiently after the initial research.

Data Collection Instruments

Planning Data Collection

Data collection is a crucial step to ensuring a study's reliability (Yin, 2013). To achieve quality in scientific research, a researcher must create a methodological framework that integrates ethics in data gathering and analysis (Rimando et al., 2015). Anyan (2013) supported the use of various sources of evidence to provide in-depth insights. The data collection planning was essential to develop, based on the requirement to anticipate ethical issues. In developing the data collection plan, I aimed to (a) identify the appropriate method to use, (b) assess all steps in gathering data, (c) plan resources and make them available, (d) identify possible ethical issues, and (e) write the protocol to access participants and data. The steps involved in the data collection included identifying and gaining access to SMs, obtaining participant consent, collecting and storing information, addressing implied constraints (Yin, 2012), and conducting member checking (Simpson & Quigley, 2016). In this study, I built a positive relationship with participants as a premise for successfully gathering data.

Data Collection Instrument

Yin’s (2012) interpretation of the data-gathering instruments considered the methods associated with the utilization of any particular source of data. Yin advocated the combination of multiple evidentiary sources to strengthen the credibility of the findings. I used interviews and documentary analysis to triangulate information. I also used the interview protocol to describe the background of the study and the quality measures undertaken to protect participants. The interview protocol (see Appendix A) included the interview questions, the procedural nature of interviewing, and the policies of protecting and maintaining the independence of the participants as they develop their thoughts (Van Wijk, 2014).

I used supplementary electronic instruments—a SONY Voice Recorder and ATLAS.ti—for data recording and coding, respectively. The voice recording allowed me to capture detailed information from the interviews that I might otherwise have overlooked. The SONY Voice Recorder device allowed maintaining eye contact with the person interviewed. Cornish et al. (2013) and Tummons (2014) claimed that the computer program Atlas.ti is an efficient and effective data coding and analysis tool.

Leedy and Ormrod (2013) maintained that qualitative researchers often serve as instruments for data gathering. I was the primary instrument, as a researcher, for the data collection. The researcher, as a primary instrument of data collection, might threaten the integrity of a study if he or she fails to have the appropriate self-awareness regarding potential sources of bias during the data-collection process (Ritchie et al., 2013). To mitigate these possible sources of bias, I reviewed the transcripts and allowed the senior managers to do the same. According to Harper and Cole (2012) and Loh (2013), allowing member checking can address the convoluted issue of trustworthiness. During the member checking, the SMs had the opportunity to review their statements. Of 32 interviews, three SMs called for revisions of some answers to the interview questions.

Guba and Lincoln (1994) suggested that participant review should occur at the end of each interview or near the end of the data-gathering process. According to Guba and Lincoln, the researcher needs to review the transcripts, identify central themes, synthesize the findings into few paragraphs, and submit the summary to participants for reflection and authentication. Harper and Cole (2012) recommended that a researcher summarize information at the end of each interview and ask the participant to authenticate the accuracy of the summary.

Member checking can occur during the interviews or after data have been gathered; these two approaches are not mutually exclusive. Because the data gathering and analysis occurred concurrently, I used both methods in this research. I informed all participants that the interview transcript would be sent to them by e-mail so that they could reexamine the accuracy of the content. In doing so, I aimed to allow the participants to make needed corrections. Participants were also told to make required changes and return within two days to maintain the data analysis flow. Some SMs voluntarily requested to perform the transcription review for correcting mismatches or adjusting areas that might have been overlooked or to provide additional insights related to the RQ.

I emailed the transcription to the concerned SMs immediately after anonymizing. They made corrections that I classified into three categories. For example, in the first category, Participant 2A provided additional quantitative details regarding the carbon consumption efficiency. These details were overlooked in the initial interview. I documented all revisions for further referral. The transcription review process was also an approach to enhance trustworthiness and to demonstrate that I implemented the confidentiality process as discussed in the consent form. For example, none of the participants highlighted a violation of the identifying details, because the transcripts at this stage were anonymized from threats to confidentiality. In category two, the interview was transcribed incorrectly in one case. In the audio tape, the SM mentioned, "low-energy consumption contributes to reducing costs." The transcriber wrote, "low-energy consumption efficiency contributes to reducing costs." Operationally, these are two opposing sentences. In the third category of amendments, the participant added insights that he omitted in the initial statements. None of the participants removed valuable details that could influence the quality of the initial data.

In conducting the process of transcription review, I was conscious of some potential threats that participants might introduce. For instance, a participant might revise the content to alter the accuracy of the original verbal dialogue, should threats to confidentiality surface. I found that most senior managers added valuable details and new insights to answer the RQ. For example, the code about increasing the electrolytic cell lifespan emerged from the first transcription review. Increased asset lifespan can allow capital expenses minimization and production cost savings. The transcription review allowed me to improve data quality and provided more clarity to certain ambiguous statements.

Furthermore, to confirm themes after data triangulation, I interpreted the data at the end of the data-collection program, identified core themes, drafted a summary, and submitted it to two SMs in each case study to provide reflection and authentication. I used follow-up e-mail as a communication means to reach the SMs and to share the data interpretation.

Data Collection Technique

Scholars such as O'Reilly and Parker (2012), Strauss and Corbin (1998) discussed the importance of adequate sample size in qualitative research; however, no consensus has been reached to guide researchers in determining the appropriate sample size. Some researchers determine the appropriate sample size by using the concept of data saturation. For instance, Strauss and Corbin (1998) defined data saturation as attaining a level of information that answers the RQ such that no new information emerges. Based on the recommendations of Guest et al. (2006) that data saturation occurs after 12 interviews, I planned a range of 8–12 interviews for each case. After six interviews, however, I noticed that information started repeating. I decided to continue collecting data until I witnessed no new themes to develop the RQ and the subquestion. I achieved data saturation after 32 interviews (eight in each case). Additionally, 16 documents were collected (four in each case) and the member checking was solicited.

Data-Collection Steps

A proper planning of the data-collection process must start with a case study protocol (Yin, 2012). In addition to clarifying the purpose and the structure of the interviews, the protocol was the document in which I identified potential issues that may occur. I also used the case study protocol to develop strategies for addressing potential ethical intricacies. Yin outlined steps required for the data-collection process. The steps needed in this research included (a) writing the case study protocol; (b) identifying sites and participants; (c) obtaining access to human subjects and administrating informed consent; (d) resolving potential problems; and (e) interviewing, collecting, and storing data. Interviews and document gathering constituted the primary data sources. Interviews allowed direct interactions with SMs and permitted me to gain a deeper understanding of the problem under study from the perspective of participants. After each interview, the participants had the opportunity to review the summary of the most relevant points, authenticate the accuracy of the answers, and make corrections where needed. The saturation method and member checking increased the validity and credibility of the findings (Guba & Lincoln, 1994).

Interviewing

Although face-to-face interviewing is the preferred method for discovering and interacting with a participant to identify patterns (Bouchard, 2016), another strategy was to use Skype and online interviewing to access some remote participants. Online discussions allowed the participants to answer questions in an anonymous environment. Online interviewing has advantages and drawbacks when compared to the traditional method of interviewing (Bouchard, 2016; Ritchie et al., 2013). Some drawbacks pertained to the network availability and a lack of direct interaction between the interviewer and the interviewed. Notwithstanding, this interviewing setup allowed the rapid deployment of the questionnaire and a faster return of the responses.

Value Added from the Document Analysis

According to Petty, Thompson, and Stew (2012), the document analysis involves reviewing procedures, annual reports, meeting minutes, and the companies' trends. I analyzed the documents that were prevailing to complement the interviews (see the procedure located in Appendix B). Yanow (as cited in Owen, 2014) found that text analysis constitutes the evidence a researcher may use for clarity and it can corroborate or refute interview data. Using text analysis in conjunction with semistructured interviews allowed distinguishing information convergence.

Fundamental to document analysis is that a document must be valid, decipherable, original, authentic, and relevant to the context under study (Owen, 2014; Petty et al., 2012). In this study, I used annual and strategic reports. These documents were all available in the public domain and on the companies’ websites. I interpreted the material through the methodology of constant comparative analysis (CCA) as recommended by Glaser and Strauss (1967), to recognize central themes related to production cost minimization. According to Elo et al. (2014), a prerequisite for the document analysis is that a researcher must reduce data into categories and concepts that describe the RQ. CCA is an approach to data analysis by which a researcher discovers core themes through iterative reading, and by comparing new codes with the previously identified clusters (Pinto et al., 2012).

Before coding, I anonymized and uploaded the document to Atlas.ti. Furthermore, I read the report repeatedly before coding. Franzén and Brown (2013) recommended that the analysis of the textual material require deconstructing each document into quotations before identifying primary categories. As I reviewed the data and assigned a prefix to each primary code, concepts matured gradually and became self-evident. Fram (2013) suggested comparing new codes with existing codes in the dataset. I compared each new code with the previously identified concepts in the dataset. As I gathered data incrementally, I grouped similar codes into clusters to form subthemes and then the concepts of interest. During this process, I wrote memos; provisional abstractions of concepts or reflective notes about what I was learning from the data analysis, the concepts that were unfolding, and the relationships among concepts.

The RQ was about identifying the strategies that some aluminum companies might implement to reduce production costs. Pinto et al. (2012) considered primary categorization as open coding. Supplementary reading of the code list allowed me to refine the coding structure to yield the second level coding. Both the RQ and the conceptual framework provided the categorization structure for coding.

Weishaar et al. (2012) recommended comparing themes within a document, across documents, and with concepts within the existing literature. The second stage of the thematic identification involved cross-linking categories and concepts based on the potential relationship among them to generate emerging themes. Atlas.ti was helpful in this cross-linking process. I linked categories with each other within the document and across other documents through transitive relationships. In the data analysis realm, this phase is termed axial coding (Weishaar et al., 2012). In the final stage, I grouped the concepts to generate organizing themes. I further triangulated these organizing themes with those identified from interviews to yield ideas held in unison. As proposed by Petty et al. (2012), data collection and data analysis should occur concurrently, constructed via an iterative process to building codes and to addressing diverse views as well as competing explanations. I used the concurrent approach to data gathering and analysis to gain incremental experience.

Data Organization Technique

I followed the methodology established by Huberman and Miles (1994) for organizing data. According to Huberman and Miles, data organizing consists of (a) conducting interviews, (b) obtaining the transcript of each interview, (c) anonymizing all details, (d) writing memos to establish consistent criteria for coding, (e) coding, (f) creating hierarchical network, and (g) clustering groups according to their similarities.

After each interview, I provided the electronic file to the audio transcription services. The agency offered a full confidentiality package for all audio-to-text services requested. Before the transcription, I signed the letter of compliance and privacy protection with the transcription services. The transcriber transcribed each audiotaped research file verbatim. The turnaround time for each transcription was approximately 24–32 hours.

I anonymized each file received from the transcription services through removing all identifying details. Similarly, I removed all possible identifying features from each publicly held document collected before uploading it to Atlas.ti. To maintain confidentiality, I assigned a pseudonym such as "Participant #1A" to each file name. The Participant #1A denotes the name of the senior manager from Company A. Before coding I prepared the data by organizing the files into distinct computer folders based on the interview source; furthermore, I uploaded the files to Atlas.ti. In planning within- and between-case analyses, files were named Company A, B, C, or D.

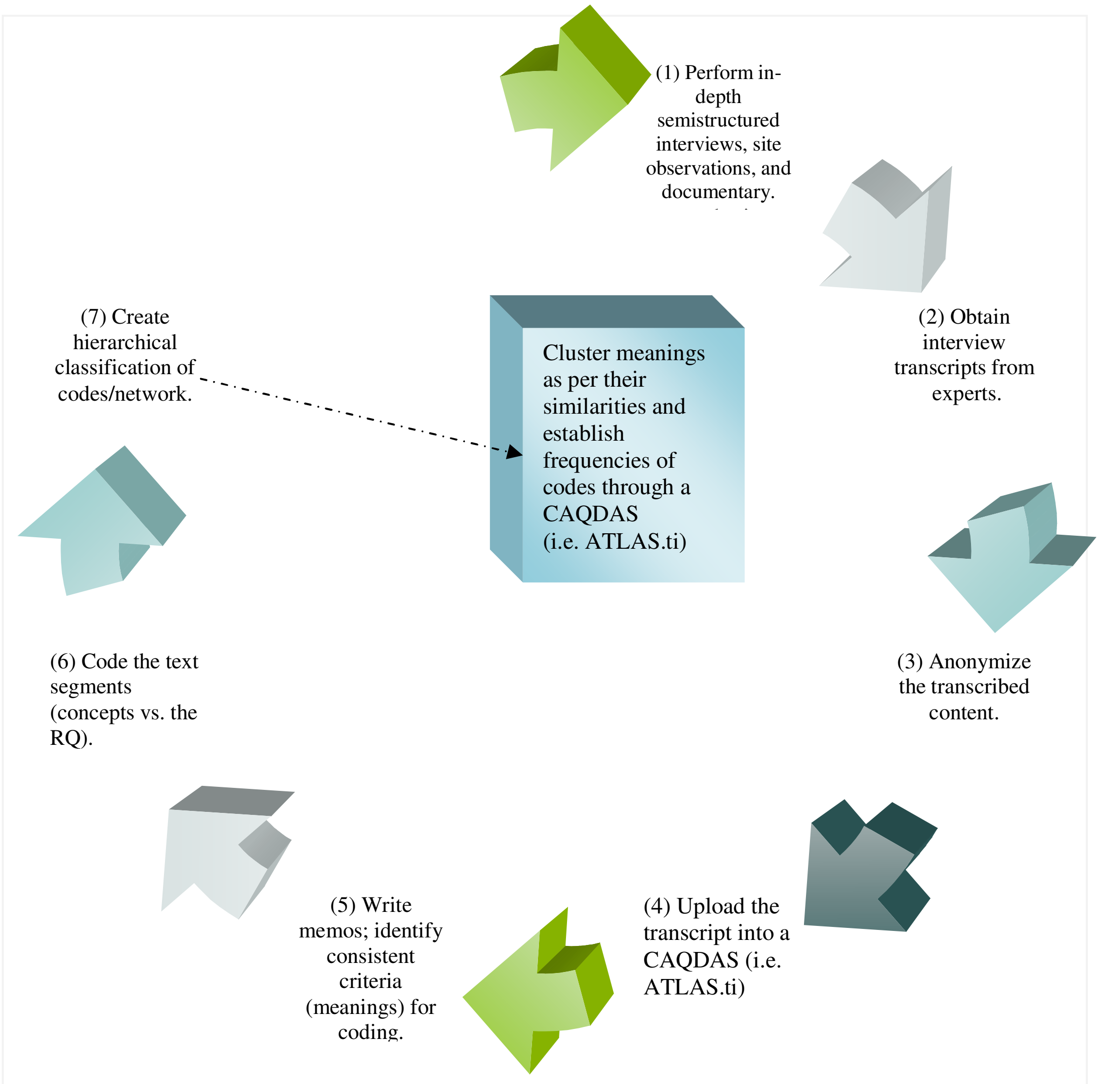


Figure 7. Data organization technique, adapted from Huberman and Miles (1994). Adapted from "Data management and analysis methods. In N. K. Denzin & Y. S. Lincoln (Eds.)," by Huberman, A. M., and Miles, M. B., 1994, Handbook of qualitative research (pp. 428–44). Thousand Oaks, CA: Sage.

Concurrency of Data Collection and Analysis

Haas, Hermanns, and Melin-Johansson (2016) and Merriam (2014) elaborated on the importance of the concurrence of the data collection and analysis. The concurrence of the data gathering and analysis presents numerous advantages. For instance, as a researcher develops codes using an iterative approach, further discussions with participants become more focused and intense (Merriam, 2014; Petty et al. 2012). I used this approach to enhance the coding quality because outcomes from all prior interviews permitted to strengthen the subsequent discussions with participants.

As recommended by Merriam (2014), I considered that data gathering and analysis was a recursive and dynamic process in which I composed codes iteratively by interacting with participants, analyzing data via a qualitative-computerized software, thinking about intervening and causal concepts, refining codes, and reversing to interviews. I assigned codes based on the pertinence of the concept used by the participants as well as the code convergence with the concepts underlying the RQ.

Data Analysis

Philosophical Assumptions for the Data Analysis Technique

Different strategies exist for analyzing qualitative data in case studies. Three influential authors, Stake (1995) and Huberman and Miles (1994), have proposed different approaches to analyzing qualitative data. More recently, methodologists, such as Yin (2012) and Merriam (2014) have added approaches to the research on analyzing qualitative data. Differences between these strategies depend on the epistemological orientation of the authors (Yazan, 2015). In this qualitative, multiple comparative case study, the methodology was rooted in constructivism and interpretivism, given both my epistemological inclination and the exploratory nature of the study.

Merriam (2014) argued that qualitative studies are based on the philosophical assumption that people interact with their social contexts to construct reality. Merriam's conception of constructivism through interactionism aligns with Huberman and Miles' (1994) theory about bringing a construction of reality into the research situation. Onwuegbuzie and Byers (2014) explained that knowledge is co-constructed by both the researcher and the participant through interactionism. With this understanding, I followed the data analysis approach proposed by Merriam (2014), Huberman and Miles (1994). Merriam (2014) outlined analytic techniques and data management strategies in qualitative research. According to this approach, data analysis is a process of producing insight out of the gathered data through the course of reducing, merging, and interpreting information received from interviews and documentary analysis.

Steps to Analyzing Data

Qualitative researchers often handle large quantities of information to make sense of the data gathered to answer the RQ of interest. For practical reasons, researchers must reduce and label the data and in the form that he or she can readily manipulate. According to Huberman and Miles (1994), three phases constitute the data analysis approach: (a) the data organizing process and indexing, (b) the data reduction and the query process (data extracting), and (c) pattern identification.

I investigated four companies that I named Companies A, B, C, and D in this study for maintaining anonymity. I based the selection criteria on the assumption that two companies were achieving low production costs and two were not. Each case study consisted of an entire study (see Figure 8), in which convergent evidence was sought with other cases to write the final report and draw conclusions. The Atlas.ti query tool was helpful in making within-case and across-case analyses. Figure 8 provides the approach used for the data analysis within and across cases.

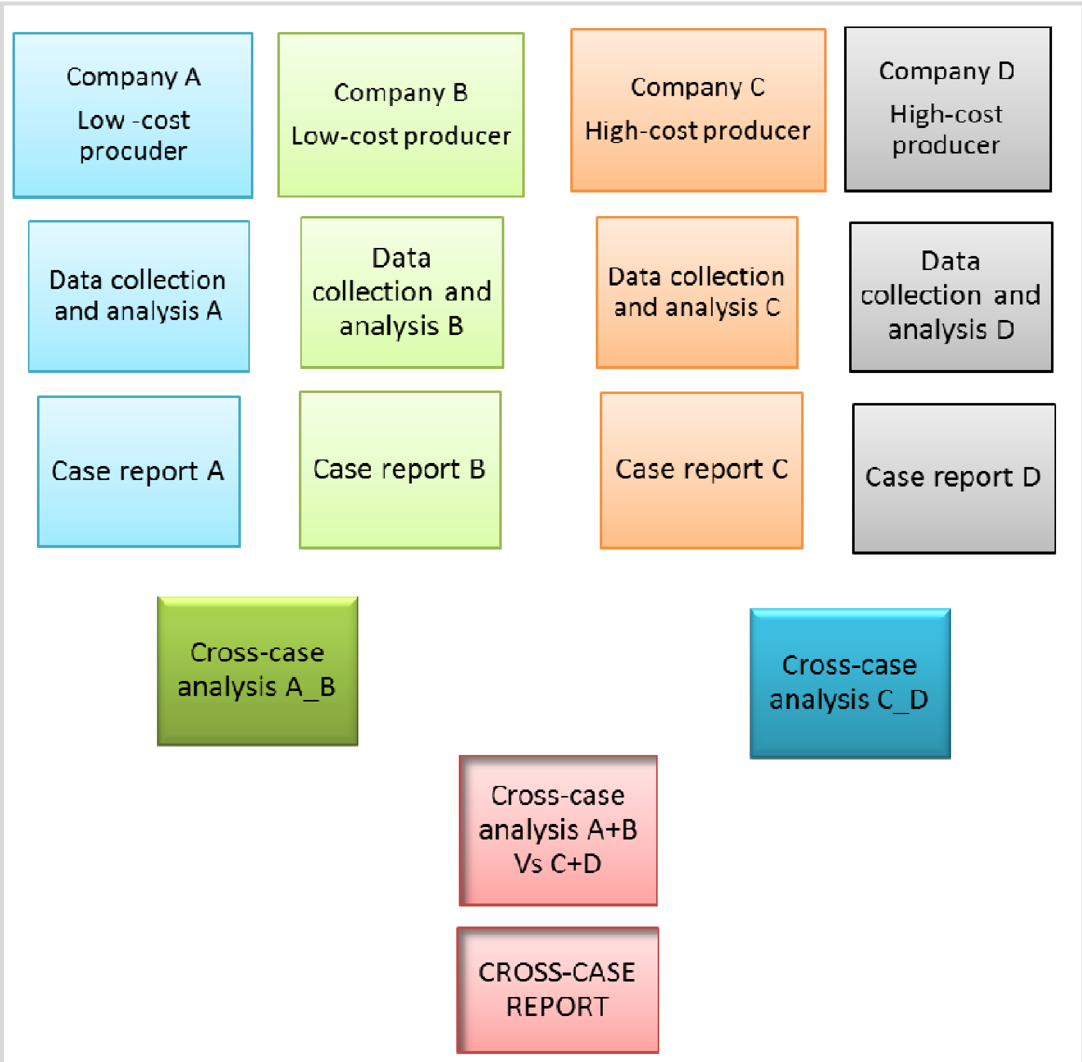


Figure 8. Data analysis method, adapted from "Application of case study research (3rded.)," by Yin, R. K., 2012, Thousand Oaks, CA: Sage.

I started the data analysis process by creating a hermeneutic unit or a project in Atlas.ti and by assigning a project name. I then uploaded all the primary documents—interview transcripts and companies' reports to the hermeneutic unit. According to Huberman and Miles (1994), data analysis starts with the reading of the text to understand the content for the material segmentation or indexation. I started reading the documents, highlighting essential segments, and developing the understanding of what participants said before delving into the process of coding. I aimed to explore and connect the raw data to the RQ and the conceptual framework, semantically. As I read, I selected important segments of text (textual quotations) derived from the source of information on which I applied codes and wrote memos. Memos were propositional abstractions and thoughtful comments that I added in Atlas.ti when thinking about the intervening conditions, the causal conditions, and the outputs of intervening concepts that lead to decreased or increased production costs. I used memos as essential notes taken inside the project when I found a striking pattern exhibiting the attributes mentioned thereof. I linked these keynotes to textual quotations, codes, or other memos. I developed 99 memos, all of which were related to other elements through assigning the proper relationship (e.g., "is part of," "contradicts," "is associated with," "is a cause of"). These relationships are built-in features of Atlas.ti. For example, "low-material-consumption efficiency" is a cause of high production costs (based on the literature review). Similarly, "reducing, recycling, and reusing material" are practices associated with "the circular economy," based on the literature review. Memos were important because I located most of the analysis within them.

To define a code, Atlas.ti provided the flexibility to read the quotations in context and assign a comment. A researcher might export comments at a later stage for further referral. The Atlas.ti code manager allowed maintaining the consistency and the accuracy of definitions. Gläser and Laudel (2013) and Pierre and Jackson (2014) discussed that computerized data analyses provide the ability after the material is coded accurately, to retrieve and interpret data as well as to outline the relationship between codes and themes. At times, I printed out all definitions using the code manager to export the codes as well as the quotations in a more readable format.

Friese (2014) suggested that a researcher might approach the process of data analysis with a deductive framework using provisional coding, or an inductive approach using open coding, or both. I approached the data analysis using both the inductive approach and the deductive method. The combination of the two procedures was appropriate, especially given the exploratory nature of the study and the case study propositions outlined in the conceptual framework.

Three types of coding are available in Atlas.ti: (a) In vivo, (b) provisional, in which codes derive from the literature, and (c) free coding. In vivo coding consisted of labeling the segments of text by using the exact word from the text; it allows inductive reasoning (Huberman & Miles, 1994). Inductive reasoning is a powerful approach to domain-specific problem solving and solving multifaceted problems (Molnár, Greiff, & Csapó, 2013). Free codes were the labels that I assigned based on my interpretation of data and after thinking about what participants said and the significant points of the documents. I created some codes by interconnecting the code’s content to the theory underlying the RQ. For example, whereas “Energy_Management” was a provisional code derived from the literature, “Operational_Excellence” was an in vivo-code, and “Price_Efficiency” was a free code. The combination of these coding practices is the evidence of the application of the three types of coding I applied in this case study.

Huberman and Miles (1994) and Strauss and Corbin (1998) defined a code as a label assigned to a quotation to reduce the complexity of what a participant tries to say by using many words. Codes reduce the complexity and provides the accurate summary of the content; notwithstanding, the meaning must reflect the participant’s perspective. Gläser and Laudel (2013) argued that indexing of the text segments should maintain the original text unchanged. In coding, I analyzed three critical strategic and operational aspects: (a) the causal conditions including contextual conditions (what influences high production costs); (b) intervening conditions or strategies and capabilities identified by participants or described in the documents, and (c) outcomes from intervening conditions or procedures. I assigned a color to each code, depending on whether it represents an intervening condition, a causal condition, or a result of an intervening condition. Furthermore, the process of grouping codes or types of actions was straightforward.

A proactive approach from the early stage was critical in planning for the data coding. For example, in labeling data, I took steps to structure the codes list in a hierarchical pattern to develop a comprehensive picture of families and categories. Organizing items into families allowed to produce clusters of codes, memos, and primary documents for more comfortable handling. Each code was assigned a prefix based on its semantic meaning. For example, all actions related to energy were prefixed by “Energy_” (e.g., Energy_Exportation, Energy_Price, Energy_efficiency). Friese (2014) suggested that a researcher must plan from the early stages the structure and the hierarchy of codes. I saved time by anticipating the structure of the codes. The Atlas.ti software was powerful in providing connections and links between elements.

In coding, the unit of analysis was not necessarily a paragraph, but a striking statement that indicated a strategy or a factor that reduces production costs or causes high cost. Textual quotations were strings of text (sentences, paragraphs) of an arbitrary size. I repeated this process for all documents. From four interviews, I identified 168 codes, created a drop-down code list, and a code matrix comprising all definitions; both were used to maintain consistency. I kept the code names brief and succinct.

Fielding (2012) recommended using data integration, or triangulation, as an approach to conceptualizing and strengthening construct validity. According to Fielding, three fundamental reasons exist for using the data integration approach: (a) to produce convergent validation, (b) to illustrate findings, and (c) to develop analytic density. Yin (2012) and Chatfield, Cooper, Holden, and Macias (2014) recommended that the inquirer should develop a within-case analysis supported by thematic analysis across cases to identify similarities and differences. An interview lasting 50 minutes generated an equivalent workload of 12–20 hours for the data analysis. For the central themes identified, I ensured that member checking occurred.

Analyzing Data through a Comparative Approach

The qualitative comparative analysis was the preferred method for the cross-analysis to describe and examine the four cases under investigation. Olson, McAllister, Grinnell, Gehrke-Walters, and Appunn (2016) argued that qualitative comparative analysis (QCA) can draw on different sources of data; notwithstanding, a researcher should focus on the analytic approach that best investigates the connection among themes and their context (case-based knowledge). This method is distinct from the traditional model of analysis that focuses on a single variable and its relationship to the RQ.

After coding, I identified categories based on the codes similarity and assigned a subtheme. The category, in this case, was the best fitting concept from all codes in a given data set of a single case study. The subthemes, which were the combination of categories, underlay the concepts. Subthemes derived from the categories that most participants introduced or themes that exhibited a core meaning to answer the RQ. I developed groups in the form of networks of subthemes. Each concept identified was compared with other concepts within the network of concepts that was unfolding. Networks facilitated the conceptualization and the visualization of the structure and permitted interconnecting assortments of similar categories in-context.

Gale, Heath, Cameron, Rashid, and Redwood (2013) and Corbin and Strauss (2014) recommended rearranging the data into subcategories and building the relationships between these subcategories by employing thematic guidelines. I used intervening concepts, contextual factors, causal conditions, strategies, and inter-relational between concepts (axial coding) to rearrange the network of subcategories. Axial coding was about reassembling the subcategories into more meaningful categories. After axial coding, I grouped the leading categories systematically to obtain a cluster that led to the concept of interest (see Table 4). Atlas.ti provided the capability to display relationships between elements in the networks' views.

Table *4*

Code Families

Primary Theme/Cluster	Subtheme	Open Code
Energy consumption efficiency	- Energy management - Price efficiency - Type of energy - Technology efficiency - Energy processing efficiency - Reduce, recycle, and reuse (circular economy)	- Reduce energy consumption - Retrofit old assets - Divest old assets - Reduce electrolytic cell voltage - Material attributes - Theoretical consumption
Raw material consumption intensity and acquisition	- Price efficiency - High level of vertical integration - Technology efficiency - Processing efficiency Increasing	- Material management - Theoretical consumption - Material handling - Material quality
Carbon manufacturing capability and consumption efficiency	- Price efficiency - Anode manufacturing capability - Reduce, recycle, reuse (circular economy)	- Operational practices - Anode quality - Process capability - Reduce sulfur content
Environmental Sustainability	- Operational excellence - Technological capability - Material attributes - Increased lifecycle - Circular economy	- Reduce emissions - Minimize greenhouse gases - Processing efficiency - Reduce transportation costs - SPLM management

According to Yin (2012), a researcher needs to describe multiple perspectives and outline potential rival explanations. Stake (1995) recommended that when a large number of dissimilarities are present as the main effects of individual cases facing similar external forces, a researcher must scrutinize the contextual characteristics. The comparison of the companies' business practices required defining critical measurable factors. I related these factors to quantifiable measures of energy and material consumption intensities and costs, as well as the capabilities used to reduce production costs. The strategies I used to minimize the probability of misinterpretation covered (a) addressing the rival explanations, (b) triangulating the data, and (c) comparing critical indicators of performance based on the theoretical requirements for the aluminum oxide electrolysis. For example, to disambiguate the competing explanations potential about the energy costs, I deconstructed all possible components of energy costs, including processes, technological, and price efficiencies. I also endeavored to understand the impact of electricity contract in each case.

Within-Case Analysis

Data Validation: Triangulation Approach

Data triangulation is an approach to facilitate validation of the information gathered from different sources (Denzin, 2012). Denzin (2012) classified three types of data triangulation: (a) time, (b) space, and (c) person. Denzin defined time-based triangulation as a methodological approach to gathering data on a phenomenon at different points in time. Space-based triangulation concerns the collection of data on the same event at separate places. Denzin (2012) further provided critical characteristics of triangulation; according to these characteristics, triangulation involves combining at least two or more data sources, theoretical viewpoints, methodological strategies, or investigators to seek convergence of findings. The two data sources I used in this study included in-depth, semistructured interviews and document analysis. Convergent validation refers to determining whether the results from different sources provide similarities (Fielding, 2012). According to Stake (1995), a researcher needs to confirm each key finding by at least two cross-sources that establish similar outputs. The average convergence of core themes from the two data sources was 71%, confirming principal findings.

Huberman and Miles (1994) suggested classifying categories into concepts or themes by constant comparison and linking them to the matrix of concepts that evolves. The constant comparison approach allows merging or grouping similar codes (Brailas, 2014). I used this method to group families. First, I displayed the list of codes using the code- manager tool in Atlas.ti. Second, I outlined the definition of all codes without exception. I based the definition of codes on my understanding and interpretation of what the participants said. Finally, I assigned a prefix to each code depending on its similarity with others. The prefix was a root for all similar codes.

Triangulating Two Data Sets

Data analysis from semistructured interviews and documentary analysis formed the core axes of information triangulation. Person- and time-based triangulations were the methodological strategies I selected to gather and analyze information. The assumption for triangulating data was based on the premise that no one method considered individually could provide the confidence and the reliability to answer this RQ. Using two data sources might help increase the confidence in data. Through data triangulation, I assessed whether the themes identified in interviews and document analysis exhibited sound similarity. The Venn diagram displayed in Figure 9 provided the methodological framework and the logic I used to triangulate the two sources of information and to validate the convergence.

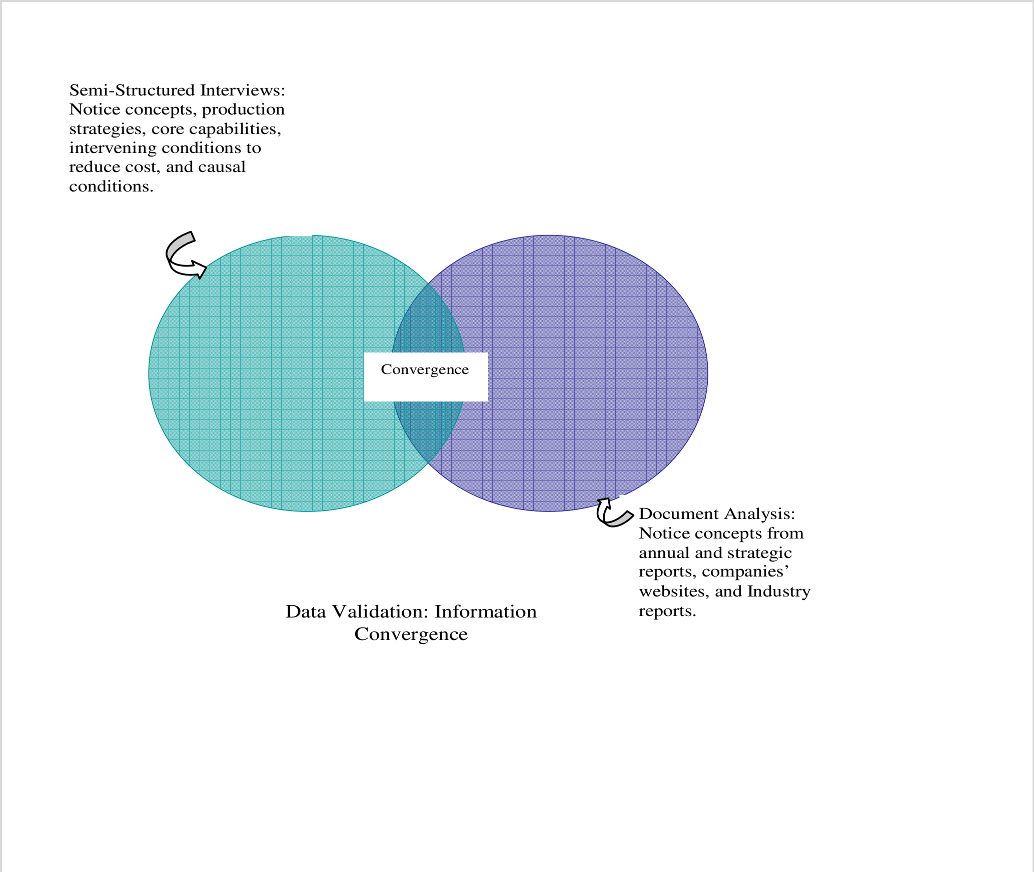


Figure 9. Strategy for triangulating two sources of data. Adapted from "Triangulation 2.0", by Denzin, N. K., 2012. *Journal of Mixed Methods Research*, *6*, 80–88. doi:10.1177?1558689812437186

The Atlas.ti query tool facilitated extracting and exporting data from the software to an Excel spreadsheet so that I could chart the frequency of codes in the radar form. The radar chart is a graphical method beneficial when displaying multivariate data in a two-dimensional form. I operationalized the data convergence through grouping similar codes under one category while considering interviews and documents separately. As it can be seen in Figures 10–13, I sought and applied the convergence approach separately to each company's dataset. The convergence strategy was implemented with two distinctive components: the qualitative and quantitative similarities of themes. I compared both the content (e.g., types of themes) and the frequency of the core themes from the two datasets (see Figures 10–13). There was alignment between the themes isolated from the documents analysis on the one hand and the interviews on the other.

The relative position, representing the frequency of each category identified, was informative of the convergence or divergence of views on a given class. Because each case consisted of eight interviews and only four documents analyzed, it was imperative to proportionate the number of the reports that I reviewed with the interviews for a greater comparability of the themes' frequency. The dotted line is a characteristic of such an approach because it extrapolates themes derived from the four documents as if the samples size were balanced. Time- and person-based triangulation provided apparent convergence of the topics of interest because the categories generated from the reports and interviews tended toward alignment of views. Notwithstanding, the theme "Purchasing_Strategies," showed a discrepancy in views between the two datasets in Company A. Similarly, the theme "Missing_Capability_Alumina" exhibited a difference because this concept frequently was mentioned in the documents but only by few participants in Company D. For these divergences, I sought corroboration and confirmation from senior managers. For example, in the case of Company D, although most senior managers recognized that internalized-alumina acquisition was a critical component of cost minimization, the vertical integration of the raw material was not implemented in this company.

In most cases, the information from the two data sources converged with approximately 71% similarity (the average similarity between the extrapolated lines with the blue lines). I obtained this number by comparing the average frequency of core concepts from interviews and documents analysis if the number of interviews and documents collected was similar. Finally, most themes introduced during the interviews were also reported in the documents. In the convergence approach, I assumed that the frequent use of a concept reflected a strategic intent, an intervening concept, a causal concept, or a condition. Given this assumption, the difference between what people said and what they reported in the documents was essential to measure. Convergent validity was established because the two data sources provided similar outputs.

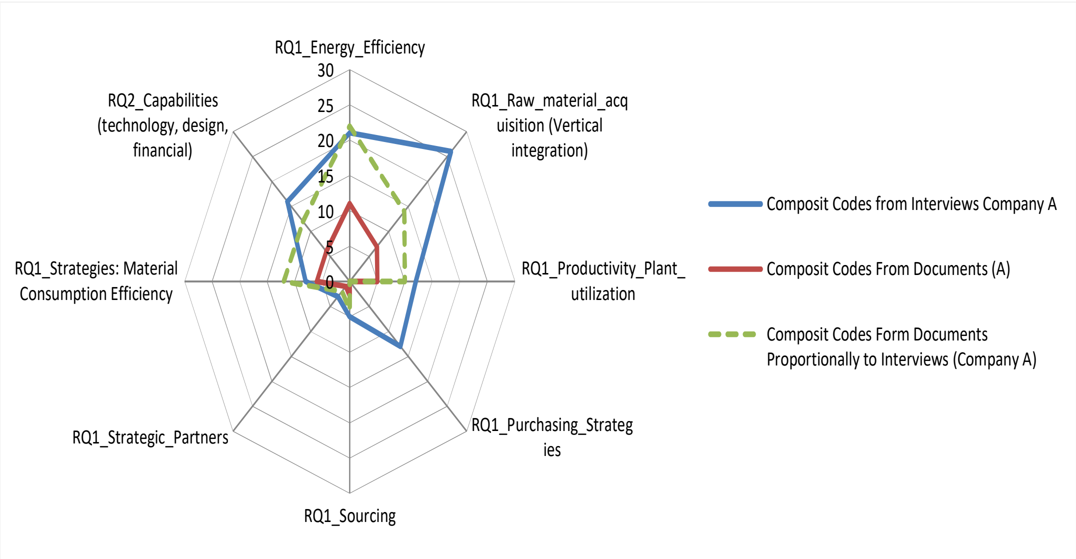


Figure 10. Thematic triangulation for Company A.

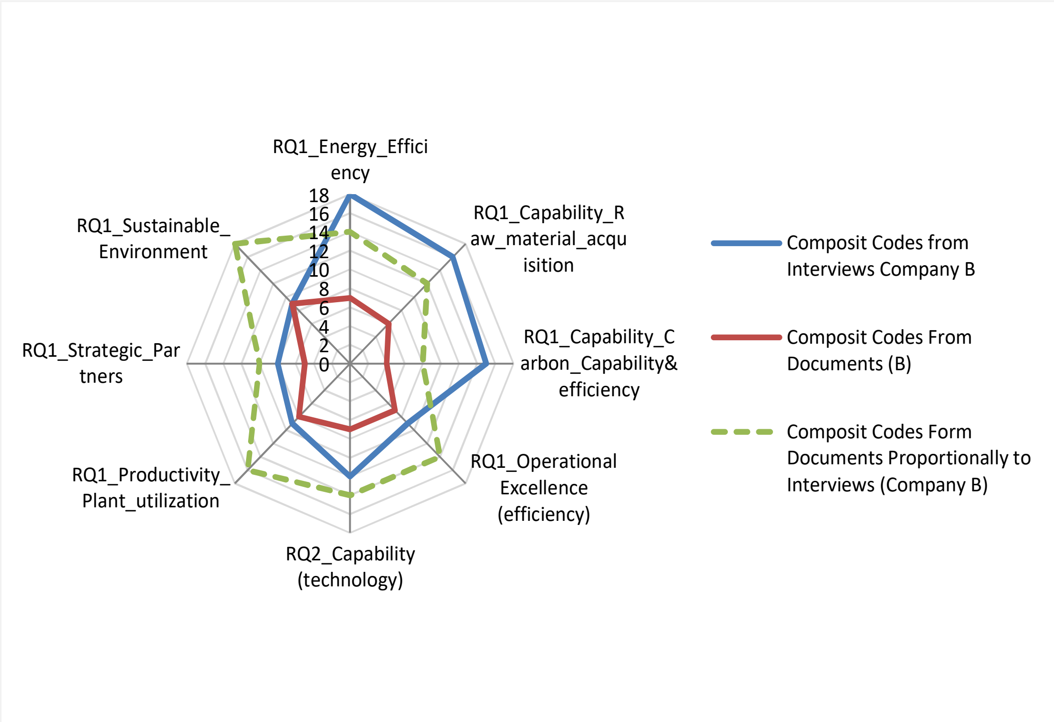


Figure 11. Thematic triangulation for Company B.

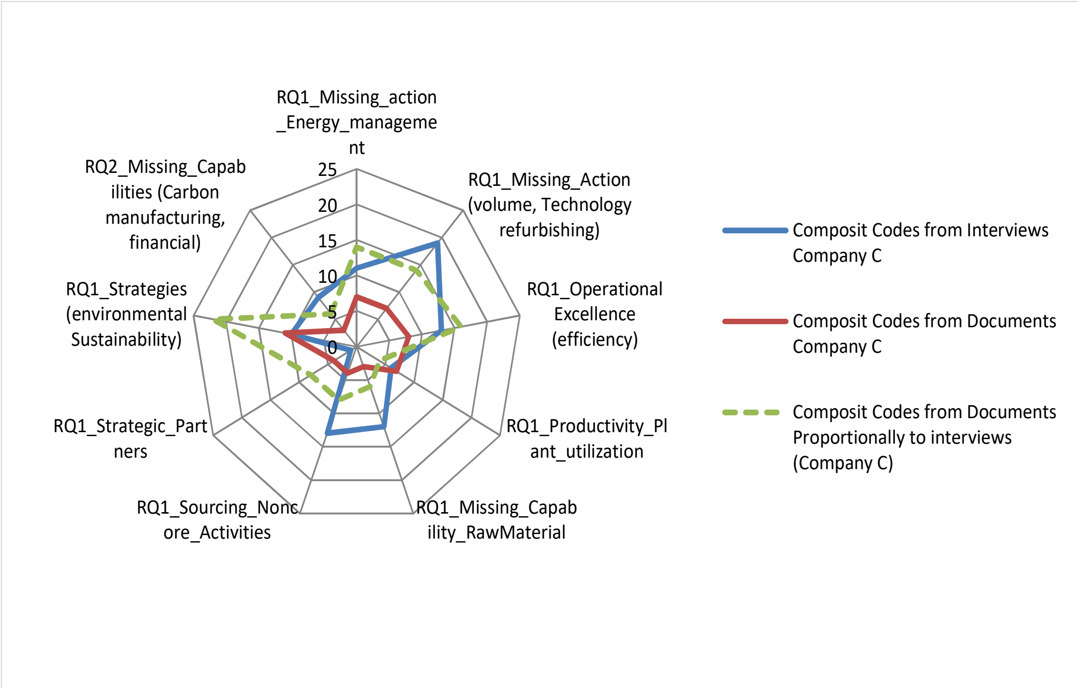


Figure 12. Thematic triangulation for Company C.

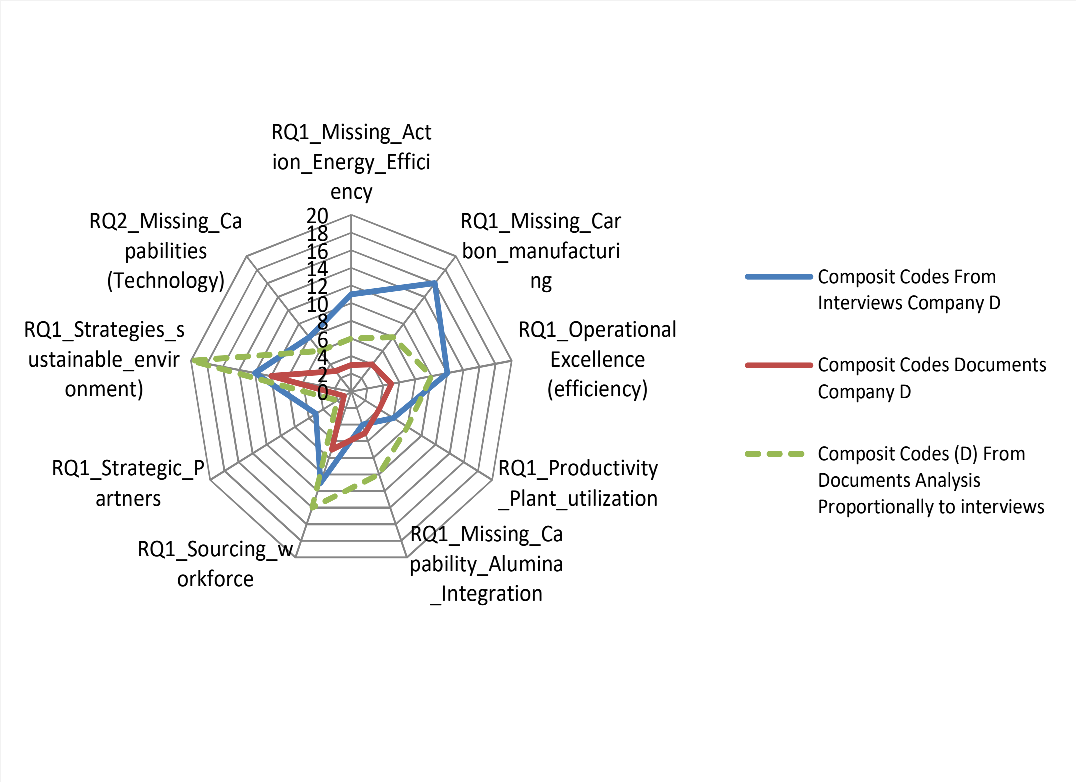


Figure 13. Thematic triangulation for Company D.

Whereas Companies A and B considered the raw material integration, carbon manufacturing capability, and reliable technology as core capabilities to reduce costs, Companies C and D acknowledged these capabilities as enablers to lower costs, but they faced shortcomings in developing them (see Figures 11 and 12). Most senior managers recognized that these components were the driving forces in production systems to reduce production costs. As a researcher, I also found them relevant to the RQ based on the literature review as Ping et al. (2013), Porter (1980), Miltenberg (2005), and Cobb and Douglas (1928) outlined. Ping et al. (2013) found that because the prices of raw materials for nonferrous metals have been rising worldwide, upstream integration in this industry would make sense. Porter (1980) and Miltenberg (2005) found that dominant suppliers might influence the price of a commodity if it is a valuable input in production downstream or if no substitute products exist. Cobb and Douglas (1928) found that the production function efficiency derives from inputs and outputs efficiency. The raw material is a critical input in the primary aluminum production as it accounts for 30-35% of the production cost. Consequently, I decided to thematize “raw material integration” in the list of core concepts.

Triangulating Four Datasets

I used the Venn diagram paradigm to connect the four sets of emerging themes characterizing companies A, B, C, and D (see Figure 14). Venn diagrams are diagrammatic representations used to display juxtapositions and the diversity of all conceivable logical relationships among datasets (Bardou, Mariette, Escudié, Djemiel, & Klopp, 2014; Cai et al., 2013). The area in the middle of the dotted-red line is the field of perfect convergence; that is, all companies use a similar strategy. For example, most participants considered “Operational_Excellence” and productivity as a strategy to reduce production costs. The overall dotted-red line outlines the area of partial convergence in which three or four companies applied a similar approach to reduce cost. For example, most companies used capacity creep as a strategy to increase the productivity of the plant and to reduce the fixed cost per ton Al. The dotted-blue lines outline the commonality of intervening or causal conditions between two different companies. For instance, whereas Companies C and D incurred high carbon costs and inefficient alumina prices, Companies A and B used upstream integration to reduce the alumina costs and, these companies exhibited sufficient production capacity of manufacturing carbon anodes.

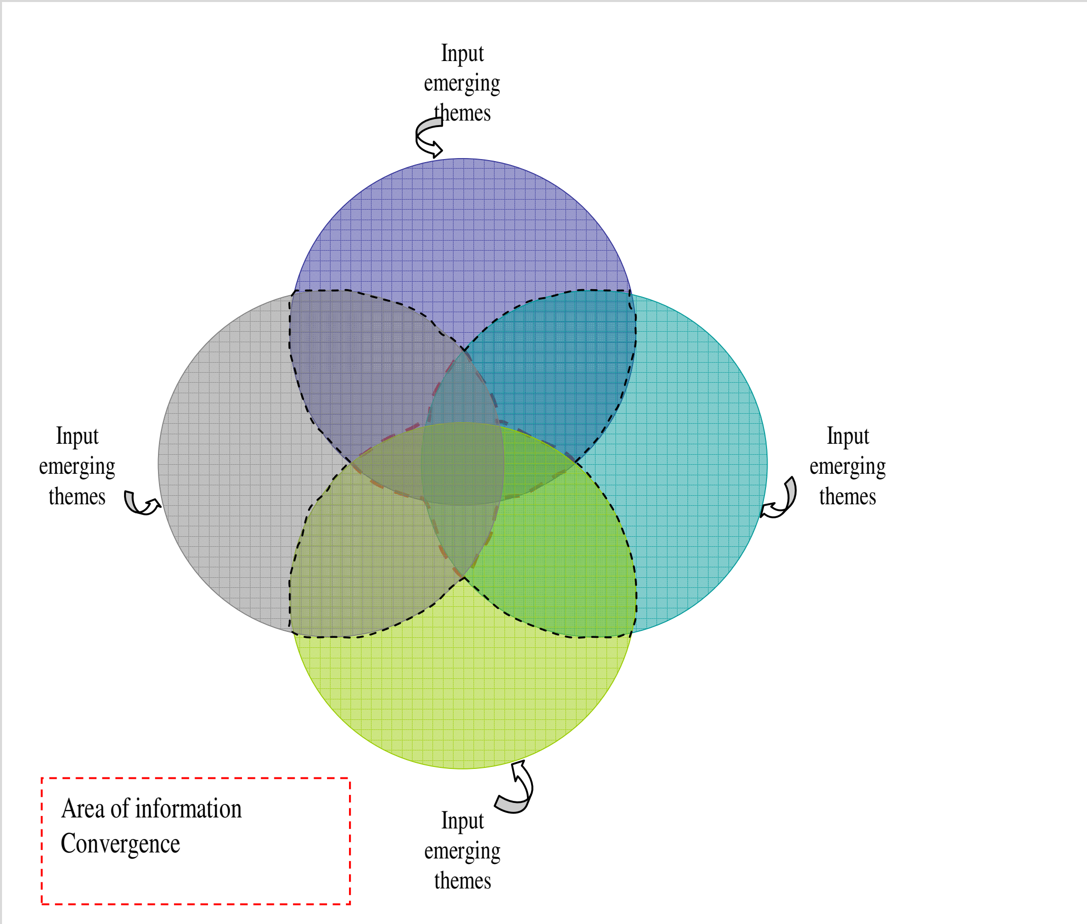


Figure 14. Strategy for triangulating four datasets.
Adapted from "Triangulation 2.0," by Denzin, N. K., 2012. *Journal of Mixed Methods Research, 6*, 80–88. doi:10.1177?1558689812437186

Yanow (as cited in Owen, 2014) found that text analysis constitutes a shred of evidence a researcher uses for clarity and may corroborate or refute observational and interview data. Using the text analysis in conjunction with semistructured interviews allowed the identification of the intervening and causal concepts as well as the outcomes of these concepts on production costs. These intervening concepts and conditions were outlined in strategic and annual reports. One fundamental element of the document analysis is that the document must be valid, decipherable, original, authentic, and relevant to the context under study (Owen, 2014). Elo et al. (2014) recommended that the content of the document to be analyzed must have a direct connection with the themes underlying the RQ. In this study, I used only valid documents, written between the year 2013 and 2016. The type of records explored included annual and strategic reports and companies' websites. Strategic reports had extensive information and enhanced data quality.

Thematic and Data Saturation Investigation

Glaser and Strauss (1967) interpreted that data saturation implies the point in the data collection process when the researcher finds no new theme to develop aspects of the RQ. According to Denzen (2012) and O'Reilly and Parker (2013), the theoretical saturation of data implies that a researcher reaches a point in the data collection and analysis at which no additional data are found to develop new insights to the RQ. No commonly recognized formula exists for determining the point of data saturation. Notwithstanding, researchers have proposed some fundamental rules regarding the point of data saturation. For instance, Guest et al. (2006) conducted semistructured interviews about socially desirable behavior and the accuracy of self-reported sexual behavior. Guest et al. identified 97% of the critical codes after just 12 of their 61 interviews. Tribedy and Venugopalan (2012) provided a statistical analysis of the number of interviews of Google Scholar Annual Citations for single case studies. Tribedy and Venugopalan found that of the top Google performers, the highest average impacts ranged from 15–30 interviews.

Furthermore, Tribedy and Venugopalan showed that the Cronbach's alpha rating for thematic prevalence was higher than .75 in the 13-to-18 interview range. In an extensive analysis of the literature regarding case studies, I found that a range of 6–20 interviews could yield a high Cronbach's alpha (Tribedy & Venugopalan, 2012) for a single case study. This information was essential in planning the interviews and related costs.

In-depth semistructured interviews were conducted to generate data saturation. In this study, I gathered data and made data analysis concurrently in an iterative process. After each interview, the material was transcribed verbatim, uploaded to Atlas.ti, coded, and interpreted. All codes and themes had equal attention in the analytic and coding procedures. I organized codes into families according to their semantic definition and connection to intervening concepts to yield organizing themes. I compared any new code to the organizing themes and assigned a prefix based on its attributes. I also established transitive relationships between codes (e.g., "is part of," "is associated with," and "is a cause of"). Furthermore, I was able to use the functionalities built-in the Atlas.ti query tool to export the code families and the thematic frequencies to a spreadsheet. A two-dimensional matrix was formed subsequently, comprising intervening and causal concepts as well as causal conditions in the rows and cost factors in the columns. All themes isolated (see Table 3) were introduced in the matrix.

I sought saturation at two levels including interviews (data saturation) and member checking (thematic saturation). These two approaches to data saturation were used concurrently to maximize benefits from the synergy. In the first level, I continued interviewing participants until there was a point where the information from many participants started repeating and providing no new insights. Notwithstanding, I assumed that participants might provide only surface level information in the interview stage and, adding the researcher self-reporting bias (Stake, 1995), I endeavored to solicit member checking. In the second level, thematic saturation was sought from member checking. I reviewed, interpreted the data, and synthesized the findings, which were sent to participants via emails to corroborate and to add or remove information. I continued this repeated and cross-verification process until there were no new themes to answer the RQ and subquestion.

Before the point of data saturation, most data were similar repeatedly in the matrix; this persistent similarity and negligible variability between documents provided reasonable confidence in the data that the categories identified were saturated and that the description that the participants provided about the strategies to reduce production costs were thick and rich. Fusch and Ness (2015) suggested that thick is about quantity, and rich is about quality. The similarity level of the new codes versus existing codes in the matrix as mentioned thereof was higher than 95%. The quality of the documents used, the consistency of the data analysis, and the member-checking process provided maximum benefits for the data and thematic saturation.

Given the multiple case study design, I sought saturation for each case, rather than a holistic saturation. I assumed that the holistic saturation of the multiple cases could be accomplished when I reached individual saturations. This characteristic was necessary from the qualitative interpretation perspective because I assumed that each case study could exhibit a different business context and operational capabilities of the aluminum production strategy. The context was an element of the production cost variance between companies.

Table 3 is a summary of the original codes isolated at a particular stage in the data collection process to produce saturation. Practically, I identified 94.5% of the principal codes after six semistructured interviews and four primary documents analyses in each case. At this stage, I gathered a total of 26 interviews and 16 reports. As most subsequent documents revealed only fewer additional new codes, I decided to conduct additional interviews. After eight subsequent interviews, two in each case study, I isolated less than 5.5% new codes.

Dependability and credibility are two criteria that influence the confidence of qualitative data (Elo et al., 2014; Noble & Smith, 2015). The consistency of analytical methods and the information quality can improve dependability (Malterud, Siersma, & Guassora, 2016). Thematic saturation might improve dependability. The depth of the data was of paramount importance to provide the information quality. The documents I used—for instance, strategic and annual reports were the repository of vital details that increased the information quality. The use of Atlas.ti facilitated the data analysis quality, its repeatability, and reproducibility.

Reliability and Validity

Different authors have differing views on data validation regarding the validity and reliability of the qualitative investigation. A divergence of views is evidence of the variation in the authors' epistemological perspectives (Yazan, 2015). Whereas the authors holding positivistic or post-positivistic views recognize the need to produce validity and reliability by capturing absolute knowledge (Yazan, 2015), constructivists maintain that knowledge is interpreted between the researcher and participants through what is already known (Merriam, 2014). The conceptualization of validity and reliability differs in the qualitative and quantitative inquiries (Merriam, 2014). Guba and Lincoln (1994) proposed four criteria that researchers should consider to increase reliability and validity in qualitative research: dependability and confirmability (reliability), and credibility and transferability (validity).

Reliability

One principle that a researcher needs to follow in informing and designing a qualitative inquiry is reliability or dependability (Noble & Smith, 2015). Reliability is synonymous with believability, consistency, and trustworthiness, all of which are core components of this concept (Elo et al., 2014). Data dependability and findings confirmability are two additional components of reliability (Guba & Lincoln, 1994; Houghton et al., 2013).

Dependability. Guba and Lincoln (1994) claimed that dependability involves findings that can be repeatable and reproducible. The procedure adopted to collect and analyze data in this case study can be reproducible by other authors. First, I endeavored to increase dependability by providing consistency in the analytical methods as recommended by Elo et al. (2014) and Noble and Smith (2015). A researcher can improve dependability by ensuring trustworthiness of the integrated process of data collection and analysis (Malterud et al., 2016). Second, companies' strategic and annual reports were the repository of critical details that increased the information quality. In addition, the use of CAQDAS (Atlas.ti) facilitated the data analysis consistency and quality, allowing improving the repeatability and reproducibility of the procedures used in this study. Next, I aimed to increase the coherence of the data-gathering and analysis procedures by building trustworthy processes and transparency with the participants. I followed a systematic and replicable approach, in that I used a case study protocol and developed a database for further referral. The former allowed strengthening the participants' preparedness for a cognitive interview process. Finally, the position of senior managers in the companies' hierarchy enhanced the quality of information gathered and the answers to the interview questions. To promote integrity, I allowed the participants to review the transcripts before writing the final report. The transcript review was a factor in maintaining neutrality and trustworthiness as recommended by Guba and Lincoln (1994) and Loh (2013).

Confirmability. Houghton et al. (2013) stated that confirmability is a qualitative research criterion associated with the degree to which a different researcher can authenticate the results and the methods of a study. To increase confirmability, I ensured that themes emerging from this study were the views of the participants and the documents review, not from my perceptions. According to Noble and Smith (2015) and Tarrozzi (2013), a researcher may improve confirmability by maintaining a high level of neutrality throughout the data collection and interpretation process. I endeavored to stay close to the data throughout the data gathering and analysis process and to produce data saturation. Similar to dependability, I aimed to increase the confirmability of the results by documenting the procedures for the data collection process and the data analysis (see

Appendixes B). I submitted the findings to some selected senior managers for review and authentication. Finally, I used two sources of data as an approach to seek information convergence for promoting confirmability within a case study. In addition, I triangulated subthemes from the four datasets of Companies A, B, C, and D to obtain core themes of interest. According to Stake (1995), data triangulation allows reducing bias from both a researcher's self-reporting and the interactions with participants because it allows integrating data from different sources and using information convergence as a criterion for validation. Follow-up questions were persuasive as they contributed to verify the reliability and validity of what the senior managers said by comparing two different responses to the same interview question. Finally, the follow-up questions supported my exploration for exceptions that permitted disconfirmation or confirmation of data in the interpretation stage. For instance, follow-up questions allowed the clarification that, yet the energy recovery was not implemented on a large-industrial scale to provide significant returns. In using the follow-up questions, I assumed that I could not capture information, detailed at a granular level from a set of predefined questions. Instead, the granular description might prevail in the follow-up questions. Finally, the follow-up questions allowed differentiating contextual factors of costs and identifying additional subthemes that were constituents of the central themes.

Validity

Addressing credibility and transferability relates to decreasing the variability of the data interpretation (Harper & Cole, 2012). Credibility and transferability both enhance research validity (Harper & Cole, 2012). Transcript review and member checking are fundamental criteria and increase benefits for validity (Simpson & Quigley, 2016). Simpson and Quigley (2016) recommended that a researcher use the member checking approach as a dialogical and flexible way to enhance the validity. The member checking approach implies that a researcher should have interview findings authenticated by the participants. In this study, I used SMs to review the results; I also used the literature review as a means of corroboration to increase validity. The SMs used the member checking approach to guaranteeing trust of the procedures and the results of the study. As Quigley (2016) recommended, I used this procedure as a reflective step on the findings by identifying inconsistencies and correcting errors while maximizing the truthfulness of the conclusions.

Another strategy for increasing validity was to reach data saturation. I reached the data saturation after eight interviews in each case study. Saturation was noticed when information started repeating and when no new concepts occurred to enrich the themes already isolated in the datasets or the aspects of the RQ. Saturation was sought at two levels including interviews (data saturation) and member checking (thematic saturation). These two approaches to data and thematic saturation were used concurrently to maximize benefits from the synergy. In the first level of the data saturation process, I continued to interviews participants until there was a point where the data from many participants started repeating and providing no new insights. Notwithstanding, I assumed that participants might provide only surface level information in the interview stage and, adding the researcher self-reporting bias (Stake, 1995); I endeavored to solicit member checking. In the second level, the thematic saturation was sought from the member checking process: I reviewed, interpreted the data, and synthesized the findings, which were sent to participants to corroborate and to add or remove information. I continued this repeated and cross-verification process until there were no new concepts to answer the RQ and subquestion.

Guba and Lincoln (1994) argued data saturation allows mitigating flawed perceptions on the part of both the researcher and the participant. In addition, Perkins et al. (2013) acknowledged the importance of keeping interviews short to maintain focus and yield consistent cognitive outcomes. Each interview for the study lasted less than 50 minutes. Finally, Yin (2012) recommended additional strategies for data validation including (a) using multiple sources of evidence converging on the same research problem, (b) maintaining a database, and (c) creating a chain of evidence that provides reciprocity between the RQ, the data, and the findings. I used two sources of data and outlined the convergence of information between these sources.

Credibility. Yin (2012) maintained that a researcher must incorporate adequate operational measures when analyzing the RQ. Similarly, Coker, Ploeg, Kaasalainen, and Fisher (2013) argued that the credibility of qualitative findings relies on the methodological stringency in data gathering and analysis. I aimed to increase the credibility of this study by the use of strategic and annual reports that enhanced the data quality. Guba and Lincoln (1994) and Munn et al. (2014) recommended that findings of research must be reflective of participants' views. Coker et al. (2013) identified the primary criterion for credibility as the accuracy of results from the viewpoint of the participants. In this study, central themes of interest reflected the participants' views and the context of the study rather than my perspective. Similarly, Coker et al. (2013) argued that researchers must follow logical relationships between the conclusions and data when analyzing them. I selected and grouped codes into categories to yield subthemes. Furthermore, I associated the subthemes through built-in relationships provided in Atlas.ti. This step was termed axial coding. The type of relationships I used to link the subthemes included “is associated with, is part of, and is a cause of.” Core themes emerged by grouping subthemes. Credibility is also enhanced when the data interpretation reflects the source of information (Munn, Porritt, Lockwood, Aromataris, & Pearson, 2014). In this study, I used three types of coding: in-vivo, free, and provisional coding. Whereas provisional codes derived from the conceptual framework and the RQ, in-vivo codes were concepts embedded in the text analyzed, and free or emergent codes were those concepts and (intervening and causal) conditions that come up in reading the material. As it can be noticed in the statement thereof, I used a hybrid strategy to coding. Whereas emergent and in-vivo codes were inductive items, provisional codes were a priori items. The conjunction of these two data coding strategies shows that findings reflected the source of data. Given the potential for literal generalizability, using a hybrid-coding logic compared to a deductive logic was critical to minimize preconceived themes and bias.

The second approach I used in this study was exploring competing explanations through follow-up questions. Follow-up questions were crucial as they permitted to investigate the responses in detail and to enhance the understanding of what participants attempted to say in the initial statements. The follow-up questions also allowed to corroborate or contradict the reliability and validity of what the senior managers said by comparing two different responses to the same interview question.

As recommended by Guba and Lincoln (1994), I implemented the transcript review procedure. This procedure assured that the findings were grounded in the participants' views and the context of study (Cope, 2014; Guba & Lincoln, 1994; Harper & Cole, 2012; Huberman & Miles, 1994) of the four companies, which could increase the credibility of findings.

I selected participants based on their position, knowledge, and functions in the aluminum production sector. The experience and knowledge of senior managers enriched the data gathered and increased the information quality. Guba and Lincoln (1994) also supported that the quality of participants is essential to improve data quality, which might allow mitigating flawed opinions. The senior managers had at least 10 years of experience in the field of aluminum production and were knowledgeable about the aluminum production strategies. I selected 10 years of experience because the market prices of primary aluminum have shown constant volatility in the last decade (World Bank, 2013), so it was appropriate to gather information from senior managers who faced these variations firsthand. Finally, I employed data convergence between semistructured interviews and document review to ensure that neither biased answers nor false information compromised the content. The triangulation of the four datasets supported the credibility of the results. The proactive strategies mentioned thereof enhanced the credibility.

Transferability. Transferability is the extent to which researchers or practitioners can use the results of a qualitative analysis in another context (Yin, 2013). Transferability also refers to assigning to another study the methodology a researcher might have implemented throughout a research process (Yin, 2013). Yin (2012) maintained that despite the uniqueness of each case study, qualitative comparative case studies should yield analytic generalizability (Yin, 2012). I increased the likelihood of transferability by using appropriate procedures that might be repeatable. For instance, I provided a detailed description of the connections between the findings and the business contexts.

Data triangulation can enhance the transferability of results (Farahani, Mohammadi, Ahmadi, & Mohammadi, 2013). Researchers use data triangulation to corroborate the same conclusions between different sources (Yin, 2013). I drew data from interviews and documentary analysis. I produced a detailed description of the production strategies that companies used to reduce production costs in the aluminum field and guaranteed that the description was representative of the contexts and the two data sources. The diversity of the business settings of the four aluminum companies, associated with the triangulation approach strengthened the transferability of the findings in a similar context.

In their seminal work on qualitative data analysis, Huberman and Miles (1994) recognized the need to select a representative sample of cases in a qualitative, comparative case design. These authors argued that a researcher should plan the selection of the sample to create both stronger inductive reasoning and enhance the ability to transfer conclusions. The selection of the four companies under study was purposive, adapted to increase the transferability potential, and to identify production practices that may lead to reducing production costs. Yin (2012) stressed that researchers could enhance transferability by addressing rival explanations. In this study, I have discussed the primary production costs drivers and outlined possible differences and similarities between companies. I also provided a detailed description of the business context and highlighted what was unique in every business context. This research also provided a foundational frame and knowledge regarding the improvements that may be made by other aluminum producers.

Transition and Summary

In this study, I aimed to understand the context of aluminum production and identify strategies aluminum producers use to reduce production costs. To achieve this goal, I gathered data from two sources and used the approach of interpretivism to analyze data. I applied interpretive procedures in the data triangulation to identify similarities and differences between the sources of data. In gathering data, I focused on intervening concepts and causal conditions that might influence production cost in the primary aluminum production sector. Social constructivism, mixed with interpretivism influenced my worldview and the methodology I used for data gathering and analysis in this study. I endeavored to capture knowledge by integrating knowledge from aluminum production SMs and the process by which they convert knowledge into strategies to reduce costs. In addition, I aimed to guarantee the integrity, the replicability, and the objectivity of the findings of this project by bracketing my perceptions to produce a high-quality research project. The use of CAQDAS promoted consistency and the reliability of the data analysis.

I aimed to construct knowledge within the companies' business context; in this regard, the goal was to understand what was context-specific, unique, or common from the perspective of aluminum producers based on a purposeful sample of four aluminum-production companies. The coherence and consistency of the procedures used in this study were bolstered by promoting trustworthiness through the researcher's interactions with aluminum producers. The quality of interactions allowed both the researcher and the senior managers to understand particular causal conditions of high production costs through analysis and interpretation.

I constructed central themes by using Huberman and Miles' (1994) data organizing and analysis strategies. During the data gathering, I focused on a particular context while socializing with aluminum production managers and maintaining a logical point of view, consistency, and integrity. This approach presupposed that I developed a precise understanding of the production processes used in aluminum production as well as the concepts underlying constructivism and interpretivism.

I assured the quality and rigor of this study by applying appropriate research tools and analytical techniques that helped deliver consistent and ethical research. In the next section, I provided an overview of the study and the research findings. I also discussed the application of the research results to professional practices and the implications for social change, along with the research limitations and recommendations for further studies.

Section 3: Application to Professional Practice and Implications for Change

Introduction

The purpose of this qualitative, multiple comparative case study was to explore the strategies some aluminum producers might implement to reduce production costs. The targeted population covered aluminum production senior managers in Western Europe. The European Commission (2013, 2014) indicated the importance of analyzing aluminum production costs in Western Europe in the context of slumping aluminum prices and limited technological, material, and energy capabilities. A purposeful sample of four companies was studied to compare production strategies: two companies that are achieving sustained production costs and two that are not.

The economic theory of production and production costs (Cobb & Douglass, 1989) provided the conceptual framework for the research. The qualitative methodology, based on constructivism and interpretivism (Merriam, 2014; Huberman & Miles, 1994), facilitated the data collection and analysis. A purposeful sample was made of 32 senior production managers who were interviewed using semistructured interviews. In addition, I collected strategic, annual, and industry reports to provide information quality. Data analysis in Atlas.ti resulted in six core themes representing intervening concepts for reducing production costs and causal conditions for high costs. I found the following concepts: (a) energy management and efficiency, (b) upstream integration, (c) operational excellence and productivity, (d) carbon-anode manufacturing capability, (e) technological capabilities, and (f) circular economy. These concepts were strategies for reducing production costs. Increased production efficiency has implications for positive social change, including lowering energy and material consumption and reducing emissions and waste.

Presentation of the Findings

The overarching RQ for this study was the following: What strategies might aluminum managers implement to reduce production costs. The following serves as a subquestion: How can a manager develop core capabilities in production units to lower production costs?

I used the Atlas.ti software to discover and analyze concepts from the unstructured data comprising interviews and companies' reports. The software allowed me to organize data, locate critical segments of text, and code information. It also assisted me in analyzing, filtering, and querying the most relevant information from the material. Figure 15 outlines some of the artifacts of the data analysis in Atlas.ti. I uploaded 53 documents into the hermeneutic unit, of which 49 were coded (32 interviews, 16 reports, and one report describing the theory of aluminum electrolysis). I organized these materials into five primary families (Companies A, B, C, D, and aluminum electrolysis theory) according to their source. The code manager and memo outputs yielded 514 codes and 99 memos, grouped into 18 and 12 families, respectively (see Figure 15). I paired the companies (e.g., A and B, and C and D) based on the characteristics outlined in the sampling strategy. I matched the samples to reduce within-case variability to derive compound themes that were best defined and straightforward to compare. I analyzed and triangulated interviews and documents independently. I operationalized the data triangulation through grouping similar codes under one category while considering interviews and documents separately. As outlined in Figures 10–13, I applied the triangulation approach separately to each company's dataset. The convergence strategy was implemented using two distinctive components: the qualitative and quantitative similarities of themes. I compared both the content (e.g., types of themes) and the frequency of the core themes of the two data sets (see Figures 10–13). There was alignment between the themes isolated from the documents on the one hand and the interviews on the other. When codes occurred again, I reviewed and compared them with existing codes to assess the information convergence. Cases were analyzed separately and were compared further to derive sub-themes. Data triangulation was the preferred approach to merging and seeking convergence from the four datasets, which were interviews and documents from Companies A, B, C, and D.

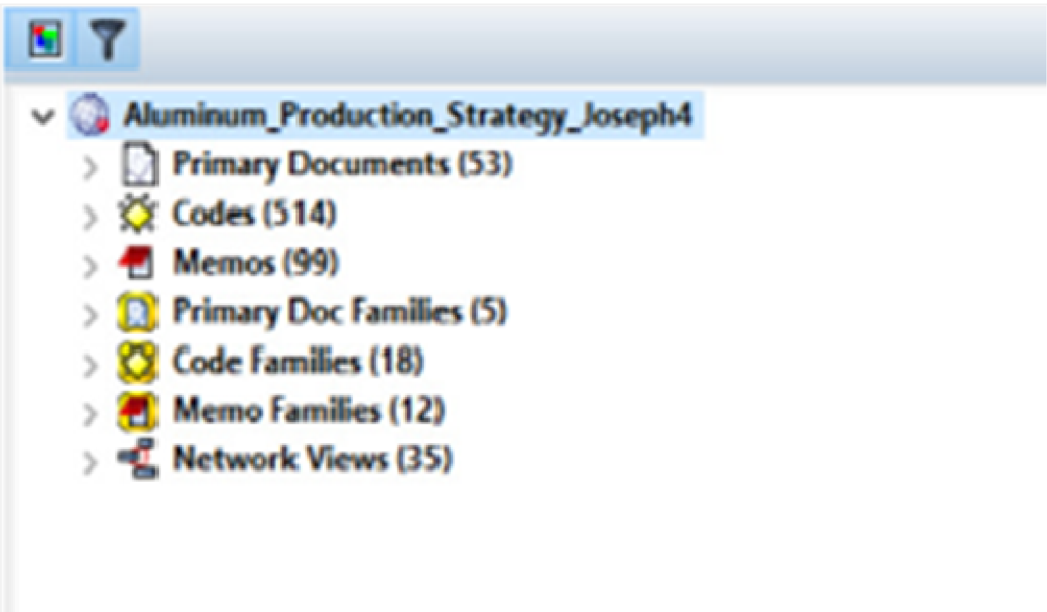


Figure 15. Hierarchical display of objects in Atlas.ti.

MEMO: Energy_tariffs (19 Quotations) (Joseph Ndjebayi, 2017-03-15 12:23:08)

P 4: Participant3A.docx:
(3:3), (6:6), (6:6), (9:9), (9:9)
P 7: Particpant5A.docx:
(3:3)
P13: Participant_6B.docx:
(21:21)
P16: Participant4B.docx:
(27:27)
P18: Participant1D.docx:
(7:7)
P19: Participant2D.docx:
(8:8)
P21: Participant4D.docx:
(6:6)
P23: Particpant5D.docx:
(3:3)
P27: Participant_3C.docx:
(11:11)
P29: Participant_5C.docx:
(13:13)
P31: Participant_1C.docx:
(13:13)
P33: Participant_6D.docx:
(11:11)
P36: Participant_3C.docx:
(11:11)
P37: Participant_4C.docx:
(17:17)
P39: Participant_7C.docx:
(12:12)

"We sign long-term energy contracts for energy acquisition with our suppliers. As aluminum prices are volatile, we needs to ensure these contracts are flexible to sustaining production costs in case of business variation. Some energy tariffs are linked to LME." I need to explore the literature on energy tariffs for the production of primary aluminum.

Figure 16. A sample memo derived from Atlas.ti.

Next, in Figure 17, is an excerpt of the codes' taxonomy and relationships as I arranged and regrouped them into families based on their meaning. It was possible to export the codes' family as well the thematic frequencies to a spreadsheet by using the Atlas.ti query tool.

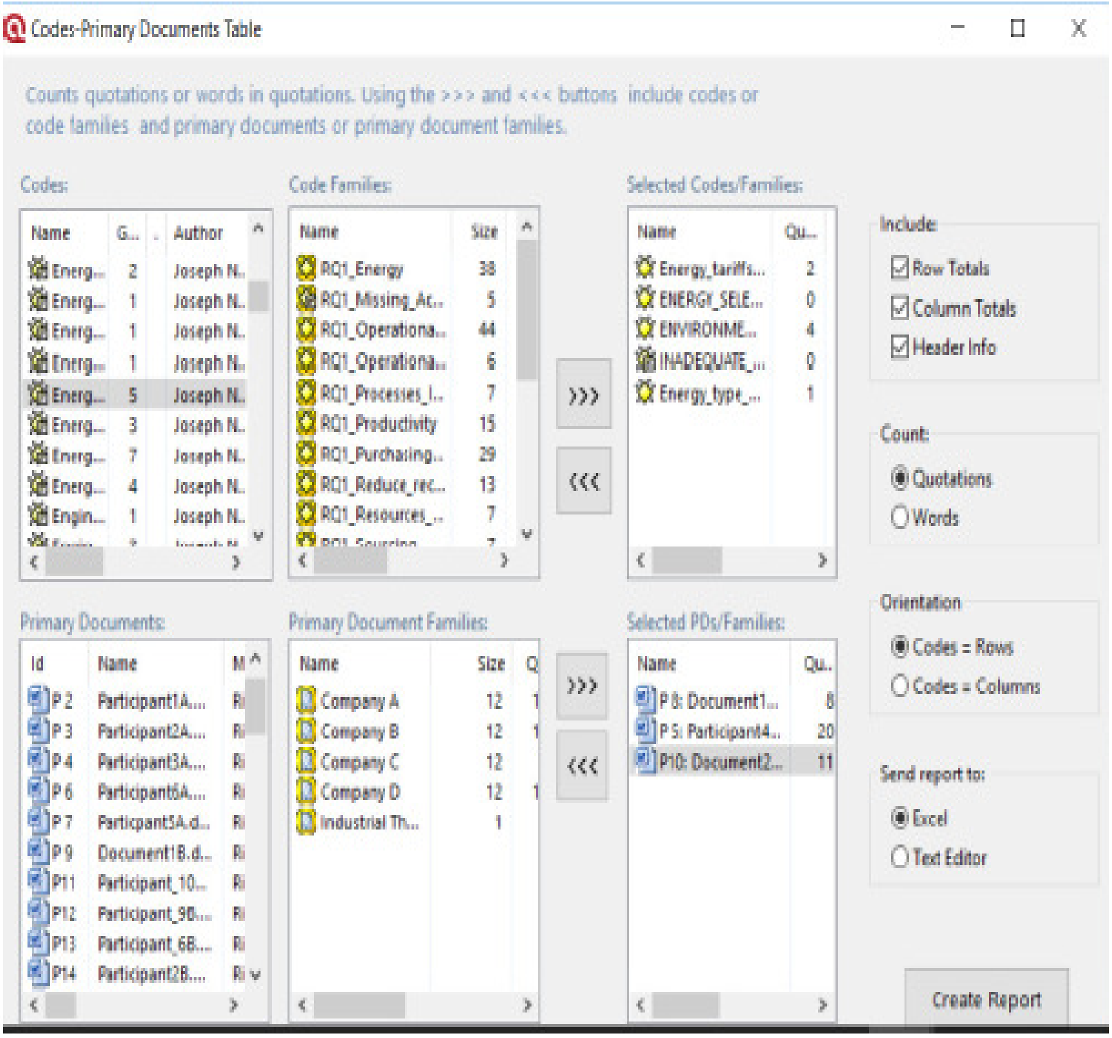


Figure 17. A sample of the Atlas.ti Query Tool.

All codes and themes were given equal attention during the analytic and coding processes. I organized the codes into families to yield clusters. I compared any new code to the groups and assigned a prefix based on its meaning. I established relationships between codes (e.g., is part of, is associated with, is a cause of). Then, a two-dimensional matrix was formed, comprising intervening concepts and causal conditions in the rows and cost factors in the columns. All themes isolated were mapped in the matrix of concepts that unfolded (see Table 3). This method was termed “constant comparison.” When no subsequent documents qualitatively provided new developments, intervening concepts, causal conditions, or categories to answer to the RQ, I considered that data saturation was reached. Graphically, I noticed the saturation when the number of new codes isolated was close to zero. Before this point, most data in the matrix were repeatedly similar. In addition, thematic saturation was sought through member checking. I reviewed, interpreted the data, and synthesized the findings, which were repeatedly sent to participants to corroborate or to add information. I continued this repeated and cross-verification process until there were no new insights to answer the RQ and subquestion. Categories identified were saturated, and the participants' descriptions of themes were thick and rich because most documents gathered were similar with negligible variability. Thick refers to quantity, and rich refers to quality (Fusch & Ness, 2015).

I achieved rigor and validity through transcript review, data triangulation, convergence validation, and data and thematic saturation. Initially, each data source yielded basic themes, which evolved into primary themes upon triangulation. This step was important because it allowed me to establish information convergence (see Figure

17). Next, I compared the primary themes among cases and within paired samples, providing the second level of topics organization. Each organizing theme derived from the hierarchical distinction of the central themes. I created the structural hierarchy of themes by selecting and dropping codes from the flat list into subcategories, and by assigning transitive relationships between items. This process resulted in 35 thematic networks or organizing themes, each linked to the other. I named this step the "semantic linkage."

The second level of concept triangulation occurred between paired data sets to yield core or overarching concepts. Six core concepts emerged from the data triangulation across cases: (a) energy management and efficiency, (b) upstream integration, (c) operational excellence and productivity, (d) carbon-anode manufacturing capability, (e) technological capabilities, and (f) circular economy.

Most of these themes were prevailing, expected from the study's conceptual framework. The circular economy and material characteristics and prices efficiency were serendipitous concepts that were missing from the literature. Production managers might use these concepts as intervening strategies to lower costs. Some themes might also be considered as causal conditions that could increase costs depending on how they are used. Next, I provide the cases description and data analysis. For the sake of simplification, I used the following symbols in the text to symbolize participants and documents from Company A: P1A, 2A…, and D1A, D2A respectively. Similarly, participants and documents from Companies B, C, and D will be represented by the symbols P1B, 2B,…, P1C, 2C,..., P1D, 2D,…, and D1B, D2C,…, D4D respectively.

Case Analysis Company A

Case Description

Company A was a smelter in Western Europe specializing in the production of primary aluminum. It was one of the biggest producers of aluminum in Europe. It produced aluminum slabs and extrusion billets. The company's vision was to enhance productivity and minimize environmental impacts. The ultimate goal was to be one of the most successful primary aluminum producers in the world. The production plant was commissioned in the late 20th century for a production capacity of 220,000 tons per year, equivalent to an electrical current input of 300 KA. Today, the smelter had a capacity of 275,000 tons of aluminum per year—approximately 120% of its initial capacity. This exceptional shift in plant capacity was made possible by technological capabilities and energy availability, according to one participant interviewed. The total cost savings delivered in 2014 was USD 150 million posttax, according to documents reviewed. The company achieved the savings through productivity improvements, cost reductions, and the divestiture of high-cost assets, according to documents reviewed.

Table 5 outlines the overall codes prevalence from the two datasets (interviews and documents review) after data triangulation. Tables 6 and 7 show the frequency of codes for the core themes derived from interviews and the documents analyzed in Company A. Each core concept emerged from the subthemes that I obtained by clustering data based on their similarity with existing information in the matrix of codes that was developing.

Table 5

Overview of Core Concepts, Company A

	Energy Management & Efficiency	Raw Material Vertical Integration	Product-ivity & Plant Utilization	Purchasing Strategy	Insourcing Strategy	Strategic Partners	Material Consumption Efficiency	Technology Design	Totals:
Participant1A.docx	3	4	2	1	0	0	2	2	14
Participant2A.docx	2	3	3	3	1	1	2	3	18
Participant3A.docx	3	3	1	2	1	1	0	2	13
Participant4A.docx	7	6	0	0	0	1	1	1	16
Participant5A.docx	3	2	1	1	1	0	2	3	13
Participant6A.docx	1	4	1	2	0	0	0	4	12
Particpant7A.docx	2	4	2	3	1	0	1	0	13
Participant8A.docx	0	0	2	1	1	0	0	1	5
Document1A.pdf	7	0	0	0	0	0	0	1	8
Document2A.docx	1	2	1	0	0	0	2	2	8
Document3A.docx	1	3	3	0	1	0	4	2	14
Document4A.docx	2	2	1	0	1	1	0	1	8
Code Occurrence	29	29	15	12	7	4	12	20	128
Code Frequency	23%	23%	12%	9%	5%	3%	9%	16%	
Frequency of Participants	88%	88%	88%	88%	63%	38%	63%	63%	
Frequency of Documents	100%	75%	75%	0%	50%	25%	50%	50%	

I organized data interpretation in two steps: first, I presented a concise description of the primary themes distinctly from each dataset. Next, I provided a complete description of the participants' views as well as the outcome of the documents review. Step 2 was the integration of the two datasets; the integration was a comprehensive synthesis of the composite views of participants and the output of the documents review. The integration also involved identifying convergence or divergence of the composite views.

Table 6

Codes Frequency Based on Participants' Views

	Participant 1A.docx	Participant 2A.docx	Participant 3A.docx	Participant 4A.docx	Participant 5A.docx	Participant 6A.docx	Participant 7A.docx	Participant 8A.docx	Code Occurrence	Frequency of Codes
RQ1_Energy_ Management& Efficiency	3	2	3	7	3	1	2	0	21	20.2%
RQ1_Raw Material :Vertical Integration	4	3	3	6	2	4	4	0	26	25.0%
RQ1_Productivity _Plant_Utilization	2	3	1	0	1	1	2	2	12	11.5%
RQ1_Purchasing Strategies	1	3	2	0	1	2	3	1	13	12.5%
RQ1_Sourcing	0	1	1	0	1	0	1	1	5	4.8%
RQ1_Strategic Partners	0	1	1	1	0	0	0	0	3	2.9%
Material Consumption Efficiency	2	2	0	1	2	0	1	0	8	7.7%
RQ2_Capabilities (Technology, Design)	2	3	2	1	3	4	0	1	16	15.4%
TOTALS:	14	18	13	16	13	12	13	5	104	100.0%

Table 7

Codes Frequency Based on the Documents Reviewed

	Document 1A.pdf	Document 2A.docx	Document 3A.docx	Document 4A.docx	Code Occurrence	Frequency of Codes
RQ1_Energy_Efficiency	7	1	1	2	11	29%
RQ1_Raw_Material: Vertical Integration	0	2	3	2	7	18%
RQ1_Productivity_ Plant Utilization	0	1	3	1	5	13%
RQ1_Purchasing_ Strategies	0	0	0	0	0	0%
RQ1_Sourcing	0	0	1	1	2	5%
RQ1_Strategic_Partners	0	0	0	1	1	3%
RQ1_Material Consumption Efficiency	0	2	4	0	6	16%
RQ2_Capabilities (Technology, Design)	1	2	2	1	6	16%
TOTALS:	8	8	14	8	38	100%

Core Theme 1: Energy Management and Efficiency

Energy management and consumption efficiency stemmed from four subthemes: the energy type used, energy processing efficiency, prices efficiency, and energy management options (see Figure 18). Energy management involved the set of strategies that production managers used to optimize energy consumption intensity while maximizing profits. The energy management approach involved appropriate procedures that consisted of reducing the energy requirements per unit of material processed while maintaining other inputs and output of the production constants.

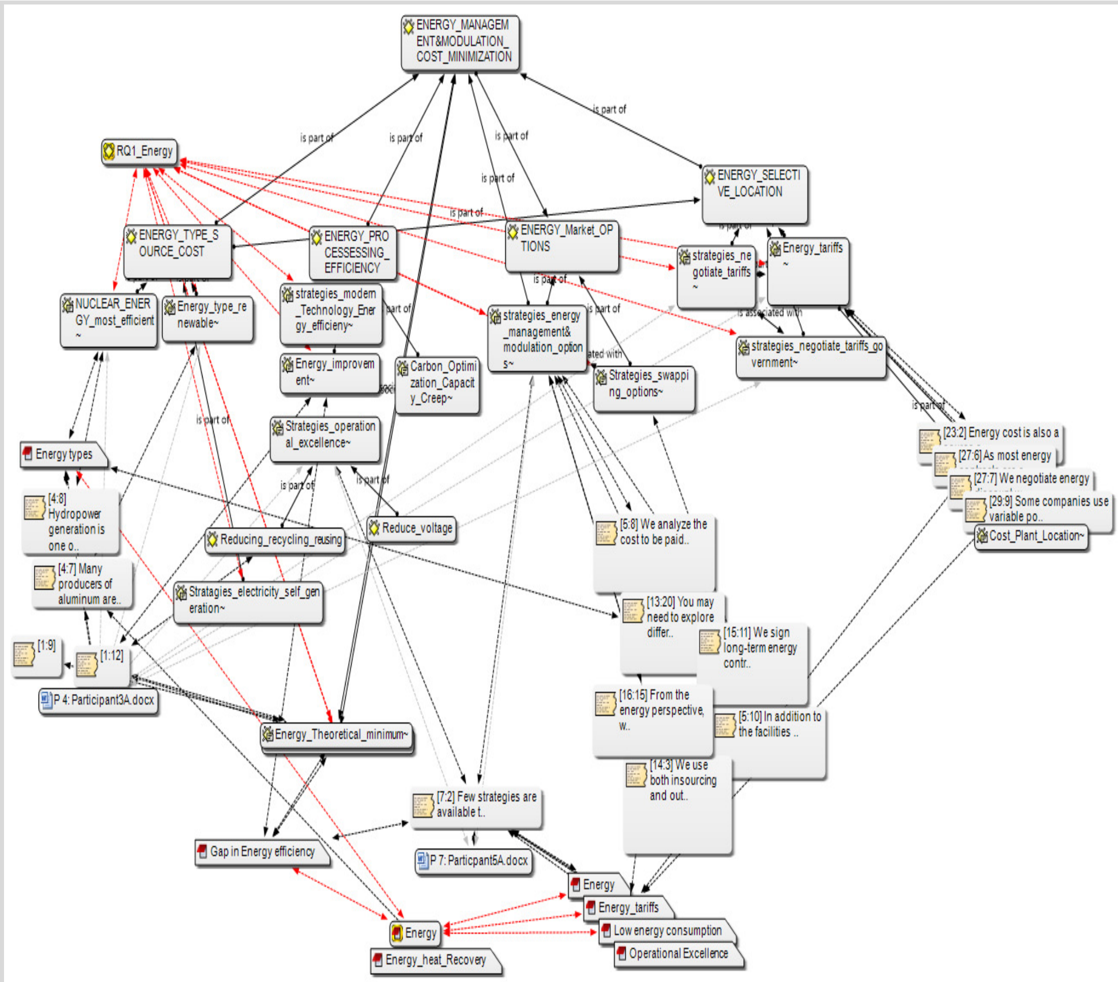


Figure 18. Conceptual network for Company A of energy cost minimization, derived from Atlas.ti.

Subtheme 1: Energy management.

Data source: interviews. Energy management emerged as one of the prominent themes from the data analysis and triangulation. Of the participants interviewed, 87% mentioned that energy management was a core strategy to allow reducing production costs. Table 6 shows that energy management and consumption efficiency accounted for

20% of the codes frequency. The table also indicates that 7 out of 8 participants identified this concept as an important strategy to reduce production costs. Most senior managers except one shared the view that energy was the most important cost factor. Whereas participant 8A did not mention energy as a driving factor to reduce production cost, Participant 3A highlighted this concept seven times during the interview. According to senior manager 3A, energy prices will only go increasingly given environmental restrictions and increasing energy demands. Energy management systems are often used by aluminum companies to control their energy cost by importing or exporting energy based on the seasonality of energy market prices (P1A & P2A, March 2017). Participant 1A further concluded that the flexibility of contractual agreements is an enabler to leverage market options of energy prices. Flexibility involves incorporating the potential changes or modifications to the contract, making sure that both contractual parties exceed their expectations.

Data source: document review. Table 7 indicates that energy management and efficiency accounted for 29% of the codes isolated. Of the documents analyzed, 100% introduced the energy management and consumption efficiency (see Table 7) as a core concept to reduce cost. Document D1A highlighted this concept seven times, indicating its central role in the company's portfolio of strategy to reduce production costs. As shown in Figure 18, the energy management and efficiency emerged from a cluster of four subthemes including energy contracts, processing efficiency, power source, and market options. Energy processing efficiency derived from technological and operational capabilities to lower electrolytic cell voltage while maintaining or improving the productivity. Figure 18 shows the conceptual network of energy cost minimization. Efficiency also derived from the use of low-cost assets.

Subthemes 2: Energy type and price efficiency.

Data source: interviews. Participants agreed that energy costs depend on the source of energy available at the national level and the type of contract. One SM stated that Company A uses nuclear power, one of the cheapest energy sources available; the company uses a long-term fixed-energy contract (P1A & 3A, March 2017). The cost of nuclear power per MWh was around USD 28, half the price of coal. This price was competitive at the EU level, according to participants 2A and 6A. Participants 1A and 8A argued that the energy costs account for 28% of the company's production costs. In addition, because of its nuclear base, this energy has no carbon effect (P1A & 4A, March 2017), thus providing an extra charge advantage.

Subtheme 3: Energy-processing efficiency.

Data source: interviews. This important theme was introduced in most documents as outlined in Table 6 and Figure 18. The company generated cash from the smelting business and by utilizing energy modulation as a strategy to increase revenues. In addition, the technology used in electrolytic reduction provided one of the lowest energy and carbon footprints in the aluminum industry, according to participants P6A and P8A. Most aluminum producers viewed this technology as a global benchmark regarding production costs, energy consumption, and environmental performance, according to participants (P2A & P3A, March 2017). The energy efficiency of the material processing was 60%, or 12.7 MWh/ton of aluminum output, which was 15% above the average performance in the industry. Although the energy cost was competitive, the company could still lower it further. For instance, Lucio et al. (2013) found that energy self-generation in the primary aluminum business is competitive. Self-generation provides security to the electricity supply.

The company was 15% more efficient than other businesses were in the same industry; but when compared to technical requirements or the thermodynamic calculation, the company was still incurring some additional opportunity cost. Gutowski et al. (2013) found that high-energy efficiency could be achieved by implementing low-cost capacity machines or by replacing high-cost technologies. The costs of inefficiency compared to the benchmark (12.5 MWh/ton Al) were only USD 5/ton of aluminum production, annualized to USD 12.6 million production costs. Compared to the theoretical consumption, the company incurred extra expenses of USD 84/ton Al. It has invested USD100 million in the last two years in energy saving and efficiency improvements in the production units (D2A & D4A, March 2017). The chart below outlines the current energy used versus the technical requirement for the production of primary aluminum.

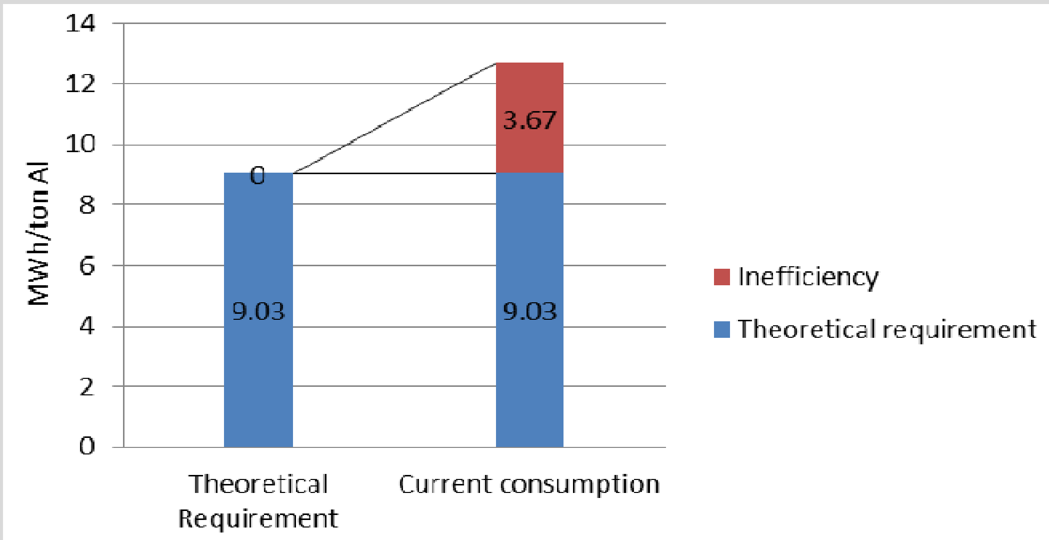


Figure 19. Energy consumption efficiency, Company A exhibited.

Data integration. Energy management, which consisted of importing or exporting a portion of a company's energy quota in the power grid, might allow an aluminum company to optimize operational expenses or increase revenues. An increased revenue allows reducing fixed costs per unit output. Energy contract should be agreed to achieving both the cost efficiency and the flexibility of options, based on the market prices to create value. According to Gaudard and Romerio (2014), two demand curves for the energy management in Western Europe are available: one for peak and the other for off-peak periods. Given this periodic availability (Gils, 2014), aluminum producers can import or export energy to create additional value and gain opportunity costs. The two datasets provided alignment of views regarding the central role that the energy management and efficiency play in the aluminum production cost.

Core Concept 2: Upstream Integration and Geographical Location

Data source: interviews. Raw material vertical integration accounted for 25% of the codes frequency. Similarly, Table 6 indicates that 7 out of 8 participants (87%) shared the views that raw material integration allowed the company to reduce cost and improve efficiency. Raw material integration emerged by grouping all subthemes including price efficiency, alumina supply risk minimization, and price volatility. Porter (1980) and Miltenberg (2005) also recognized the benefits of vertical integration on a company operating costs as it could allow decreasing prices and transportation expenses and reducing turnaround time. Vertical integration can occur in two directions: forward integration and backward integration. In the case of interest, the company has integrated the raw material in its production process according to one participant interviewed.

Data source: documents review. Table 7 outlines the code frequency based on the reports reviewed. Data indicate that 18% of the total codes isolated and 75% of reports highlighted the raw material integration as a valuable strategy to reduce costs. This theme emerged from the clustering of all subthemes including price efficiency, alumina-supply risk minimization, and price volatility. The majority of documents reported the use of this strategy given the alumina prices volatility and the need for securing alumina supplies in the long term (Documents D2, 3, & 4, March 2017).

Data integration. Data integration from interviews and the documents reviewed indicated that seven participants out of eight (87%) and 75% of reports suggested that the vertical integration of alumina supply is a strategy to reduce production costs. Two main subthemes related the backward integration concept (see Figure 20) to production costs:

(a) the need for alumina supply security and (b) the need to enhance material supply planning according to (P1A, 3A, & 4A; D2A, & 4A, March 2017). Ramanathan (2014) also found that supply chain performance could be improved when a company replenishes materials, coordinates planning, and forecasts supplies optimally.

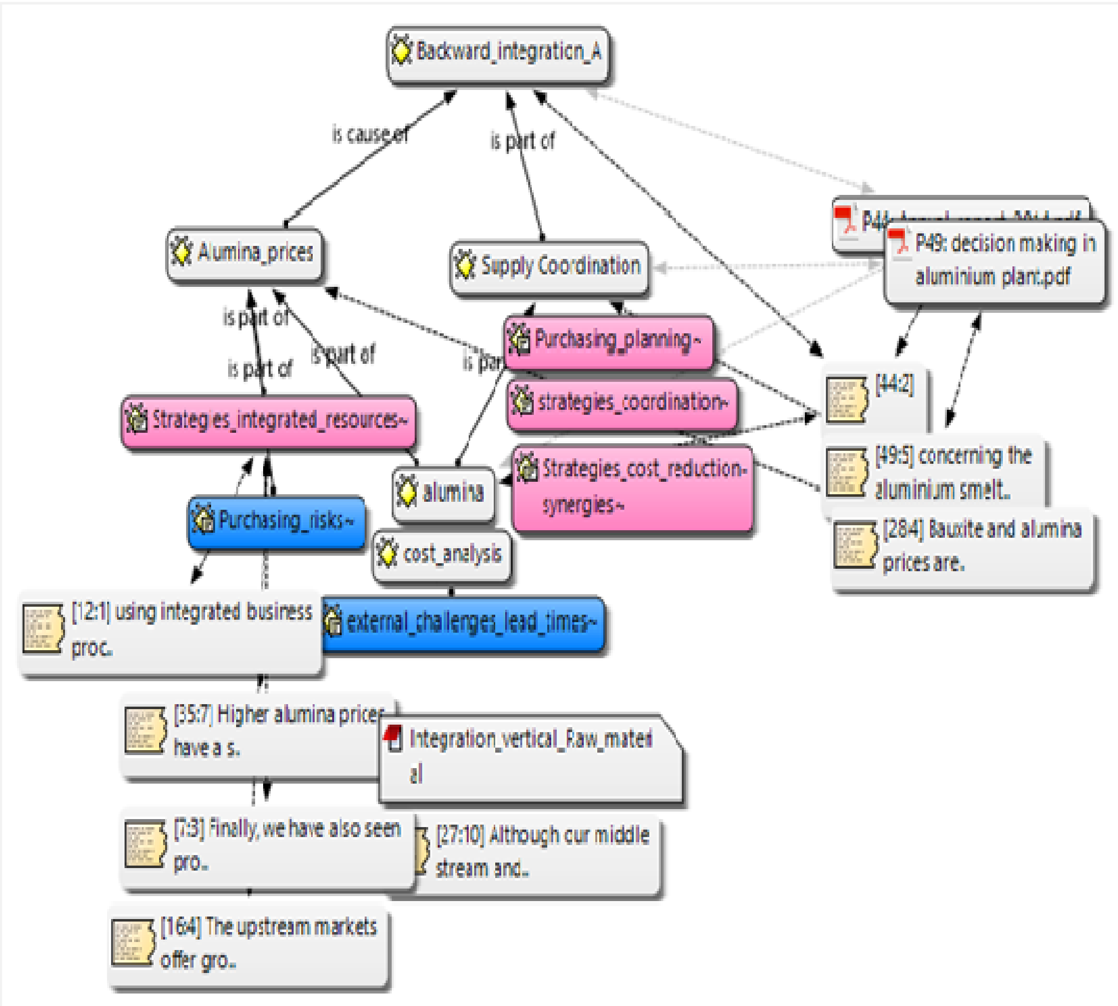


Figure 20. The conceptual network for Company A of alumina cost minimization, derived from Atlas.ti.

Company A was a component of a corporate business that had access to the industry's largest bauxite reserves. The company had integrated midstream and alumina activities. This competitive advantage made it one of the world's leading bauxite producers (D2A & 4A. March 2017); therefore, the company might not incur additional costs associated with alumina price uncertainty. Trench, Sykes, and Robinson (2015) also found that alumina demand is expected to increase based on China's ongoing alumina needs. Furthermore, Trench, Sykes, and Robinson found that a high demand in the market of alumina could foster prices to increase 15–20% by 2020. In this alumina demand-rich context, it makes sense to plan investments for integrating the raw material.

The company shipped the raw material to its production plant by sea. The plant's production facilities are integrated with the port terminals. This strategic location allowed minimizing transportation costs for the raw material supplies compared to its competitors, according to documents reviewed (D4A, March 2017). Shipping costs for raw materials between the maritime port terminal and the production plant were negligible because the company handled the raw material by a dense-phase pneumatic conveying system, an efficient method for bulk material handling (D4A, March 2017). The port's availability and proximity to its customers allowed viable transportation costs.

Core Concept 3: Productivity and Plant utilization

Data source: interviews. Table 6 indicates that 87% of participants considered productivity and plant utilization as a core theme for reducing production cost. This theme accounted for 11.5 % of the codes frequency. The concepts derived from numerous subthemes (see Figure 21) including (a) technological design and capability, (b) operational excellence, (c) asset utilization, and (d) skilled labor. Most participants conveyed operational productivity as the baseline for improving the overall company's performance. One senior manager (2A) stated that Company A increased productivity by increasing the capacity of all critical resources. Operational productivity is about maximizing the reliability of operations and processes to maximize uptime and life cycles, and improve quality while minimizing production cost. Improvement efforts were prioritized to sustaining initiatives and aligning to the leadership vision according to participants (2A &5A, March 2017).

Data source: documents review. Table 6 shows that 13% of the code prevalence was related to productivity and asset utilization. The table also indicates that 75% of the documents reviewed reported the productivity and high plant utilization as strategies to minimize the fixed cost per unit output. The company focused on low-cost assets and divested most of its high-cost assets. Of the four documents analyzed, one did not highlight the use of productivity as a means to streamline operations. The focus of this report was to highlight significant successes relative to green initiatives. Document 4D emphasized that operational productivity and excellence allow minimizing the resources used.

Data integration. Operational productivity was the most commonly used concept that participants highlighted as influencing the production costs. The concepts derived from numerous subthemes (see Figure 21) including (a) technological design and capability, (b) operational excellence, (c) asset utilization, and (d) skilled labor. Seven participants (87%) and three documents (75%) highlighted sustainable operations and productivity as intervening concepts to reduce production costs. The company applied operational excellence by ensuring quality at the bottom line, minimizing waste, embracing scientific thinking, and focusing on the processes performance (P3A, 4A, & 7A; D2A & 4A, March 2017).

Operational productivity is about maximizing the reliability of operations and processes to increase uptime, life cycles, and quality while minimizing production cost. Improvement efforts were prioritized to sustain initiatives and align operational capabilities to the leadership vision according to participants (2A &5A, March 2017). One senior manager stated that there is no one path to production cost minimization and sustainable value creation, each subdepartment tailors its operational capabilities by focusing on the primary cost drivers in the value chain. The company developed a robust problem-solving ability through state-of-the-art knowledge and deep functional expertise. It also realized and captured synergies between functional areas.

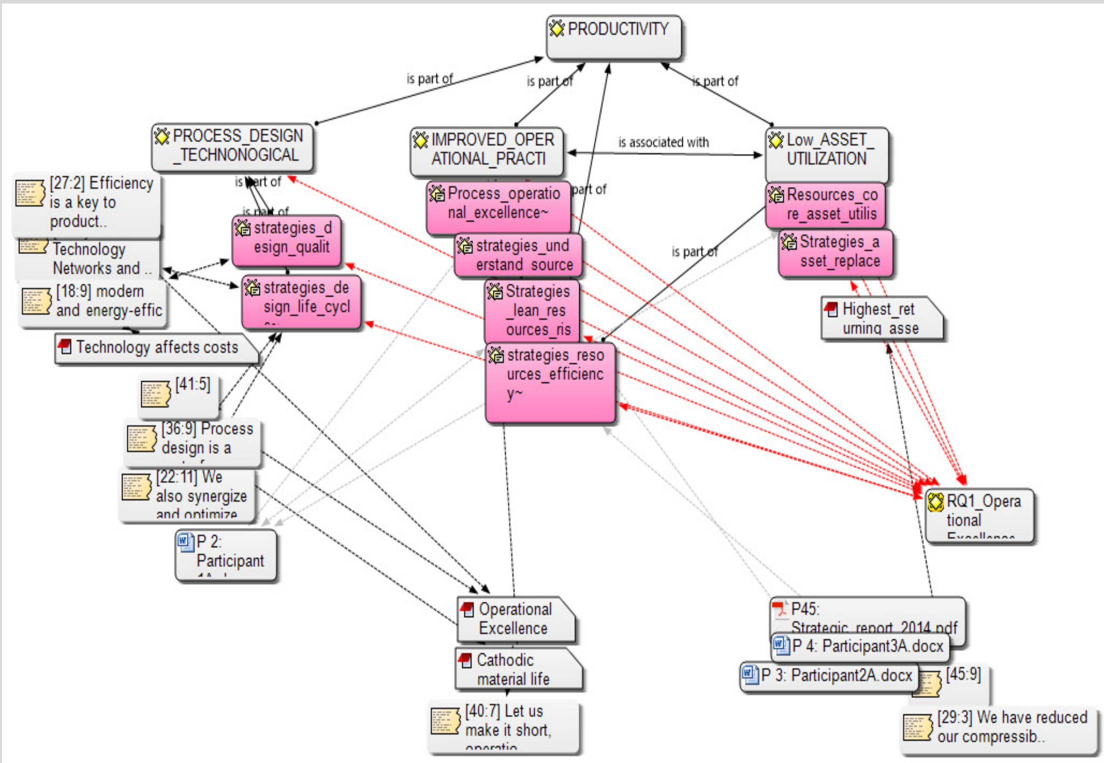


Figure 21. The conceptual network for Company A of operational excellence and productivity to reduce costs, derived from Atlas.ti.

Subthemes 3.1 and 3.3: Technological design, capability, and asset utilization. Technical capability supported high-production capacity creep (asset utilization) and economies of scales, according to a participant interviewed. Porter (1980) and Miltenberg (2005) also highlighted the impacts of economies of scales in fixed costs. An increased capacity (keeping production factors constant) allowed increasing productivity and reducing fixed costs per unit output (P5A, 6A, & 7A, March 2017). For instance, if a manager makes resources idle, assets would be underutilized, the production facilities might generate high per-unit cost, and profit potential could reduce. Conversely, high capacity utilization of assets may result in lower per-unit costs and increased profit potential. Asset or capacity utilization, which is the ratio of current outputs to possible outputs, provides insight into the overall slack that a firm may use to increase its productivity while reducing fixed cost per unit production. Capacity utilization contributes to a company's technical efficiency (Farrell, 1975).

The production plant was in the lowest half of the industry cost curve because of its technological capability and its competitive access to mines, according to documents reviewed. The documents reviewed also showed that the company focused relentlessly on cash generation by divesting high-cost assets. The technological capability supported low-capital and high-return creep (D4A, March 2017).

Subtheme 3.2. Operational Excellence. The views of participants and the documents reviewed were concordant about operational excellence (OE) being a decisive step for strengthening cost efficiency in production units. OE focuses on total quality management philosophy, according to a participant interviewed. Participants also maintained that OE allowed addressing quality and safety issues, protecting the environment, optimizing processes, and minimizing the resources used. The company focused on various self-assessment activities to identify gaps in production and used scientific tools to improve production performance by leveraging technological capability and problem-solving abilities (P3A & 8A, March 2017).

The company also generated value by sharing best practices and supply chain benefits across production plants. It demonstrated a strong commitment to excellence in health, safety, and environmental performance, according to the documents reviewed, and it had a clear, focused strategy for each production unit. There were 559 permanent workers and a temporary workforce of 15%. The annual production capacity was 275,000 tons (P8A, March 2017).

Core Concept 4: Raw Material Consumption and Efficiency

Data source: interviews. The code prevalence for the raw material consumption and efficiency was 7.7% according to Table 6. In addition, of participants, 68% identified material use efficiency as a factor to reduce production cost. According to P1A, 2A, 4A, and 5A, the raw material consumption efficiency allowed reducing greenhouse gases, and the energy required to process aluminum oxide. The raw material consumption efficiency resulted from clustering all the codes relative to carbon and alumina cost minimization. Some codes composing these two subthemes included prices efficiency, circular economy, reduced environmental impacts, and reduced waste. One senior manager mentioned the savings that can be gained from recycling, recovering, and reusing solid waste. According to this view, recycling is a source of raw materials potential in the future.

Data source: documents review. Of the reports analyzed, 50% highlighted the material consumption intensity as an influential factor in production costs. The code prevalence for this theme was 16%, about twice as higher than what participants said. Document 3A showed the influence of the material consumption efficiency on environmental protection and cost, as well as the preservation of natural resources. In paper 2A, the company identified opportunity costs by recovering, segregating, and recycling some waste within the internal business process. Material consumption efficiency also created opportunities for greener growth, which reduced taxes paid to the community.

Data integration. Carbon and alumina were the two persuasive raw materials used in the aluminum electrolytic process. Two prevailing subthemes emerged under carbon and alumina consumption efficiency: price efficiency and material use efficiency (see Figure 22). Most perspectives developed in the documents reviewed converged on the idea that the use of the materials extracted from natural resources has significant environmental, economic, and social consequences in the community and ecosystem (P1A, 2A, D2A, & 3A, March 2017). These social impacts often go in tandem with environmental costs that companies must pay to sovereign governments. Materials consumption efficiency was identified as a determinant of productivity improvement.

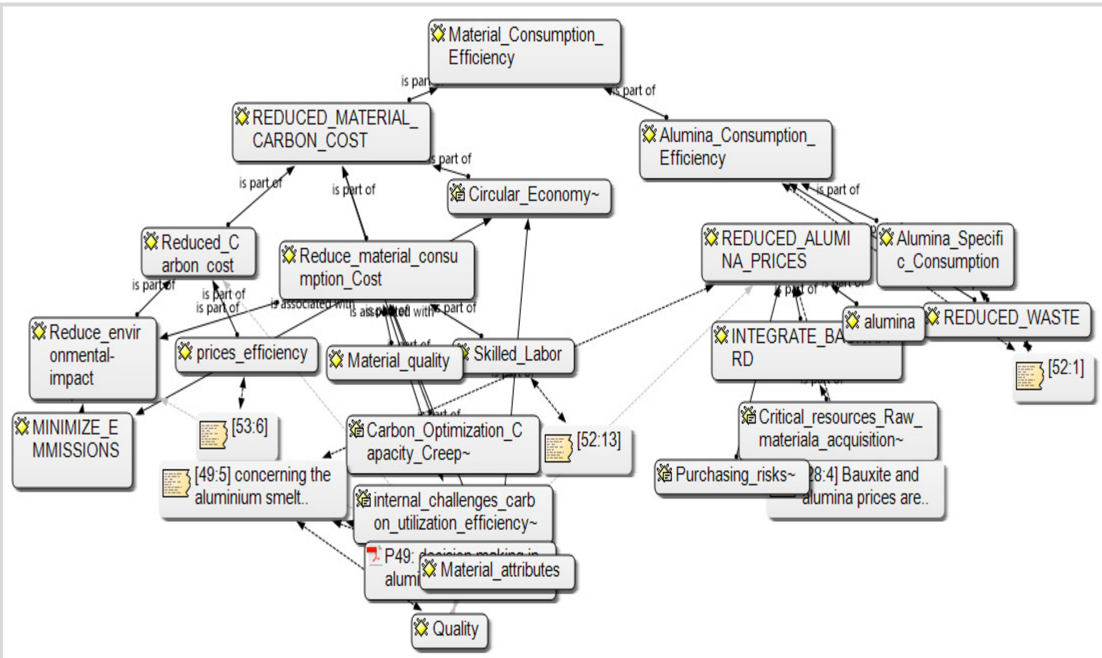


Figure 22. The conceptual network for Company A of material efficiency to lower costs, derived from Atlas.ti.

Subtheme 4.1: Carbon consumption efficiency. The carbon consumption rate in an electrolytic cell was 405 kg of carbon/ton of aluminum, according to a participant interviewed. The theoretical minimum, based on stoichiometric factors, is 333 kg C/ton Al. The observed efficiency was only 68%, indicating a gap in the material consumption. Given the carbon costs described in Table 4, 32% of the carbon-processing inefficiency was equivalent to USD72/Al. This amount may sound inconsequential, but based on the annual production capacity of 0.275 million Al, the cost avoidance could generate USD 19.8 million per year. In practice, the real carbon consumption is higher than the technical requirement because carbon anodes are exposed to ambient air, and observed current efficiency is lower than 100%. Nevertheless, the carbon inefficiency was attributed to technological and operational capabilities, according to a participant interviewed. Most senior managers and documents reviewed agreed that progress in material consumption efficiency should derive from technological change, operational efficiency, and the substitution of resources-intensive materials by efficient ones (e.g., inert carbon and cathode).

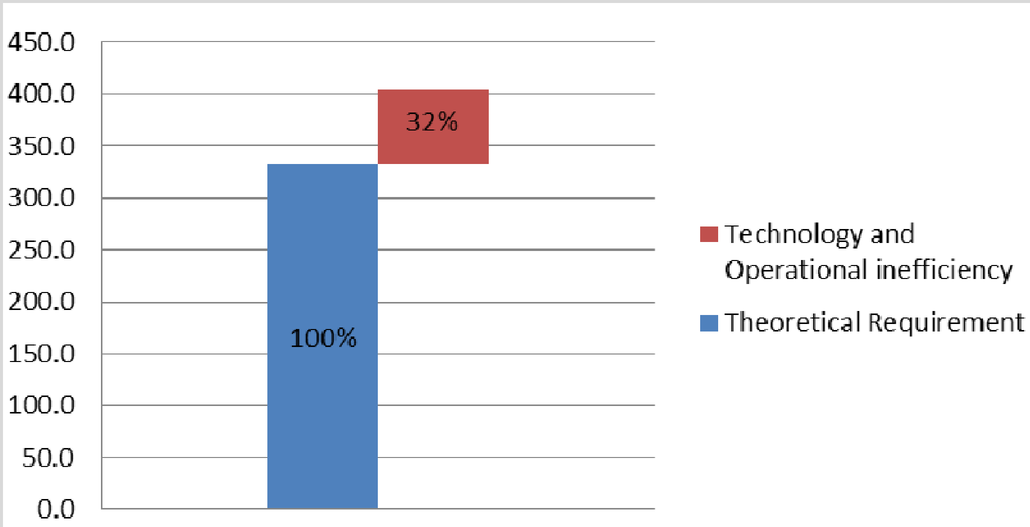


Figure 23. Carbon Consumption efficiency for Company A exhibited.

Subtheme 4-1. Alumina consumption efficiency. The ratio of the theoretical alumina consumption to aluminum output is 1.89:1—that is, 1.89 kg of alumina is required for every ton aluminum production according to stoichiometric factors. Company A used a proportion of 1.91, according to participants interviewed. Observed material inefficiency was 0.02 kg of alumina per kg Al. Participants also described how this waste reflected the losses as well as the low current efficiency of electrolytic cells (P 2A, 7A, &8A, March 2017), which was equivalent to USD7/ton of aluminum. This amount of waste may seem insignificant; however, based on the annual production capacity of 0.275 million tons, the cost savings could generate USD2 million per year.

Alumina was lost in aluminum processing through volatilization because of its fine particles size and a high attrition rate during trans-loading, transportation, and handling. The volatilization of this valuable material throughout the conveying and electrolytic processes necessitated tight controls and procedures to limit losses (D4A, March 2017). The company designed and built low-maintenance, environmentally friendly systems for optimal material transportation and handling requirements, from ships to in-plant systems incorporating conveying and pressure-vessel capability, according to documents observed. The system was designed to minimize alumina attrition by using very low-conveying velocities. The segregation of fine and coarse particles also affected the material efficiency and environmental emissions according to one SM interviewed. The documents reviewed also showed that anti-segregation technology for alumina storage was outfitted to maintaining uniform grain-size distribution, as materials were unloaded and conveyed. Reduced attrition and increased homogeneity enhanced the raw material quality, resulting in reduced anode effects and greenhouse gas emissions as well as energy use.

Core Concept 5: Technology and R&D Capabilities

Data source: Interviews. Of participants, 63% interviewed identified technological capabilities and R&D as a core factor to minimize resources consumption and to yield efficient production processes. The code prevalence for this core theme was 15.6%, the third most influential intervening concepts to reduce cost, according to the senior managers interviewed. One senior manager stated that the company developed a technology roadmap; this roadmap outlined a strategic plan, designed to focus on technological sustainability, energy minimization, and electrolytic cell lifespan improvement. Some senior managers identified the cell lifespan as a significant source of capital expenses. The lifespan increased through improving the carbon-cathode material use efficiency, which is only 40-45%. The company pursued its technological development through an organized agenda focusing on processing efficiency and engineered-material solutions.

Data source: **documents review**. Of the documents reviewed, 50% described technological capabilities and R&D as the primary factors in reducing production costs. In addition, the code prevalence for this theme was 16%. Most reports highlighted the importance of technical capabilities to increase energy efficiency, plant utilization, and reduce carbon dioxide emissions. These concepts are components of production costs in the aluminum production process. Document 2A and 3A indicated that the company managed to reduce carbon dioxide emissions through a rapid change in technological design. Some of the essential goals included developing alternative concepts (e.g., inert anodes and cathodes), exceeding 12.5 kWh/kg for alumina processing, reducing the cost of production, and improving cell life cycle by 2025.

Data integration. Technology and R&D were the driving forces of technical capabilities (D3A & 4A, March 2017). R&D activities promoted technological learning, derived from a firm's involvement in networking with other aluminum companies to increase innovativeness. Technology teams are aiming to develop a new generation of electrolytic cells that supports leading-edge operational and process control practices (P1A & 3A; D4A, March 2017). The technical capability also allowed the company to improve the productivity and the competitiveness of the plant through capacity creep, according to documents reviewed. Technology provided some advances in the reduction process, carbon casting, recycling, and environmental performance.

The company worked in close collaboration with universities, customers, equipment manufacturers, and specialized firms to drive improvements in aluminum smelting and recycling, according to the documents observed. The company also promoted the capacity for innovation through the long-term collaboration with approximately 20 external, scientific partners. Collaboration served many purposes such as sharing innovation opportunities. The technology, resulting from expertise and experience allowed the integration of capabilities that led to a sustainable performance at the lowest economic cost (P3A& D5A, March 2017).

Case Analysis Company B

Case Description

Company B was a primary aluminum producer located in Europe. The company produced semi-manufactured products such as T-ingots, slabs, and extrusion billets. Its vision was to create a viable society by developing natural resources and products in innovative and efficient ways, according to documents reviewed. This company was one of the largest primary aluminum producers in Europe. It was a global player operating along the entire value chain—from the production of bauxite, alumina, primary aluminum, and energy generation to the recycling of solid aluminum (D3B, March 2017). In the last decade, its production capacity increased from 0.35 million to 0.4 million metric tons of molten aluminum. The company's low-cost capability and energy availability allowed 14% production capacity creep according to a participant interviewed and a document reviewed. Increased volume per working hour produced productivity gains when inputs were kept constants.

The company was located close to waterfalls that it used to develop hydropower. Hydroelectricity was the primary source of energy utilized in the production of aluminum. The company was close to port terminals and therefore enjoyed cost advantages due to the geographical proximity (D1B, March 2017). It employed 750 workforces for a production capacity of 0.4 million tons, according to documents observed. It benefited a robust competitive security in the raw material supply for its production plants. The 2015 EBITDA margins rose to 25% from the 2014 baseline according to the company's annual report. The additional revenues stemmed from operational efficiency and cost reduction initiatives (P3B, 4B, & 7B, March 2017). This company was within the first quartile of the cost curve for the production of primary aluminum.

Table 8 outlines the codes prevalence for all themes isolated from the two datasets (interviews and documents review) after data triangulation. Tables 9 and 10 outline the frequency of codes for the core themes derived from interviews and the documents I reviewed in Company B. Each core concept arose from the subthemes I obtained by clustering data based on their similarity with existing information in the matrix of codes that was developing.

Table 8

Overview of Core Concepts, Company B

	Energy Management & Efficiency	Raw Material Acquisition: Vertical Integration	Carbon Manufactu ring Efficiency	Operational Excellence	Capabilities Technology / Design	Productivit y Plant Utilization	Strategic Partners	Sustainable Environmen	Totals:
Participant_1B.docx	4	5	1	1	0	1	2	1	15
Participant_2B.docx	2	3	2	0	2	1	2	2	14
Participant_3B.docx	4	2	0	1	0	1	0	2	10
Participant4B.docx	2	3	2	0	4	2	1	0	14
Participant5B.docx	3	2	2	1	1	1	0	0	10
Participant6B.docx	3	0	3	1	1	0	1	1	10
Participant7B.docx	0	0	3	2	1	3	1	2	12
Participant8B.docx	0	1	2	3	3	0	1	1	11
Document1B.docx	1	0	0	2	2	3	0	1	9
Document2B.docx	2	1	2	1	3	3	2	2	16
Document3B.docx	3	2	2	4	2	1	0	3	17
Document4B.docx	1	3	0	0	0	1	3	3	11
Code Occurrence	25	22	19	16	19	17	13	18	149
Code Frequency	17%	15%	13%	11%	13%	11%	9%	12%	
Frequency of Participants	75%	75%	88%	75%	75%	75%	75%	75%	
Frequency of Documents	100%	75%	50%	75%	75%	100%	50%	100%	

Table 9

Summary of Codes from Interviews

	Partici pant 1B.docx	Partici Pant 2B.docx	Partici Pant 3B.docx	Partici Pant 4B.docx	Partici Pant 5B.docx	Partici Pant 6B.docx	Partici Pant 7B.docx	Partici Pant 8B.docx	Code Frequen cy	Percentage of codes
RQ1_Energy Efficiency	4	2	4	2	3	3	0	0	18	18.8%
RQ1_Raw Material Vertical integration	5	3	2	3	2	0	0	1	16	16.7%
RQ1_Carbon Anode Manufacturing Efficiency	1	2	0	2	2	3	3	2	15	15.6%
RQ1_Operational Excellence	1	0	1	0	1	1	2	3	9	9.4%
RQ2_Capabilities Technology/ Design	0	2	0	4	1	1	1	3	12	12.5%
RQ1_Productivity Plant Utilization	1	1	1	2	1	0	3	0	9	9.4%
RQ1_Strategic_Partners	2	2	0	1	0	1	1	1	8	8.3%
RQ1_Sustainable_Environment/Circular Economy	1	2	2	0	0	1	2	1	9	9.4%
TOTALS:	15	14	10	14	10	10	12	11	96	100%

Table 10

Overview of Codes from Document Review

	Document 1B.docx	Document 2B.docx	Document 3B.docx	Document 4B.docx	Code Occurrence	Code Frequency	Frequency of Documents
RQ1_Energy Management & Efficiency	1	2	3	1	7	13%	100%
RQ1_Raw Material Acquisition Vertical Integration	0	1	2	3	6	11%	75%
RQ1_Carbon Anode Manufacturing Capability & Efficiency	0	2	2	0	4	8%	50%
RQ1_Operational Excellence	2	1	4	0	7	13%	75%
RQ2_Capabilities Technology/Design	2	3	2	0	7	13%	75%
RQ1_Productivity Plant Utilization	3	3	1	1	8	15%	100%
RQ1_Strategic Partners	0	2	0	3	5	9%	50%
RQ1_Sustainable Environment/Circular Economy	1	2	3	3	9	17%	100%
TOTALS:	9	16	17	11	53	100%	

Core Concept 1: Sustainable Energy Management and Efficiency

Data source: interviews. Energy management and efficiency emerged as a core theme of the data analysis. Of participants, 75% mentioned that energy efficiency was a core strategy to reduce production costs. As shown in figure 25, energy management and efficiency emerged through clustering codes of similar meaning. This grouping yielded five subthemes including electricity contract, prices efficiency, processing efficiency, heat recovery, and energy management options. The objectives of energy management were energy consumption efficiency, cost minimization, and promoting environmental conservation. Of the senior managers interviewed, 50% discussed the influence of electricity prices on production costs. The company used fixed-price energy contracts (P1B, 2B, 3B, & 5B, March 2017). The price paid to the energy supplier might not change during the contractual period regardless of the energy market prices. Prices efficiency was linked with the type of energy and contract used.

Energy processing efficiency was realized by adopting alumina-feeding strategy that aimed at reducing cell voltage and greenhouse gases emissions (P4B & 5B, March 2017). Energy processing efficiency also was gained through using alternative materials that allowed low-energy consumption while maintaining reasonable production output.

Data source: documents review. The concept of energy efficiency and management was introduced in 100% of the reports analyzed. The company used fixed-term energy contracts (D2B & D3B, March 2017) and hydropower for the production of aluminum. Hydroelectricity is a clean source, which neither pollutes air nor generates greenhouse gases. According to one document reviewed, it is the most efficient energy source.

On the other hand, efforts were considered to reducing energy consumption intensity through technological and operational capabilities. According to document D3B, part of the energy released from electrolytic cells was recovered in the form of heat. Heat recovery allowed increasing the energy efficiency, which allowed reducing environmental emissions.

Data integration. The two data sources exhibited remarkable convergence of information, indicating the critical role energy has in aluminum production costs. Energy management and efficiency derived from five subthemes including (a) energy sources and price efficiency, (b) power management options, (c) heat recovery, (d) energy-processing efficiency, and (e) alumina-feeding strategy and greenhouse gases minimization. Strategies for the energy management require profound understanding and knowledge of the primary aluminum technical, economic, and regulatory limits to derive opportunity costs when making operational decisions.

Subtheme 1.1. Energy source and price efficiency, data source: documents review. Seventy percent of the company's power supply was carbon-free, according to the documents reviewed. The energy sources for alumina electrolysis were renewable, as the company used hydropower and gas. One participant stated that hydropower price was about one-half the price of nuclear power, which was also considered as a competitive source of electricity generation. Hydropower and gas were the cleanest forms of electricity; as such, their energy prices remained competitive compared to other energy sources such as coal and fuel. In addition, the company used fixed-term energy contracts (D1B, & 3B, March 2017), provided prices stability and enhanced quality forecast.

Subtheme 1.2. Energy management options, data source: interviews. Energy management was one of the company's core strategies. Energy management was implemented through importing or exporting power within the distribution network, according to 50% of the senior managers interviewed. The senior managers also indicated that the energy management system was a public-private partnership or cooperation that major energy consumers such as aluminum plants used to increase their competitiveness (see Figure 25). With the growing public demand and the prices of energy, power modulation increasingly provided incentives to maximize the revenues in some European aluminum companies. Depending on the market options, energy exportation to the national grid often led to additional revenues in the company's portfolio. Nevertheless, the power modulation also resulted in reduced production output because the aluminum output was a linear function of the current input. According to a senior production manager interviewed, the revenues growth gained by exporting energy allowed compensating the cost incurred due to production loss. The volatility of energy prices in the European market affected companies' predictable costs.

Subtheme 1.4. Energy-processing efficiency: **Data integration**. The company strived to use new materials with lower energy intensity to reduce the power consumption for the material processing (P1B, 3B, 4B, & P4B, March 2017). The senior manager stated that Company B consumed 12.5 MWh/ton Al in its new electrolytic cells, providing a competitive edge over the companies that consumed 14 MWh/ton Al. Table 4 shows that 1.5 MWh/ton Al represented USD44/ton Al. Other sources of energy improvements related to voltage minimization.

The company's energy efficiency was 66%; it faced 34% inefficiency based on the theoretical baseline (see Figure 24). Energy processing efficiency improvement was a crucial operational capability to lowering production costs and to increasing predictable earnings (P4B, 5B, & D4B, March 2017). The company used fixed-term energy contracts (D1B, & 3B, March 2017), which provided prices stability and enhanced quality forecast.

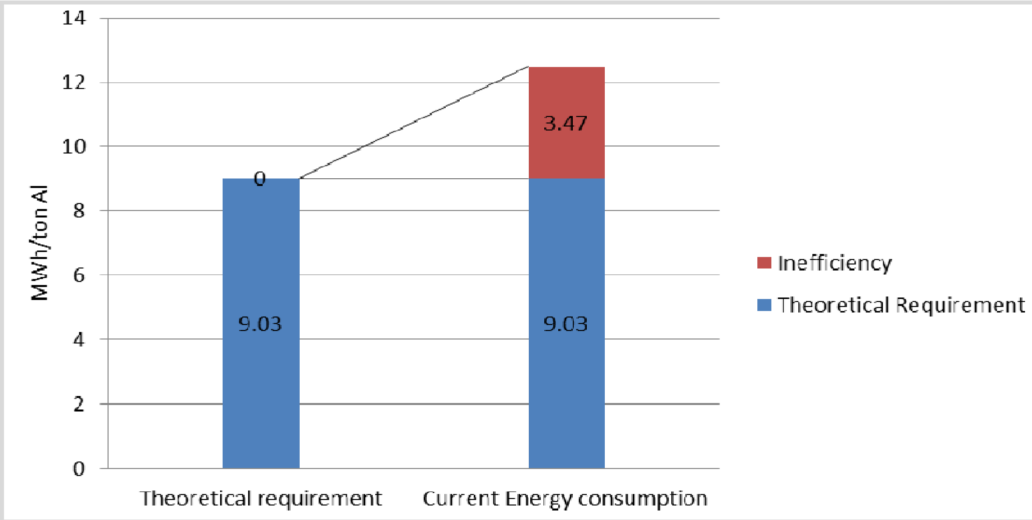


Figure 24. Energy consumption for Company B.

Subtheme 1.5. Alumina feeding strategy and greenhouse gases generation, **data source**: **interviews**. The primary greenhouse gas emitted from modern aluminum production plants was carbon dioxide. This gas was generated from the electrical current flowing into the carbon anode and the carbon reacting with oxygen in the molten electrolyte. Highly potent greenhouse gases such as perfluorocarbons also developed when the alumina concentration dropped below a minimum level in the electrolyte, resulting in the so-called "anode effect," which increased the cell voltage ten times higher than the average voltage. Governmental taxes were proportional to the overall energy used and emissions (P2B & 4B, March 2017). The company minimized these gases through optimal alumina-feeding strategies and highly resilient operational processes, according to a participant interviewed.

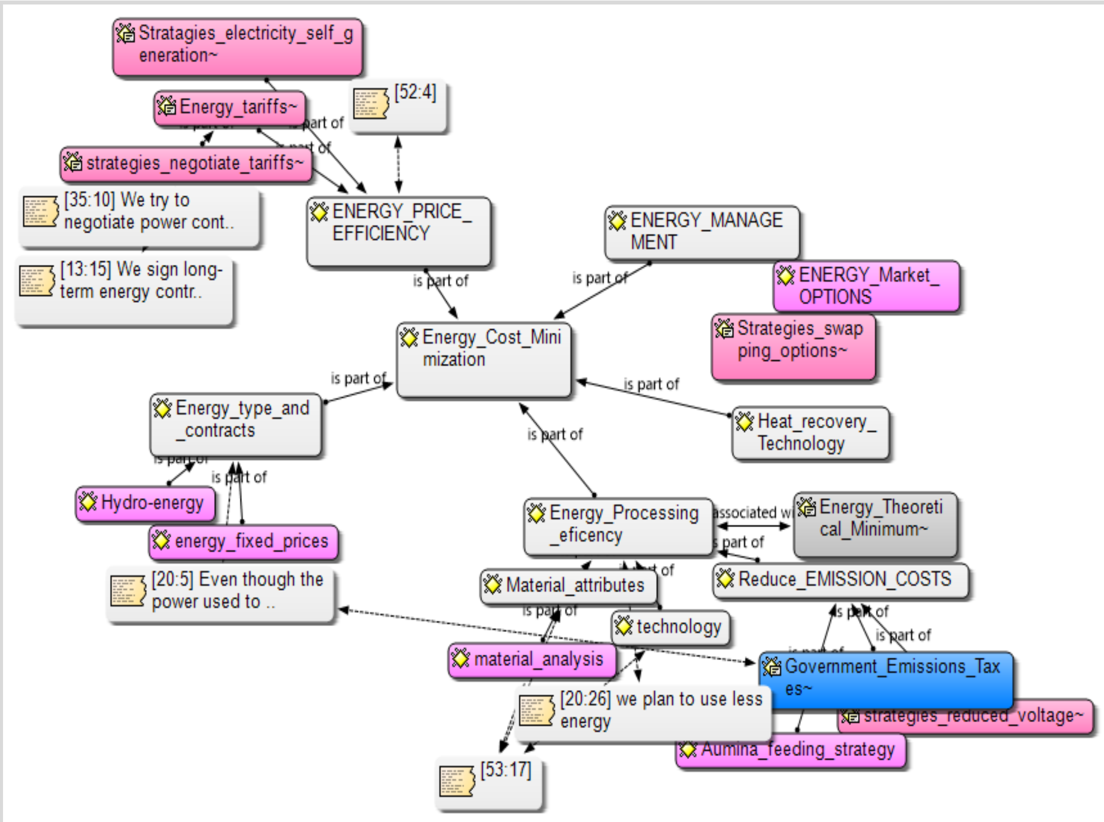


Figure 25. A conceptual network of Company B for energy cost minimization, derived from Atlas.ti.Core Concept 2: Upstream Integration and Geographical Location

Data source: interviews. Table 9 shows that 75% of the participants interviewed identified the vertical integration of alumina as a competitive strategy for minimizing prices volatility impact on production costs. The raw material integration composed 16.7% of the total codes occurrence, making it the second most important strategy to lower production cost. One participant stated that integrated production activities provided a significant advantage regarding business planning and flexibility in the supply of raw material.

Most alumina suppliers tended to shift toward index-pricing ties, which might be based on futures or spot prices**.** Buying commodity on spot prices might lead to disadvantageous economic costs for the primary aluminum producers, according to a participant interviewed. The index-pricing link allowed suppliers to price alumina based on the market price of aluminum on the LME. Increased alumina price affected not only production costs but also offset gains on aluminum commodity prices (P2B, 3B, & 8B, March 2017). Lin et al. (2014) found that internalized supplies of high-quality resources through vertically integrated functions might capture a premium.

Nevertheless, one senior manager stated that backward integration was a risky strategy –expensive, and challenging to reverse. Companies must analyze all potential risks before embracing this approach. Lin, Parlaktürk, and Swaminathan (2014) also found that upstream and downstream integrations tended to intensify competition.

Data source: document review. The raw material integration influenced production cost for primary aluminum according to 75% of the documents reviewed. Table 10 indicated that the code occurrence of this theme was higher than 11%. The company has integrated its midstream production processes backward to its upstream activities, providing access to alumina (D1B, 3B, & 4B, March 2017). This strategy increased the quality planning of budgets as the company might take advantage of the prices stability (D2B, March 2017). The integrated refinery capability was a state-of-the-art process technology designed to minimize energy costs, raw material consumption, and waste according to a document reviewed.

Data integration. The views developed in the two datasets indicated concordant results and implied that the raw material acquisition cost tended to reduce when alumina production and supply were integrated with the midstream activities. Vertical integration enhances planning, increased coordination effectiveness, improves forecasting predictability, and the quality of replenishment (Glock & Kim, 2015; Jin, Amydee, & Fawcett, 2013), but might intensify completion, which has some impacts on prices. Two senior managers provided quantitative data that allowed comparing the company's performance with competitors whose business used non-integrated strategies. The alumina cost of USD377 composed 23% of the total production costs, as compared to USD467 (29%) for the highest price observed. The difference of USD 90/ton of aluminum output indicated that, on average, Company B was 24% more cost-efficient than a non-integrated company was. Document 2D highlighted that transaction costs and the risk of exploitation reduced when a business realizes vertical integration. The document also considered that vertical integration creates market power and raises barriers to entry. Transaction costs depend on prices volatility, material quality, and delivery performance. According to document 2D, the company's proximity, and access to a port terminal also provided advantageous commercial transportation costs in importing and exporting materials and finished products, according to a participant interviewed.

Core Concept 3: Material Attributes and the Circular Economy

Figure 26 shows the conceptual network for the material attributes and circular economy. Three subthemes, including material characteristics, recycling and reusing, and increased electrolytic cell lifespan provided the conceptual framework of the network.

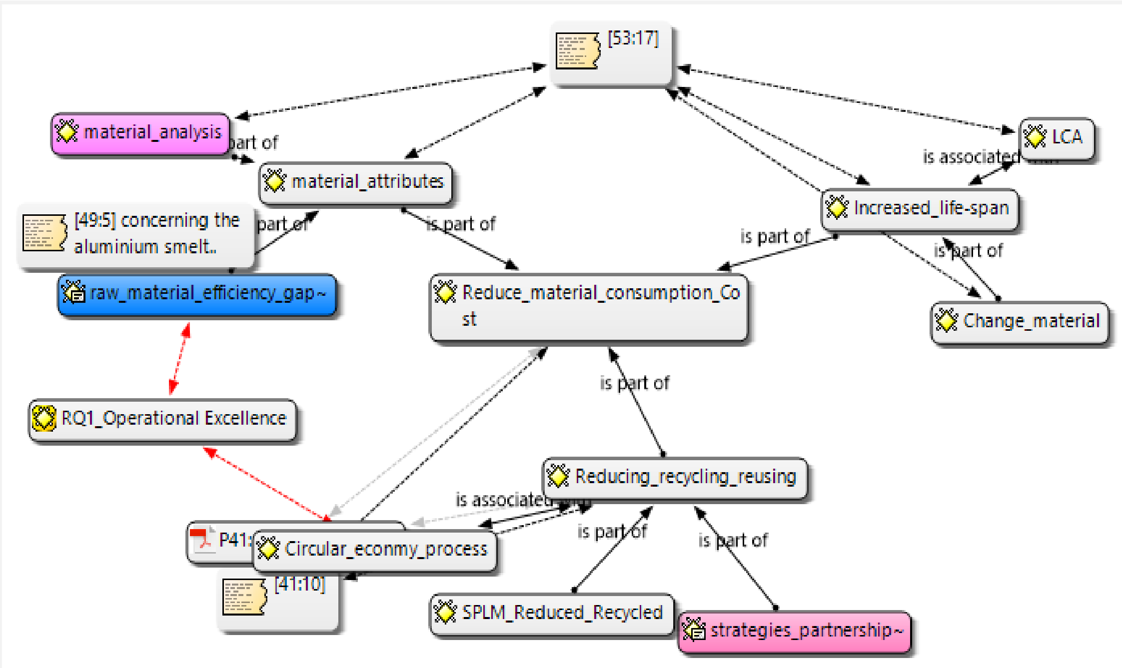


Figure 26. The conceptual network for Company B of material cost reductions, derived from Atlas.ti.

Subtheme 3.1: Reducing, recycling, and reusing.

Data source: interviews. The company assessed the reliability of the raw material through the material attributes assessment, which allowed it to anticipate and minimize the relative cost-per-unit volume and harmful effects while planning the costs of recycling (Participant 2B, March 2017). Materials must have the characteristics to serve a definite industrial goal efficiently, effectively, and safely. While materials are designed to transmit electricity and heat, increase life cycle, store energy, and insulate systems in the production of primary aluminum, minimizing operational costs and waste should be the primary goal in selecting the material according to a participant interviewed. For example, the carbon cathode material, which is the main constituent of the electrolytic cell lifespan, must be designed to increase the material use efficiency to minimizing investment and refurbishment costs (Participant 2B & 3B, March 2017). Company B also intensified the use of solid aluminum recycling as a means to reduce energy consumption. One senior manager reported that the company used recycling because it improved energy consumption intensity. Emissions also were reduced, and the costs paid to governmental agencies reduced by a rate of 20% in recent years."

Data source: documents review. The materials characteristics assessment allowed the company to identify a material's suitability to maximize the use efficiency (D1B &4B, March 2017). The company recycled some of its materials for sustainable development. Extraction and transformation of natural resources affect environmental biodiversity. The company implemented circular economics to minimize adverse environmental effects according to a participant interviewed. The recycling of aluminum enabled aluminum producers to reduce waste according to a document reviewed. The documents analyzed indicated that recycling had a lower energy requirement when compared with the production of primary aluminum because it consumes only 5% of the power.

Subthemes 3.2 and 3.3: Lifecycle and product attributes.

***Data source*: *interviews*.** Increased cathode life can allow lowering the purchasing cost as well as the cash outflow for the cathodic bloc replenishment. According to some participants interviewed, reducing the carbon-material erosion rate or increasing its utilization would allow increasing cathode lifespan. Aluminum producers might achieve these two characteristics through efficient technological and operational capabilities and new materials design. For instance, aiming for the homogeneous current distribution across the cathodic surface could drive the optimum erosion pattern that allows maximizing the cathode life (P7A, March 2017). Too often, when the cathodic material fails in a running cell, only 35-40% of the material is used; the remainder is treated and handled as waste (P7B & 8B, March 2017). The continuous improvement of new generation electrolytic cells should support optimal solutions to increasing cathode life while maintaining homogeneous erosion across its surface. This performance might improve the aluminum cell life, productivity, energy efficiency, and lower production cost according to a participant interviewed.

***Data source*: *documents review*.** According to the documents observed and some participants, the cement industry can use spent pot lining material (SPLM) as a raw material in its process, provided the product be hazard free. The company used a local partnership approach to handling SPLM. Local collaboration also allowed the company to reduce transportation costs. In addition, residual aluminum from the casting process, which was solid waste, was recycled to reduce environmental impacts. The recycling and recovering of this material had significant economic implications. Residual aluminum, removed from the casting process has high aluminum content. One SM described how "the company melts residual aluminum in a specialized-recycling furnace that was set aside for this special use and to reduce landfilling its waste."

Data integration. All documents reviewed (100%) and 75% of participants mentioned the circular economy as a robust strategy the company used to reduce costs. The codes frequencies representing this theme were 17% and 9.4% from the document reviewed and the interviews respectively. Three critical subthemes emerged from the data organizing and categorizing: (a) reducing, recycling, and reusing materials; (b) material attributes, and (c) increased lifespan (see Figure 26). The material quality contributed significantly to energy consumption and the product lifecycle, according to a participant interviewed. The objective of using the high-quality material in production systems was to reduce the energy processing demand and emissions and other environmental impacts of the business. The material characteristics approach allowed minimizing the negative environmental impact of aluminum production through efficient and moderated use of energy (P3B &5B, March 2017). Most SMs mentioned cathodic and carbon anode materials as elements of sustainability. The use of high-quality material to reduce energy consumption was a conscious and proactive approach to energy and environmental conservation. The material selection was an important step to minimizing cost while meeting the process requirements. Finally, the company used a local partner to handle and transform SPLM. The local collaboration allowed the company to reduce transportation costs.

Core Concept 4: Operational Excellence and Productivity

Data source: interviews. Participant 1B and 2B mentioned that high productivity derived from high-plant utilization rate that allowed the company to reduce environmental waste and improve asset efficiency. Operational excellence and productivity were highlighted by 75% of the participants. The code frequency of this core theme constituted 9.4% of the total codes recorded. Figure 27 indicates that productivity derived from three subthemes: reduced environmental impact, increased asset utilization, and increased asset efficiency. Production efficiency, which involved material, energy, and labor factor capabilities, were fundamental elements of the production cost minimization (P3B &5B, March 2017). Most senior managers agreed that productivity improvement increased efficiency and reduced resources use while increasing output. Notwithstanding, the SMs acknowledged that challenges exist regarding the estimation of the resource productivity and its optimal use to address its implications (P3B, March 2017).

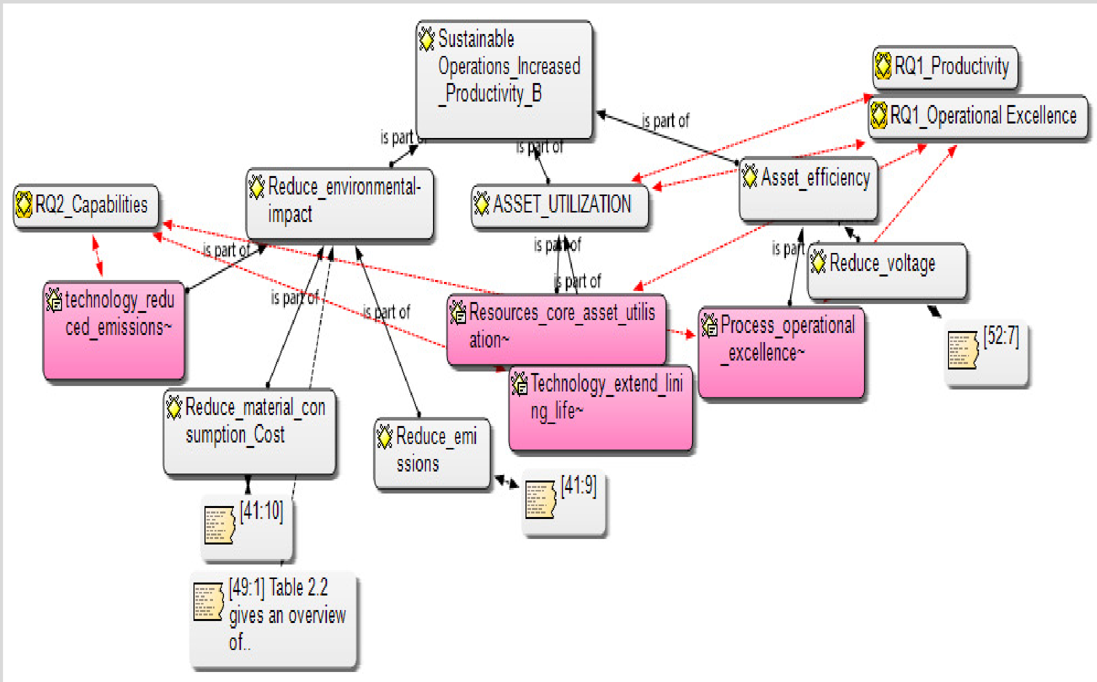


Figure 27. The conceptual network of Company B for operational excellence and productivity, derived from Atlas.ti.

Data source: documents review. Of the documents analyzed, 100% highlighted productivity and plant utilization as an important theme to reduce production costs. In addition, the theme composed 15% of the total codes occurrence. Documents 2B and 4B identified technological capabilities, and process innovativeness as components of productivity and capacity creep. Innovativeness, which is the quality of being innovative, promotes creativity and continuous improvement. Production capacity is the quantity of aluminum that a company produces in a given period based on available resources. When the volume of output increases while maintaining inputs constant, the production efficiency improves and the marginal cost per ton of aluminum decreases. The company implemented automation and process improvement methodologies throughout its value chain (D1B & D3B, March 2017).

Aluminum production is a resource- and energy-intensive process; starting with the bauxite mining, aluminum fluoride, and coke, all these minerals are extracted from the earth crust in millions of tons per annum. Aluminum production growth threatens environmental sustainability. Whereas most producers attempted to increase the production capacity to sustain high-fixed costs, the rate at which the raw material is demanded, consumed, and some of it discarded in the form of waste has not abated due to reduced efficiency and the lack of innovative processes of recycling (D4B, Mach 2017). The growing resource consumption and waste generation together, place increasing demands on financial capabilities and might further drive production costs upwards. Document 4D further highlighted that the limited resources necessitated efficient production functions and processes to alleviating sustainability and productivity concerns. A firm's cash flow and profitability are exposed to resources consumption efficiency.

Data integration. The two datasets showed that increased productivity and plant utilization reduced production costs. Technological capabilities and processes innovativeness, as well as assets efficiency, can improve productivity and material efficiency. Productivity derived from finding effective production methods of doing things efficiently. It is different from costs cutting or increasing volumes of output regardless of the returns. The measurement of the production frontier should guide the decision to estimate the inputs requirements for a given production output. Gutowski et al. (2013) found that implementing low-cost capacity machines or replacing high-cost technologies increases efficiency.

Subtheme 4.1 Reduced emissions, data source: documents review. The company improved performance through significant cost reductions and process efficiency. The management focused on top-tier assets and curtailed high-cost capacity, according to the documents reviewed. One participant interviewed described how the company had lowered its greenhouse gas emissions by approximately 20% in the last 10 years, significantly reducing production costs. The reduction of the emissions generation arose from (a) investments in breakthrough technologies for purifying and recycling gases, (b) the closure refurbishment of old-or higher-carbon energy assets, and (c) operational improvements, according to documents reviewed.

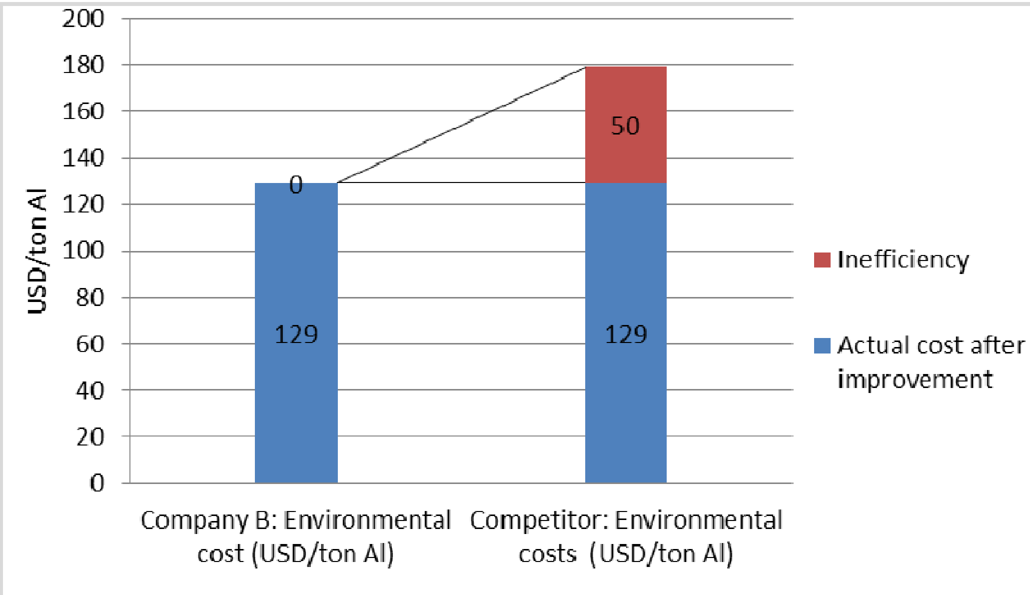


Figure 28. Environmental costs for Company B exhibited.

Subthemes 4.2: Increased plant utilization and efficiency, data source: documents review. The company improved performance through significant cost reductions and process efficiencies. The company's strategy was to focus on top-tier assets and curtail high-cost capacity, according to documents reviewed. The company consolidated its position as one of the world's leading aluminum businesses regarding the quality of assets, productivity, and profitability. The documents review also indicated that Company B delivered earnings of USD370 million in 2015, including increased EBITDA margins, despite decreased average London Metal Exchange (LME) prices. It launched 700 cost-reduction initiatives in 2015, resulting in significant earnings improvements as highlighted in its annual report. These cost initiatives included production efficiencies, negotiated prices of raw materials, and increased capacities of output units, according to annual reports. Qualified staff, as well as highly technical standards, and superior design were the company's core capabilities (P4A &7A, March 2017). The company employed 750 people, 10% of which were subcontractors, for a production capacity of 0.4 million tons per year.

Core Concept 5: Material-Consumption Efficiency

Data integration. Table 9 shows that 87% of participants and 50% of the documents reviewed mentioned the material consumption efficiency as a strategy to reduce costs. The material consumption efficiency constituted 15.6% and 8% of the codes occurrence from the interviews and documents reviewed, respectively. Carbon and alumina were the most important raw materials in the aluminum processing (P1B, 2B, & 3D, March 2017). The carbon consumption rate in the electrolytic cell was approximately 400 kg of carbon/ton of aluminum (Annual Report, 2014), as compared to a technical consumption requirement of 333 kg. The observed efficiency was 80%. The carbon inefficiency of 20% was equivalent to 67 kilograms of carbon wasted for every ton of aluminum output, corresponding to USD45 per ton. At a capacity of 0.4 million tons Al, the cost improvement could generate USD18.3 million additional revenues per year.

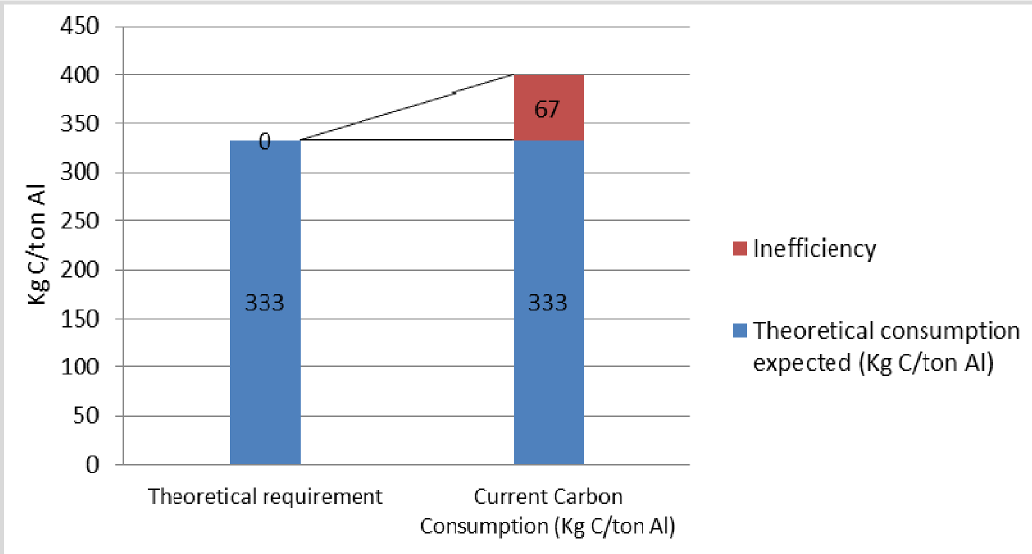


Figure 29. Carbon consumption efficiency for Company B.

The ratio of alumina consumption to aluminum output was 1.92:1. Observed material inefficiency was 0.03 kg of alumina wasted per kg Al. This additional alumina consumed reflected losses as well as the low current efficiency of electrolytic cells and was equivalent to USD 6/ton Al (P1B, March 2017), generating additional production costs, annualized to USD2.4 million.

Core Concept 6: Technology and R&D Capabilities

Data source: **interviews**. Data showed that 75% of participants mentioned technology and R&D as an enabler to lower production costs. P5A and 8A reported that the company was engaged in the modernization projects of old assets; these investments would allow the company to leverage the low-cost hydropower capability to reduce fixed costs. The new technological capability developed in the reduction process was designed to delivering lower economic costs of production, according to documents observed. One senior manager stated, “The benefits expected included 20% higher productivity per electrolytic cell and 7% greater workforce productivity.” The participants also described the way technology allowed the company to enhance the predictability of its production cells life cycle through promoting high-quality material. In addition, the senior manager explained how the company was continually working to develop energy-efficient cells to improve economic performance and create a sustainable production system.

Data source: documents review. Company B had a fully integrated alumina transportation design and trans-loading capability, including point feeding and hyperactive dense-phase systems that kept transportation costs at a minimum, according to documents reviewed. In addition, the integrated-carbon-anode manufacturing capability allowed minimizing transactional costs of purchasing anodes and supply risk potential (D2 & 3D, March 2017). High electrolytic cell productivity increased production outputs while reducing energy consumption intensity. As one document described, “High environmental and safety standards, improved facilities quality, and equipment design reduced incidents and security costs” (D3D, March 2017).

Data integration. Technology and R&D were enablers to reduce costs through innovation. The technological capability had implications on material and energy consumption intensities. The company refurbished low-energy efficiency electrolytic cells to reduce energy consumption intensity. Technology also allowed some energy recovery and waste minimization.

Case Analysis Company C

Case Description

Company C's electrolysis plant was located in Western Europe. The company produced primary aluminum through the Hall–Héroult process, the primary industrial process for alumina electrolysis. The plant produced a diversified portfolio of specialized light metal products, including alloys in the form of ingots, slab, and wire. The smelter was commissioned in the early 20th century to produce high-quality aluminum and sustainable material with high productivity. At full capacity, the company produced 145,000 tons of aluminum per year and used a workforce of 600 employees.

The company required competitive security for its raw material supply to its production units because it purchased directly from the market, according to a participant interviewed. The senior manager went further to highlight that businesses that buy the raw material based on spot prices face price uncertainty. One senior manager stated that the company realized less than 5% ROI in 2015, despite improvements in aluminum prices in the last quarter of 2015. Figure 30 outlines five causal conditions of high production cost in Company C: (a) energy and raw material cost inefficiency, (b) energy-processing inefficiency, (c) material-consumption inefficiency, (d) lack of carbon anode manufacturing capability, and (e) reduced asset utilization. Conversely, three core themes emerged for reducing production costs including (a) operational excellence, (b) sourcing, and (d) strategic collaboration.

Table 11 is a summary of the codes prevalence for all themes isolated from the two datasets (interviews and documents review) after data triangulation. Tables 12 and 13 profiled the frequency of the codes for the core themes obtained from interviews and documents analysis in Company C. Each core theme stemmed from the subthemes that I obtained by clustering data based on their similarity with existing information in the matrix of codes that was growing.

Table 11

Overview of Core Concepts: Company C

	Energy Manageme nt/ Modulation	Missing Capability: Raw Material Integration	Limited Carbon Anode Manufacturi ng	Operational Excellence	Purchasing Strategies	Sourcing Strategies	Strategic Partners	Circular Economy	Capability Technology / Design	Totals:
Participant 1C.docx	2	2	0	0	2	3	0	4	0	13
Participant 2C.docx	2	4	2	1	1	1	0	5	0	16
Participant 3C.docx	3	1	3	1	2	1	0	0	1	12
Participant 4C.docx	1	2	2	2	0	1	1	1	1	11
Participant 5C.docx	0	2	0	0	1	5	0	0	0	8
Participant 6C.docx	1	5	2	2	0	1	1	1	0	13
Participant 7C.docx	1	3	2	0	1	1	0	0	0	8
Participant 8C.docx	1	0	2	0	2	0	1	3	2	11
Document 1C.pdf	3	1	2	1	0	0	0	2	0	9
Document 2C.pdf	1	3	1	0	0	1	0	1	3	10
Document 3C.pdf	3	1	0	1	1	3	0	6	0	15
Document 4C.pdf	0	2	0	0	1	0	0	2	0	5
Code Occurrence	18	26	16	8	11	17	3	25	7	131
Code Frequency	14%	20%	12%	6%	8%	13%	2%	19%	5%	
Frequency of Participants	88%	88%	75%	50%	75%	88%	38%	63%	38%	
Frequency of Documents	75%	100%	50%	50%	50%	50%	25%	100%	50%	

Table 12

Code Occurrence from Interviews

	Energy Management/ Modulation	Missing Capability: Raw Material Integration	Limited Carbon Anode Manufacturing	Operational Excellence	Purchasing Strategies	Sourcing Strategies	Strategic Partners	Circular Economy	Capability Technology / Design	Totals:
Participant _1C.docx	2	2	0	0	2	3	0	4	0	13
Participant _2C.docx	2	4	2	1	1	1	0	5	0	16
Participant _3C.docx	3	1	3	1	2	1	0	0	1	12
Participant _4C.docx	1	2	2	2	0	1	1	1	1	11
Participant _5C.docx	0	2	0	0	1	5	0	0	0	8
Participant 6C.docx	1	5	2	2	0	1	1	1	0	13
Participant _7C.docx	1	3	2	0	1	1	0	0	0	8
Participant _8C.docx	1	0	2	0	2	0	1	3	2	11
Code Occurrence	11	19	13	6	9	13	3	14	4	92
Code Frequency	12%	21%	14%	7%	10%	14%	3%	15%	4%	100%
Frequency of Participants	88%	88%	88%	50%	75%	88%	38%	50%	38%	

Table 13

Code Occurrence from Documents Review

	Document _1C.pdf	Document _2C.pdf	Document _3C.pdf	Document _4C.pdf	Code Occurrence	Code Frequency	Frequency of Documents
RQ1_Missing_Capability _Energy_Efficiency	3	1	3	0	7	16%	75%
RQ1_Missing_Capability _Raw Material Integration	1	3	1	2	7	16%	100%
RQ1_Missing_Capability _Carbon Anode Manufacturing	2	1	0	0	3	7%	50%
RQ1_Productivity_Operational_Excellence	1	1	1	1	4	9%	100%
RQ1_Purchasing Strategies	0	0	1	1	2	5%	50%
RQ1_Sourcing	0	1	3	0	4	9%	50%
RQ1_Strategic Partners	0	2	0	0	2	5%	25%
RQ1_Strategies_Sustainable_Environment/Circular Economy	2	1	6	2	11	26%	100%
RQ2_Capability Technology	0	3	0	0	3	7%	25%
TOTALS:	9	13	15	6	43	100%	

Causal Condition 1: Energy Inefficiency

Subtheme 1.1: Energy processing.

Data source*: *interviews. Table 12 shows that 87.5% of participants considered energy as a decisive production factor for reducing expenses, although the company suffered low-energy-processing efficiency. Energy efficiency constituted 11.6% of the codes occurrence. Technology, which contributed to energy cost minimization, was also identified as a significant component of production competitiveness. Participants voiced concordant views on the adverse impact of old technology on productivity and plant utilization. Most SMs seemed in consensus that the current electrolytic cells required modernization to meeting the energy efficiency expectation (P2C, 3C, 4C, &6C, March 2017). One SM stated that the driving force for renovating old-aluminum electrolytic cells was incentivized from reducing electrical-energy demands and minimizing adverse environmental impacts. On the other hand, Participant 2C indicated that increased raw materials prices and high-energy costs were driving the use of recycling solid aluminum rather than processing primary material as the primary strategy of production. Recycling allowed the company to reduce energy costs for processing alumina.

While the energy efficiency was approximately 37.8%, according to participants (3C, 4C, & 6C, March 2017), the cost efficiency compared to the benchmark was 57%. I evaluated the technological and operational efficiency by differentiating components of energy costs including (a) total energy expenses incurred per unit of material produced, (b) energy price, and (c) observed power consumption compared to the benchmark within the same industry in the same region. Company C incurred additional USD113 and USD 238 because of price, technological and operational inefficiencies, respectively.

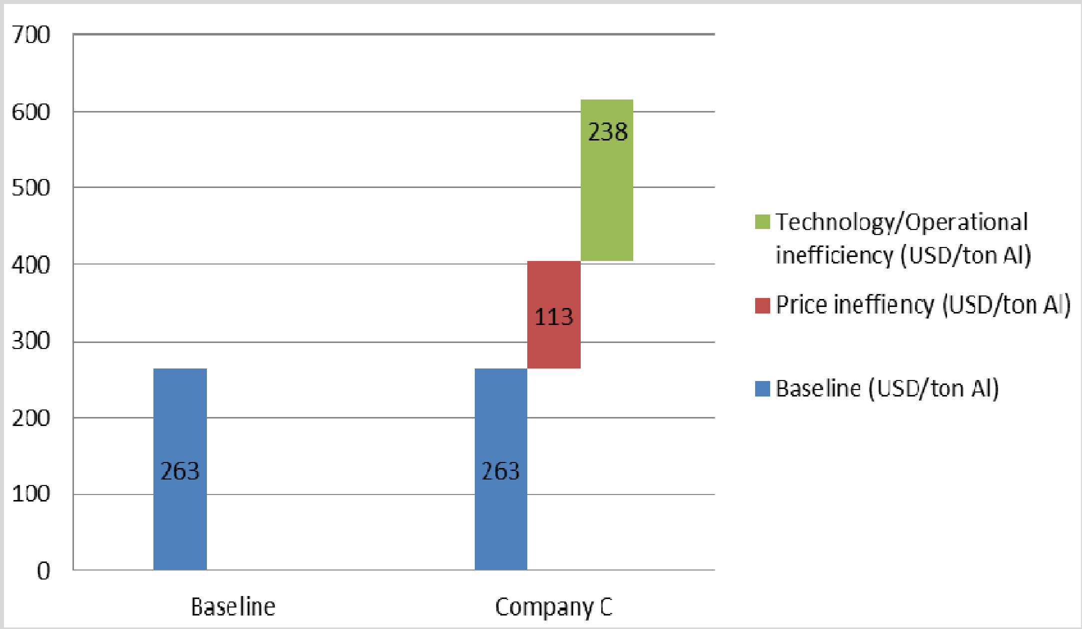


Figure 30. Energy efficiency of Company C, according to a participant interviewed.

Data source: documents review. Table 13 shows that 75% of the records analyzed considered energy as an influential production factor for reducing costs. Energy efficiency also composed 16% of the codes occurrence. Two documents out of four mentioned that energy consumption intensity had a direct implication on greenhouse gases emissions. Most costs savings realized in energy processing derived from operational excellence or the implementation of good practices in production units. Document 3C considered that the company needed to create the right conditions through innovative technologies and revamping of high-cost assets to making savings in energy consumption. The highest demand for energy consumption derived from the processing of aluminum oxide. The company attempted to reduce its energy intensity through secondary aluminum production, which was less energy-intensive than the primary-aluminum processing (D2C & 4C, March 2017).

Subtheme 1.2: Energy contract and price inefficiency.

Data source: interviews. Company C used fuel and nuclear power as the primary energy sources for its electrolytic cells according to senior managers. The energy contract was a partnership arrangement with the sovereign government (P3C & 7C, March 2017). The company paid the energy supplier a price proportional to power generation costs. The SM also indicated that the cost paid was indexed based on the operating expenses of the nuclear plant, which might follow the global prices volatility (P3C, March 2017). Notwithstanding, fuel costs were subject to significant volatility given the country's reliance on this energy source (P2C, March 2017). Energy costs were the most critical components in the production of primary aluminum, and the company's ability to negotiate tariffs in Western Europe was of paramount importance. At market prices, it would be too costly for the plant to afford production costs, with energy cost accounting for 35%, according to a participant interviewed. Figure 30 provides a comparison of the energy costs between Company C and the theoretical baseline. The company incurred USD113/ton Al extra cost.

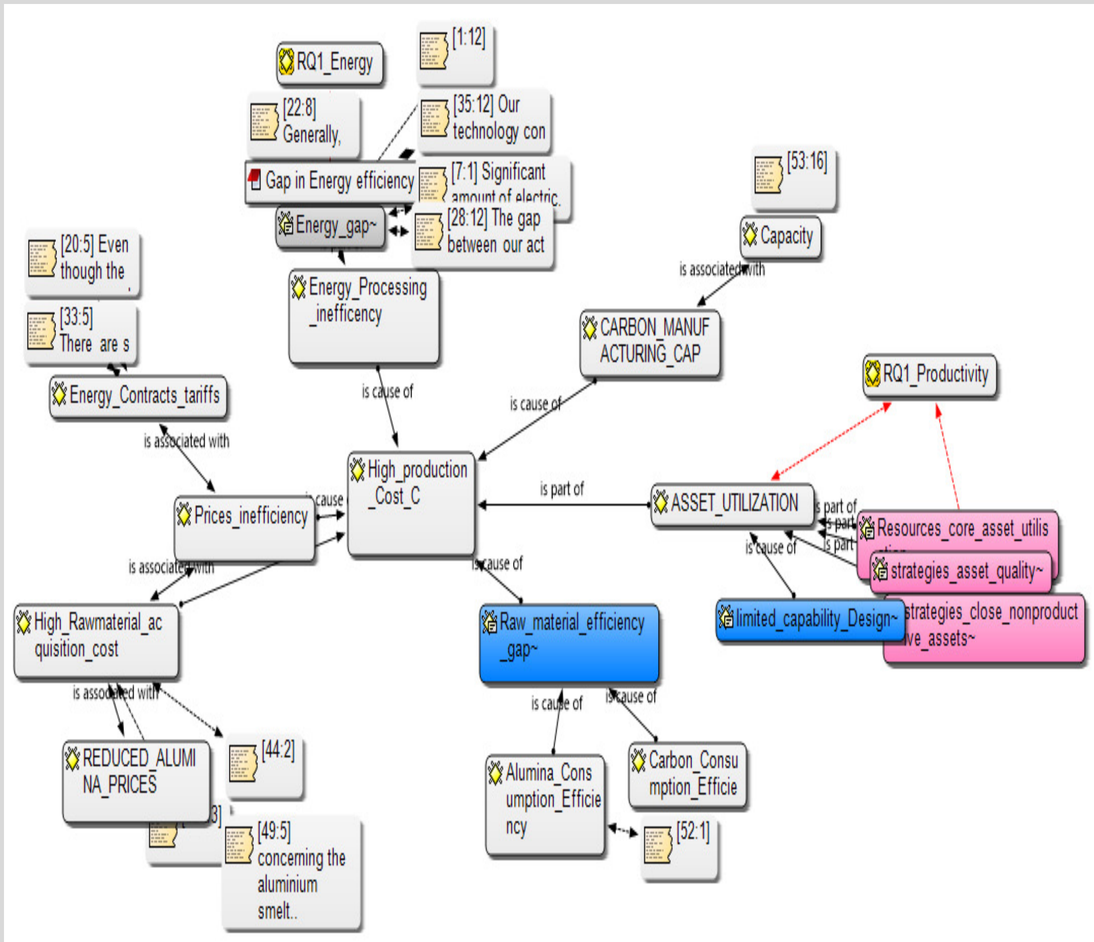


Figure 31. Causal conditions for high production costs for Company C, derived from Atlas.ti.

Causal Conditions 2: Missing Capability, Raw Material Acquisition

Data source: interviews. Most participants (75%) recognized that raw material cost was the most significant component of production costs. Some senior managers also acknowledged that the company lacked upstream integration capability. Table 12 shows that the lack of integration composed 20% of the codes occurrence. The company's alumina requirement depended on imports. Alumina accounted for 29% of the total production costs, according to a participant interviewed. Company C had a short-term contract for alumina, which was planned to expire in 2017, at which time most suppliers might link the alumina prices to the LME index (P5C, March 2017). Figure 32 shows the alumina cost difference between Company C and the benchmark. Alumina prices are 25.8% higher than the benchmark.

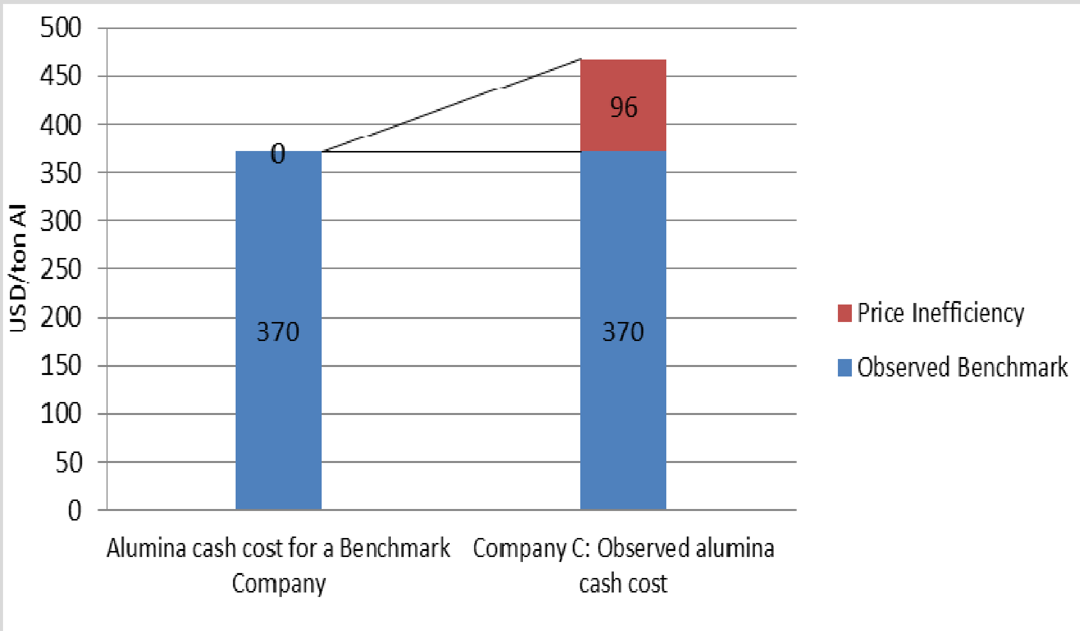


Figure 32. Alumina costs for Company C, according to a participant interviewed.

Data source: documents review. All documents reviewed (100%) highlighted the raw material as the most influential production costs component. Table 12 shows that the lack of integration composed 16% of the codes occurrence. Documents D2C reported the list of alumina suppliers from which Company C purchased alumina to meet its production requirements. The analysis of these alumina providers showed significant costs variations depending on the vendor and the quality of alumina used according to document D2C. One report also highlighted transportation as a cost factor in alumina acquisition.

Data integration. The perspectives developed in the two data sources were similar as shown in Tables 12 and 13. Most participants and documents considered that the lack of integration increased the cost of procuring alumina. One senior manager intimated that the alumina pricing mechanism had fluctuated historically in the range of 12-14.5% of the LME aluminum price. Recently, many alumina suppliers attempted to unlink the pricing mechanism from the traditional channel to spot pricing. According to participants 1C and 3C, Alcoa, who was the leading alumina supplier, implemented the change to pricing alumina based on a ratio of spot alumina pricing in preference of a percentage of the LME-based aluminum pricing. This change in pricing mechanism was driving alumina acquisition cost to rise in the range of 16-18% of LME-based alumina price according to participants and documents reviewed. Trench, Sykes, and Robinson (2015) also found that alumina demand was expected to increase based on China's ongoing alumina demands. Furthermore, Trench, Sykes, and Robinson found that a high demand in the market of alumina might enable prices to increase in the range of 15–20% by 2020. The literature appeared to corroborate the views of participants and the documents reviewed.

Causal Condition 3: Carbon Anodes and Limited Manufacturing Capacity

Data source: interviews. The company had limited capacity to manufacture carbon anodes for its electrolytic process (P1C & 6C, March 2017). Table 12 shows that the lack of carbon manufacturing capacity was the third most significant production cost factor. Of eight senior managers interviewed, 75% recognized this missing capability as a cause of additional cost. Table 12 also indicates that this theme constituted 13.7% of the codes. Company C manufactured only 75% of its carbon anodes; it purchased the remainder from China, according to a participant interviewed. The senior manager affirmed that an anode made within the company costs USD180/ton Al, whereas, the same anode bought from China increased direct costs in the range of 15-20%. Figure 33 provides the total carbon costs per ton of material output.

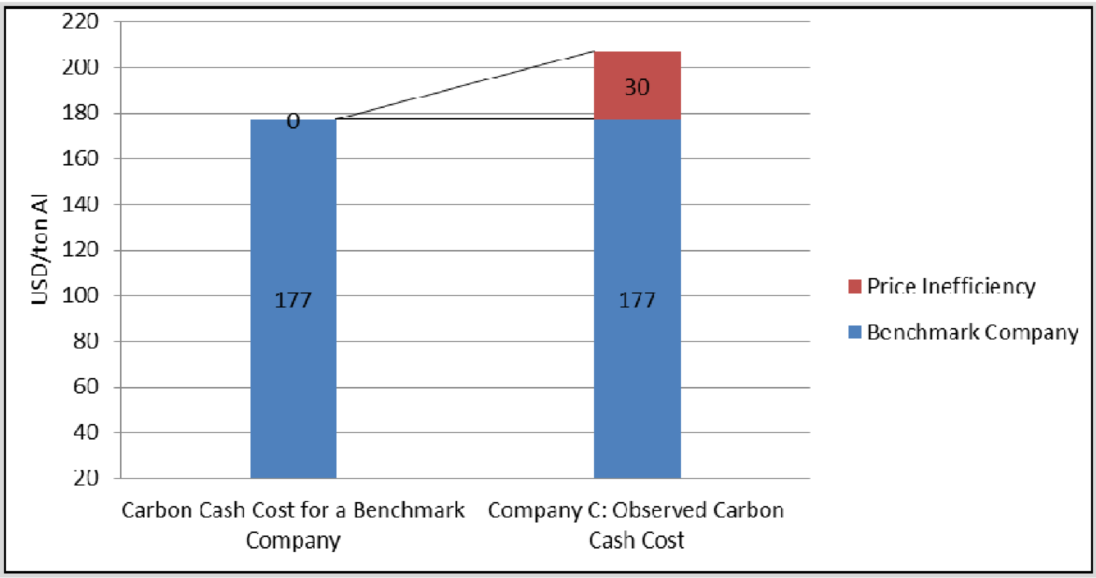


Figure 33. Carbon price inefficiency for Company C.

Data source: documents review. Of the documents reviewed, 50% reported the requirement to reduce anode-manufacturing costs. In one report, the company compared the anode manufacturing cost with the competition and seemed to acknowledge that there were extra charges incurred in purchasing anodes from a third party. Table 13 shows that shortcomings on carbon manufacturing capacity are a significant production cost factor. Table 13 also indicates that this factor composed 7% of the codes. One document reported that the lack of integrated in-house carbon manufacturing capability led to outsourcing a portion of their carbon anodes requirements. The report presented the following arguments to justify this strategy: price arbitrage between purchasing manufactured anodes and calcined petroleum coke in the commissioning phase, opportunity cost gains (through deferment of capital expenses) in building and commissioning the plant, increasing environmental restrictions, and high-energy consumption costs in manufacturing carbon anodes.

Data integration. The two datasets exhibited concordant viewpoints about the in-house carbon-anode-manufacturing impact on cost. While senior managers presented quantitative data to support the view that producers with integrated in-house carbon anode manufacturing capability incurred fewer production costs than competitors who used outsourcing strategy, the documents reviewed provided detailed qualitative information about the benefits and disadvantages of each option. This information was essential to explain the driving factors to outsource the supply of carbon anodes. These factors were market-driven, opportunity-cost driven, environmental-driven, and capital-driven as outlined in one document.

Causal Condition 4: Material Consumption

Subtheme 4.1: Carbon consumption (data source interview). The anode consumption to aluminum output ratio was approximately 420 kg C/ton Al (P5C, March 2017). This ratio was the highest observed. Compared to a benchmark within the region, Company C incurred additional costs for 20 kg of carbon/ton Al, corresponding to USD13/ton of Al. Annualized production costs equal to USD1.9 million. The extra cost incurred was due to operational inefficiency, and the high anode reactivity to air according to a participant interviewed. The carbon consumption to the theoretical value ratio observed was 1.27:1. In addition, some senior managers claimed that different anode quality resulting from a variation in operating parameters and raw materials influenced anode consumption (P3C, 5C, & 8C, March 20017). Carbon inefficiency was one of the leading environmental causes of pollution because carbon oxidization led to carbon dioxide and other greenhouse emissions. From the stoichiometric reaction standpoint, the amount of carbon dioxide in weight emitted to the environment was higher than the amount of primary Al output, and the tax paid to governmental agencies was proportional to the emissions level (P3C, 5C, & 8C, March 20017).

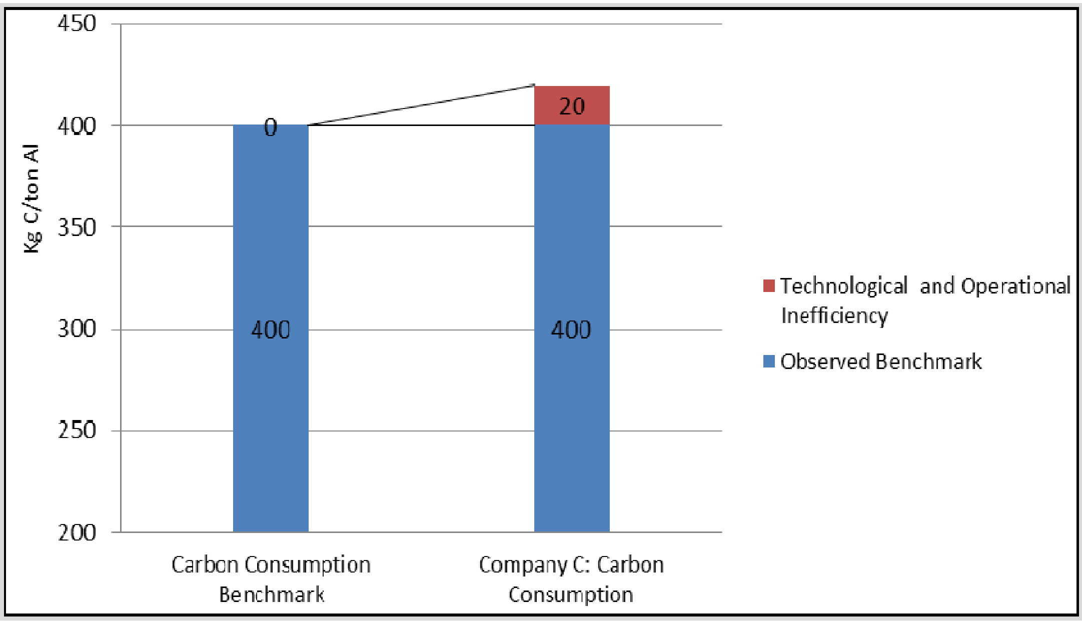


Figure 34. Carbon consumption inefficiency for Company C.

Subtheme 4.2: Alumina consumption (data source interviews). The alumina theoretical consumption to aluminum output ratio was1.89:1. Observed material inefficiency was 0.03 kg of alumina per kg Al. This additional alumina consumed reflected losses as well as the low current efficiency of electrolytic cells, according to participants 1C and 4C. The senior managers stated that the alumina consumption inefficiency was equivalent to USD7.5/ton of Al. The alumina loss generated additional production costs of USD1 million per year. The company used a pressurized alumina distribution system to minimize losses and prevent environmental spillages, according to documents reviewed. This equipment was designed for high-operational efficiency and environmental compliance.

Core Concept 2: Operational Excellence and Productivity

Data source: interviews. Data show that 75% of the senior managers considered operational excellence and productivity as influential for the business performance; in addition, this theme composed 11.3 % of the codes occurrence. Table 12 also shows that this theme was one of the most significant strategies the company used to reduce costs. The plant increased the production capacity over the last two decades from 125,000 tons to approximately 145,000 tons annually, leading to the increased machine and labor productivity. One participant stated, "We attempted to design efficient operating practices supported by the Lean, and Six Sigma approaches to minimize the resources use. These tools allowed the company to eliminate waste and streamline the workforce and material flow." Adequate implementation of these tools from the initial stage supported a culture of excellence.

Data source: document review. In the last two decades, Company C increased its production capacity, which affected fixed costs per unit produced according to documents 1D and 2D. Nevertheless, the production output remained limited given a series of challenges some mature companies face. For instance, additional production capacity beyond the nominal level might require additional investments given the limited technological capability. The company achieved growth in production capacity through continuous process improvements and capacity enhancements of reduction cells (Annual Report, 2014). These developments led to 7% increased productivity in aluminum output, according to the document reviewed. The objective of the operational excellence was to make the process more efficient and leverage operational capability to achieve business growth (1D, 2D, & 4D, March 2017).

Data integration. High-fixed costs appeared to affect the company's performance. The concordant views of the two datasets showed that operational excellence and increased productivity of resources had a significant impact on production costs. The company strived to improve the production cost through enhancing machine and labor productivity and minimizing resources use, all of which are supported by the Lean, and Six Sigma approaches. These tools allowed the company to eliminate waste and streamline the workforce and material flow.

Core Subtheme 2: Strategic Partnerships and Sourcing

Data source: interviews. Of participants, 68% identified sourcing and strategic partnership as a core strategy the company used to reduce production cost. Table 12 indicates that these aggregate themes composed 20% of the code occurrence, intimating their weight in the aluminum production strategy. Participants P1C and 3C mentioned that the company employed 470, 10% of whom are subcontractors. Outsourcing provided some benefits such as increased efficiency and reduced fixed cost per unit output. Gunasekaran, Irani, Choy, Filippi, and Papadopoulos (2015) also found that outsourcing decreases the cost of assets, allows strategic flexibility, and overcomes administrative expenses.

Outsourcing allowed the company to maximize its supply chain visibility and supported increased ROI according to four participants. From 2014 through 2015, the company saved USD5 million in supplier spending through leveraging trusted supplier data quality and strategic partnership (P2C, 3C, & 4C, March 2017). The company used automated data exchange with trading partners to maximize agility and streamline the supplier lifecycle management. One document reviewed reported, “Real-time access to data can help empower the negotiation capabilities.” In recent years, the company leveraged data analytics to increase its procurement efficiency. One senior manager also stated that the company assessed the core processes and non-core process, and analyzed the total cost of options to insource activities. It used sourcing strategy for noncore operations only.

Data source: documents review. Table 13 indicates that 50% of documents analyzed mentioned sourcing as an important strategy to reduce cost; however, only 25% of the reports highlighted the strategic partnership as being important to reduce production cost. Sourcing and strategic partnership together composed 14% of the codes occurrence. The company reduced the number of suppliers in recent years to maintain only those that enabled to streamline purchasing as they contributed to processes innovation (D2D & 3D, March 2017). The company also used specialized suppliers to provide new material that could allow reducing energy costs and minimizing environmental emissions. Sourcing strategy was used as a strategy to reduce high fixed costs.

Data integration. Although the codes occurrence for this core theme exhibited a marginal difference between the two data sources, the perspectives the participants developed by and those outlined in the documents reviewed were aligned. Strategic sourcing and partnership, as defined in one of the documents reviewed was about developing strategic channels of supplying services and materials by a strategic partner at the lowest possible cost. The company used sourcing to perform non-core activities in production units. It also used strategic partners to provide specialized services and critical materials such as carbon cathode. These strategic partners allowed to streamline purchasing and contributed to processes innovation.

Core Concept 3: Sustainable Environment

Data source: interviews. Of participants, 62% highlighted recycling and material attributes selection as a core strategy to reduce cost. This theme composed 12% of the codes occurrence. Recycling and material attributes were one of the most significant strategies the participants highlighted to cut costs. The company used selective materials that can be recycled and reused in its processes to increase energy performance. It also recycled solid aluminum (P4C, 6C, & 8C, March 2017), a practice that supported to reduce the energy consumption intensity. One senior manager stated that aluminum recycling reduced energy demand and could allow promoting a positive community life. Finally, the company used strategic partners in the cement industry to recycle the SPLM. In summary, most senior managers agreed that aluminum recycling provided environmental, energy efficiency, and community benefits; it also contributed to protect and prevent natural resources depletion.

Data source: **documents review**. All documents (100%) provided insights on the environmental benefits of recycling in the aluminum business. Environmental sustainability composed 26% of the codes occurrence. The reports showed that this theme was the most cited, symbolizing its weight in the production strategy to reduce cost. Document 3C indicated that incorporating environmental and sustainability goals into the business model promoted sustainable and environmentally responsible production processes and practices. The company continually improved its operational practices and alumina feeding strategies of the electrolytic process to reduce greenhouse gases (GHG) emissions. Carbon dioxide contributes to global warming, and sovereign governments impose taxes based on its emission (D3C, March 2017).

Data integration. The data integration shows that 100% of the documents reviewed and 62% of the senior managers interviewed considered environmental sustainability as a core strategy to reduce production costs as well as to minimize energy waste of processing aluminum. The most commonly used strategies included aluminum recycling, managing SPLM, employing high-material attributes, reducing greenhouse gases emissions through alumina feeding strategies, and optimizing operational practices.

Core Concept 4: Technology and R&D Capabilities

The two datasets exhibited a similar code occurrence of technological and R& D capabilities 4.2% for the interviews and 7% for the document reviewed (see Tables 12 and 13). Some senior managers (37.5%) mentioned that the technology used for the aluminum oxide electrolysis required modernization to minimizing energy and environmental costs. Miltenburg (2005) and Shepherd (2015) found that the wrong selection of production techniques may increase production costs. Conversely, adequate selection of technological capabilities, which is part of a manager's responsibility, involves allocative efficiency (Moll, 2014; Restuccia & Rogerson, 2013). The participants mentioned that increased automation of the equipment has contributed to a better control of the production process. Advanced automation of alumina feeding introduced through the human-machine interface pot-regulating system has allowed increased decision quality and optimal operational practices (P2C, 3C, & 4C, March 2017). Conceptually, this technology was designed to provide optimal operational safety in the commissioning phase, as part of the corporate social responsibility. Meanwhile, retrofitting is required to minimize emissions and increase efficiency, the participant concluded.

Over the past years, the company has made significant improvements in the operation of electrolytic cells. For instance, it has lowered electrolytic cell voltage and enhanced real-time operational decisions through automation according to document (D2C, March 2017). These actions had a significant impact on energy consumption and environmental emissions. Improvements in electrolytic cell voltage were introduced through a change in the lining material and the redesigning of the cathode bars, according to two participants interviewed.

Case Analysis Company D

Case Description

Company D produced primary aluminum. The company was located in Western Europe, had a production capacity of 230,000 tons of aluminum per year, and employed 640 people. The workforce consisted of 500 permanent employees and 140 contractors. It produced rolling ingots and extrusion billets used for manufacturing cars, aircraft, trains, ships, and window frames. The company was commissioned in the late 20th century and used a prebaked-anode technology to produce primary aluminum. According to participants interviewed and document analysis (Figure 35), four critical causal factors influenced production costs including (a) limited-carbon manufacturing capacity, (b) energy-processing and buying inefficiencies, (c) alumina-buying costs, and (d) the aging technological effect. Conversely, data showed that the four central concepts that the company used to reduce costs included: (a) operational excellence and productivity enhancement, (b) recycling, (c) sourcing and collaborating, and (d) retrofitting aging technologies. Table 14 outlines core concepts the company used to reduce production cost. Tables 15 and 16 show the codes occurrence derived from the two data sources. The tables also contain a summary of missing capabilities or causal conditions that led to high production cost. The company incurred significant production costs of energy processing and material acquisition. Figure 35 outlines the network of causal conditions of high production costs as derived from Atlas.ti.

Table 14

Overview of Core Concepts: Company D

	Energy Manage ment/Mo dulation	Missing Capability: Alumina Integration	Limited Carbon Anode Manufacturing Capability	Productivity/ Operational Excellence	Purchasing Strategies	Sourcing Strategies	Strategic Partners	Sustainable Environment /Circular Economy	Capability Technology	Totals:
Participant _1D.docx	1	4	2	0	1	1	0	2	1	12
Participant _2D.docx	2	2	2	1	0	4	0	0	1	12
Participant 3D.docx	1	1	1	0	0	1	0	1	0	5
Participant _4D.docx	2	2	0	1	0	0	0	0	0	5
Participant _5D.docx	0	4	2	1	3	1	1	3	1	16
Participant _6D.docx	2	1	2	0	0	1	1	2	0	9
Participant _7D.docx	2	1	1	1	0	1	0	1	1	8
Participant _8D.docx	1	1	2	2	0	2	1	3	1	13
Document 1D.pdf	1	2	2	2	0	1	0	4	0	12
Document 2D.pdf	1	0	1	0	1	4	0	3	0	10
Document 3D.pdf	1	2	2	1	2	3	0	1	2	14
Document 4D.pdf	0	0	0	0	2	2	0	2	1	7
Code Occurrence	14	20	17	9	9	21	3	22	8	123
Code Frequency	11%	16%	14%	7%	7%	17%	2%	18%	7%	
Code Frequency	88%	100%	88%	63%	38%	88%	38%	75%	63%	
Frequency of Participants	75%	50%	75%	75%	100%	100%	25%	100%	50%	

Table 15

Overview of Codes Occurrence: Interviews

	Missing Capability: Energy Management /Efficiency	Missing Capability Raw Material Integration	Limited Carbon Anode Manufacturing Capability	Productivity/ Operational Excellence	Purchasing Strategies	Sourcing Strategies	Strategic Partners	Sustainable Environment Circular Economy	Capability Technology /R&D	Totals:
Participant_ 1D.docx	1	4	2	0	1	1	0	2	1	12
Participant_ 2D.docx	2	2	2	1	0	4	0	0	1	12
Participant_ 3D.docx	1	1	1	0	0	1	0	1	0	5
Participant_ 4D.docx	2	2	0	1	0	0	0	0	0	5
Participant_ 5D.docx	0	4	2	1	3	1	1	3	1	16
Participant_ 6D.docx	2	1	2	0	0	1	1	2	0	9
Participant_ 7D.docx	2	1	1	1	0	1	0	1	1	8
Participant_ 8D.docx	1	1	2	2	0	2	1	3	1	13
Code Occurrence	11	16	12	6	4	11	3	12	5	80
Code Frequency	14%	20%	15%	8%	5%	14%	4%	15%	6%	100%
Frequency of Participants	88%	100%	88%	63%	38%	88%	38%	75%	63%	

Table 16

Summary of Codes Occurrence: Document Review

	Document 1D.pdf	Document 2D.pdf	Document 3D.pdf	Document 4D.pdf	Code Occurrence	Code Frequency	Frequency of Document
RQ1_Missing Capability Energy Efficiency	1	1	1	0	3	7%	75%
RQ1_Missing Action Raw Material Integration	2	0	2	0	4	9%	50%
RQ1_Productivity/ Operational Excellence	2	1	2	0	5	12%	75%
RQ2_Limited Anode Manufacturing Capacity	2	0	1	0	3	7%	50%
RQ1_Purchasing Strategies	0	1	2	2	5	12%	75%
RQ1_Sourcing	1	4	3	2	10	23%	100%
RQ1_Strategic Partners	0	0	0	0	0	0%	0%
RQ1_Strategies Circular Economy	4	3	1	2	10	23%	100%
RQ2_Capabilities Technology/R&D	0	0	2	1	3	7%	50%
Totals:	12	10	14	7	43	100%	

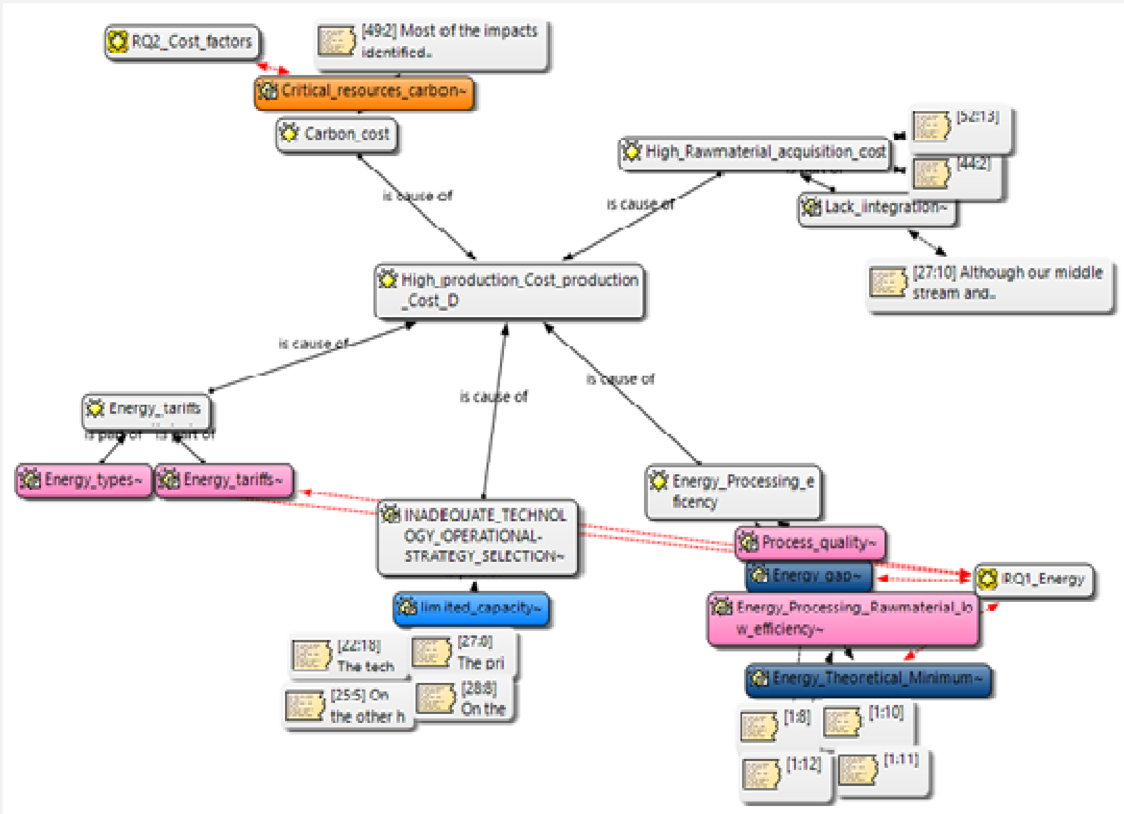


Figure 35. Causal conditions for high production costs in Company D, derived from Atlas.ti.

Causal Condition 1: Limited Anode Manufacturing Capacity Because of Limited Facilities Capability

Data source: interviews. Table 14 shows that 63% of senior managers considered the lack of integrated-in-house carbon- anode manufacturing capacity as a cause of high production cost. The missing carbon anode manufacturing capacity composed 8% of the codes occurrence. The aluminum plant was built with a limited anode production capacity because of three critical cost factors. First, carbon anode production generates significant greenhouse gases subject to environmental restrictions and national taxes. Second, the energy consumption to manufacture carbon anode could have limited the power available for processing aluminum. Third, at the time the plant was commissioned, purchasing cheaply manufactured anodes from China was economically attractive compared to manufacturing internally (P2D & P4D, March 2017). Meanwhile, the aluminum business environment has changed, which corroborated Porter's (1980) arguments that multiple changes in a company's external business environment in which it operates might influence its strategic planning. With the hindsight, some managers have realized the magnitude of these changes on the cost incurred in purchasing carbon anodes externally. No one-business environment appears to be unlimitedly stable over time; business people must be versatile to external changes and their impacts on the planning.

In addition, the quality of carbon anodes influenced the carbon consumption efficiency and had an impact on the aluminum production efficiency according to participants. Similarly, the quality of the raw material has a significant impact on environmental emissions due to its chemical content. Defective anodes, purchased overseas incur significant transportation and production cost, and other indirect costs for replacement because defects could not be corrected economically in the aluminum electrolytic process (P2D, March 2017).

Data source: document review. Table 16 shows that 50% of the documents reviewed mentioned insufficient anode manufacturing capacity as a cause of high production costs. The code occurrence for this theme was 7%. Anode production prevailed as one of the most significant cost drivers in the primary aluminum production. Carbon anodes were manufactured from the raw material involving petroleum coke, a binder pitch, and recycled spent anodes. The use of recycled anodes allowed the company to minimize the raw material cost and natural resource depletion. The existing anode plant has only limited-expansion capacity potential (P1D, 2D, & 4D, March 2017). Figure 36 shows that the company incurred USD 102 extra charge as its purchased carbon anodes overseas. The company increased its aluminum production capacity from 200,000 to 230,000 tons in the last decade. Increased aluminum production capacity has exacerbated the shortage of carbon anodes requirements.

Data integration. The views developed in the two datasets set were similar as most senior managers, and the documents reviewed highlighted that carbon anode manufacturing cost might reduce, should the company develop in-house manufacturing capability to fulfilling the anode consumption demand. On the other hand, purchasing carbon anodes from a third party had some environmental and capital expenses advantages. For instance, a company might gain opportunity overhead cost, investments deferment, and labor costs. Figure 36 exhibits the production cost difference between the two options: purchasing carbon anodes and developing in-house manufacturing capability. Whereas in-house production capability might require significant investments in a short-term, this strategy is considered as cost competitive in the long-term according to participants.

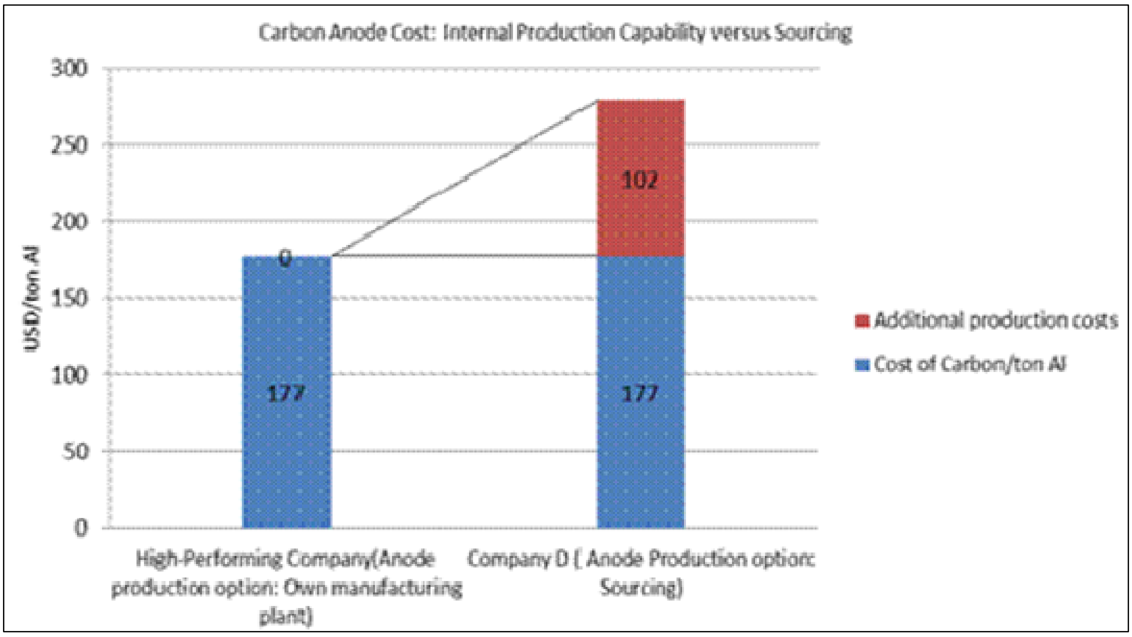


Figure 36. Carbon anode costs for Company D, derived from Atlas.ti.
Note. Investment and environmental costs are excluded. Nevertheless, a fair comparison should consider these costs in the case of integrated-in-house manufacturing capability.

For a company to outsource anode production, it must have a reliable and robust supply chain to lower transportation costs (P7D &8D, March 2017). Company D used strategic partners and public seaport terminals for all logistic solutions, including shipping manufactured anodes, according to a participant interviewed. Company D signed a long-term supply contract for carbon anodes supplies, which it renews every two years. Carbon costs per ton of Al were USD274, compared to USD177 for a high-performing company.

Figure 36 shows that outsourcing carbon manufacturing incurred 57% extra costs compared to in-house manufacturing. Nevertheless, because the volume of carbon anode produced was reduced, some overhead costs could be avoided. For instance, Participant 7D stated that overhead expenses, capital expenses, environmental and raw material costs were reduced. The company should conduct the net present value and internal rate of return of options for further strategic decision-making.

Causal Condition 2: Energy Prices and Processing Inefficiencies

Two subthemes composed the energy costs and processing efficiency: contracts efficiency (rates) and processing efficiency. Whereas the price efficiency derived from the contractual agreements, the energy processing efficiency derived from technological and operational capabilities.

Energy consumption efficiency.

Data source: interviews. Of participants, 88% highlighted energy consumption inefficiency as a critical cause of high production costs. Table 15 also indicates that the power consumption composed 14% of the codes occurrence. Company D used a highly energy-intensive technology, for which the power consumption rate is higher than 14.5 MWh/ton Al according to two participants interviewed. Energy costs were 40% of production costs and were expected to increase to 45% (P1D & 2D, March 2017).

Power consumption also depended on operational and electrolytic process efficiency. The ability to operate an electrolytic cell near the thermodynamic limit of the Hall-Heroult Process is of paramount importance to mitigate energy consumption. The effectiveness of the material used to conduct electricity also allowed lowering power consumption according to a senior manager. Figure 37 outlines the company's energy consumption efficiency compared to the benchmark.

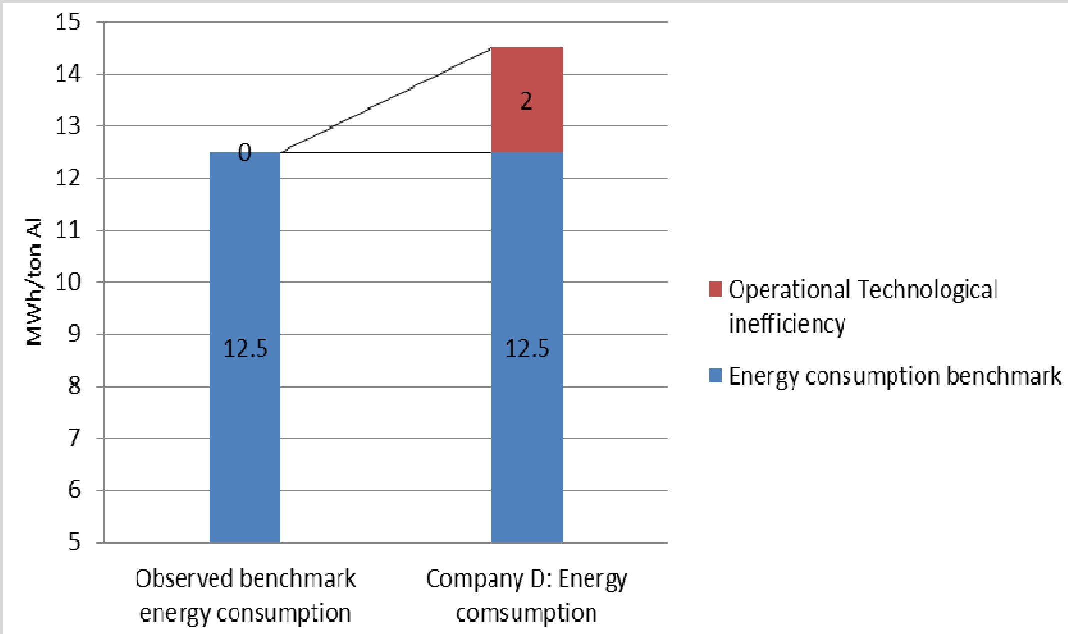


Figure 37. Energy consumption efficiency for Company D, derived from Atlas.ti

Data source: document review. Of the documents reviewed, 75% identified the high-energy consumption as a cause of high production costs. This code constituted 7% of the code occurrence. According to documents 2D and 3D, the modernization of the technology was yet to commence. Refurbishing consisted of introducing high-conductive materials with a low electrical resistivity that could improve the energy consumption efficiency. Document 3D further highlighted that saving energy and reducing carbon dioxide emissions would come from redesigning and modernizing the current electrolytic cell design. The report concluded that the combination of technological improvements and operational efficiency had the potential to develop a step-change and improvement of the production costs.

Energy price inefficiency (**data source interviews**). Participant 1D stated that high electricity costs and reduced-processing efficiency caused the current high production costs. Another senior manager intimated that changes in energy prices resulted in a reduced financial performance in recent years. Figure 38 shows a significant gap between the price paid to purchase electricity and a benchmark. The cost inefficiency derived from two subthemes: the contractual agreements and the type of energy used. Company's D electricity price was 1.6 times higher than the benchmark (see Figure 38). The company used a variable price contract; this price depended on the energy cost the electricity provider incurred to produce energy. According to participants 6D and 8D, the company faced the seasonal energy rates between winter and summer times.

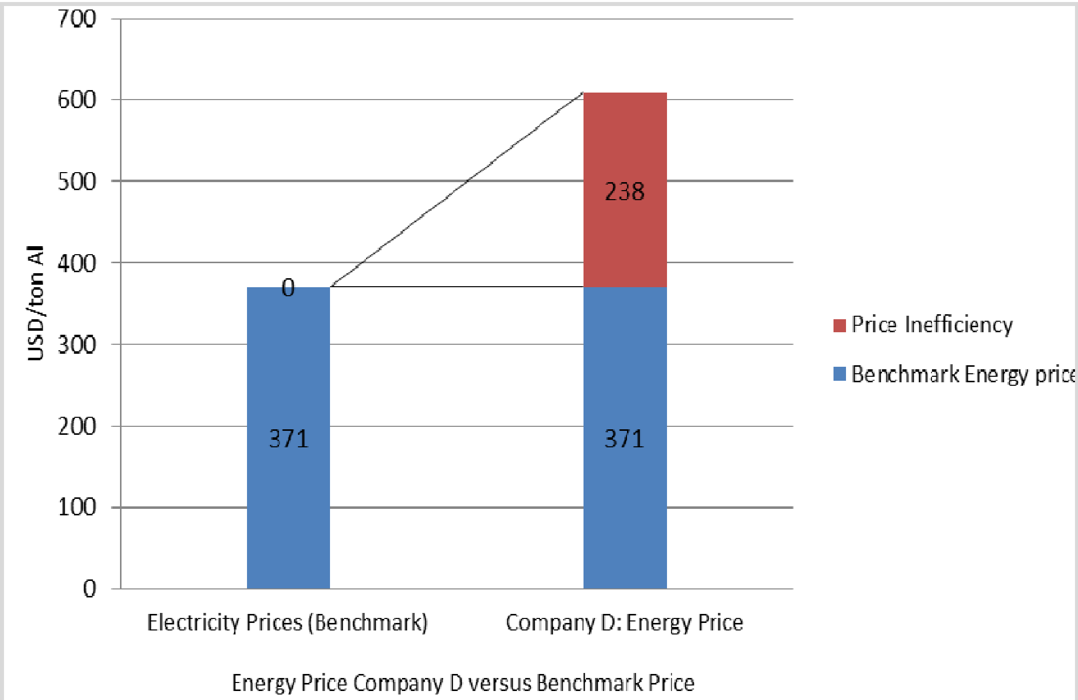


Figure 38. Energy price inefficiency for Company D, derived from Atlas.ti.

Data integration. The power consumption inefficiency for the primary aluminum production was 16% and 60% higher than the observed benchmark and the technical requirements, respectively. The company incurred extra production costs because of operational and technological inefficiencies. The additional charge was USD116/ton Al. The primary energy consumption processes included carbon anode manufacturing, casting, and alumina processing. The electricity price disadvantage also added extra costs equivalent to USD238/ton Al. The two datasets highlighted that improvements in aluminum production technology and operational efficiency, as well as prices efficiency, could benefit both aluminum production cost and environmental emissions. The material attributes also might contribute to lower the overall cell voltage through the lower resistivity of the material.

Core Concept 1: Improving Energy Efficiency

According to a participant interviewed, Company D considered efficiency across the full lifecycle of primary aluminum production. According to a document reviewed, the company worked on multiple fronts to save energy. First, the company worked on energy-efficiency initiatives across production units, including carbon-anode manufacturing, smelting, and aluminum casting. Second, the leadership decided to retrofit the technology to lower the current density while increasing the production capacity. Finally, Company D was also negotiating its energy contract with the energy supplier and the EU.

The company intended to add efficient industrial equipment and ramp up solid-metal recycling to reducing power consumption by over 4–5% by 2018 according to a senior manager. The senior manager also stated that power modulation was expected to support achieving these aggressive goals. Operational efficiency would permit cost savings, waste reduction, and direct environmental impact reduction."

Causal Condition 3: Raw Material Access, Disintegration

Data source: interviews. Table 15 shows that 100% of participants considered the lack of raw material integration as the primary cause of high production costs. This theme composed 20% of the codes occurrence. Raw material cost accounted for 30% of the production costs (P1D, 2D, & 3D, March 2017). The participants considered that alumina integration, which was a missing capability, influenced the company's business competitiveness. The company purchased the raw material as a commodity in the market. Most alumina suppliers started indexing alumina price based on the LME price, which had surged by 7% because of persistent Chinese buying interest (P5D & 6D, March 2017). Participant 5D further concluded that an increased alumina cost had worsened the company's financial performance in 2016 through 2017.

Data source: **documents review**. Table 16 indicates that 50% of the reports reviewed mentioned this missing action as a cause of high production cost. The Table also shows that this theme composed 9% of codes occurrence. Document 1D detailed the alumina cost ratio, which rose to 17.4% of the LME-based alumina price, from a level of 14.2% in 2014. The document indicated that a 2.8% increase in alumina price could have a double impact on the production cost.

Data integration. The alumina disintegration influenced the company's costs efficiency and supply visibility. This finding was predicted in the literature based on the change in pricing mechanism of alumina acquisition. For instance, Trench, Sykes, and

Robinson (2015) found a strong correlation between alumina prices and increased China's ongoing alumina requirements. The literature corroborated the views of participants and the documents reviewed. The alumina price variation would have a double impact on aluminum production based on the stoichiometric ratios of the leading chemical reaction that reduces aluminum oxide into metallic aluminum.

Core Concept 2: Circular Economy and the Material Attributes Selection

The circular economy emerged by grouping similar codes including the material consumption efficiency and environmental emissions. The circular economy model plays an essential role in the preservation of resource use; it is a regenerative model for the resources input (e.g., energy and the raw materials) as well as waste minimization.

Subtheme 1: Material-consumption efficiency

Data source: interviews. The ratio of carbon consumption to aluminum output is 417 kg C/ton, Al. This ratio was the second highest observed. Compared to a highly efficient benchmark within the industry in the region; the company incurred additional costs for 17 kg carbon/ton Al, corresponding to USD11/ton Al (P1D & 2D, March 2017). The losses suffered were USD 2.5 million annually. The ratio of observed carbon consumption to theoretical value was 1.25:1—that is, the production process consumed 25% extra material, more than the technical requirements. Material use inefficiency derived from the low technological and current inefficiencies, ambient-air oxidization, and low-anode quality according to participants. Figure 39 shows the carbon consumption rate of Company D compared to the benchmark.

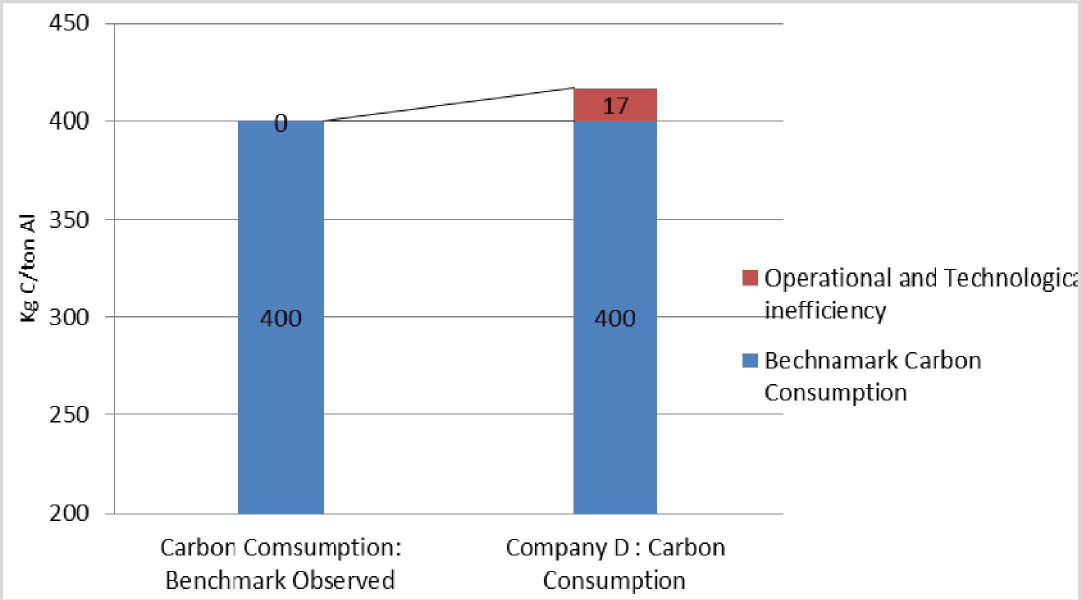


Figure 39. Carbon consumption efficiency for Company D, derived from Atlas.ti.

Observed alumina inefficiency was 0.02 kg of material consumption per kg of Al. This additional alumina consumed reflected the losses as well as the low current efficiency of electrolytic cells. The extra cost incurred was equivalent to USD7/ton Al, according to a participant interviewed. Applied to the nominal production capacity, 0.02 kg of alumina loss generated additional production costs of USD1.6 million per year. Figure 40 outlines the alumina price inefficiency. The expenses incurred were USD89/ton, Al, annualized to USD 20million.

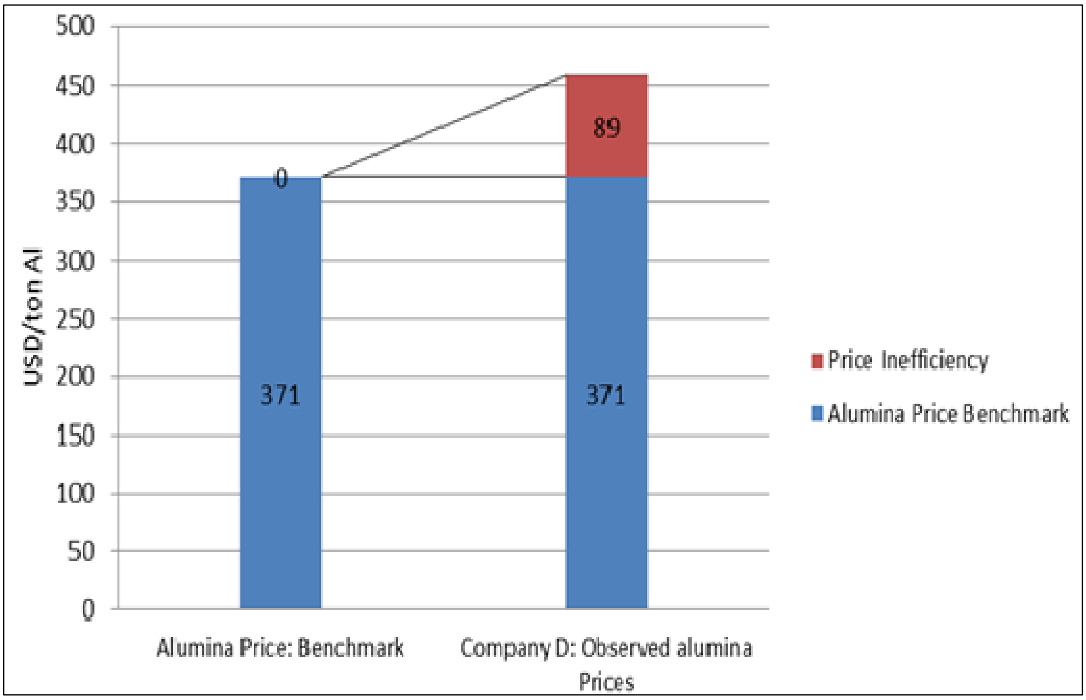


Figure 40. Alumina price efficiency for Company D, derived from Atlas.ti.

Subtheme 2: recycling and material attributes.

Data source: interviews. Of participants, 75% highlighted recycling and the material attributes selection as a core strategy to reduce cost. This subtheme also constituted 15% of the codes occurrence. The material characteristics analysis allowed estimating the impact potential of the material in the business and the environment. In the ongoing efforts to develop an environmentally responsible business, the company invested in new recycling capabilities and high-performance materials to improve energy efficiency according to participants (P3D, 6D, & 8D, March 2017). The company has strategic customers who played a vital partnership role in innovation. For instance, its partners recommended critical materials for use in manufacturing electrolytic-cell cathodes (P5D & 6D, March 2017). Selective material attributes allowed the company to reduce waste from operations, increase life cycle, maximize the recyclability at the end of life, and improve the energy efficiency of the reduction process, according to participants interviewed.

In addition, the company optimized costs through consolidated spending. Supply-chain spending was one of the targeted areas the company used for cost reduction. One participant stated, “We aggregate the material purchasing and use integrated sourcing and procurement strategies with strategic partners. We explore competitive suppliers and establish performance metrics that allow assessing supply costs.”

Data source: documents review. All documents highlighted the sustainable business as a corporate social responsibility of the company. Table 17 shows that the sustainable environment strategy composed 23% of the codes occurrence. The company has set aggressive targets for sustainable aluminum production. For example, one of the documents reviewed described the 2015 goal the company established to reducing landfills by 70% and increasing solid aluminum recycling by 15% compared to the 2014 baseline. Aluminum recycling allowed reducing energy demands per ton of material output (D2D & 4D, March 2017). Company D used strategic partners in the cement industry to recycle the SPLM, which enabled the company to reduce its national taxes according to a document reviewed.

Data integration. The material characteristics analysis allowed estimating the effect potential of the material in the business and the environment. High-performance materials allowed high-recyclability, improved energy efficiency, and increased lifecycle.

Improved lifecycle contributed to reducing capital expenses requirements. Investing in recycling capabilities might allow absorbing all solid waste stored in the landfill.

Core Concept 3: Technology and R&D Capabilities

Data source: interviews. Of participants, 63% maintained that technology and R&D capabilities contributed to reducing production cost. In addition, this theme composed 6% of the codes occurrence. In partnership with strategic partners and customers, the company attempted to retrofit old assets that were the cause of inefficiency (P4D & 8D, March 2017). Two participants stated that technology allowed the company to lower adverse alumina effects on production performance; specifically through alumina distribution strategies and silo management. Silo management reduced operational disturbances that affected the anode effect rate and greenhouse gas emissions, which had significant impacts on environmental costs.

Data source: documents review. Table 17 indicates that 50% of the reports highlighted the technological and R&D capabilities as a production cost driver. The code frequency of the technology and R&D was 7%. Technical capabilities were discussed in documents 3D and 4D. Documents 3D highlighted that using technological innovations in electrolytic process, and in-house carbon manufacturing can increase the productivity and provide a competitive advantage. The company implemented technological changes across productions lines, improved functions, and reduced resources used per ton of aluminum output to increase efficiency. Shepherd (2015) also found that the wrong selection of production techniques might lead to increased production costs. Moll (2014) and Restuccia Rogerson (2013) supported that technological capabilities require allocative efficiency. According to document 3D, technology allowed eliminating redundancies. Technology also allowed optimizing inventories and replenishments, which contributed to lower logistics and transportation costs according to the documents reviewed.

Data integration. The data analysis indicates that Company D used technology for inventory management, process innovation, and to lower the cycle time to execute activities. The company implemented technology to allow high automation of critical functionalities such as alumina storage and distribution strategy. The high level of automation allowed reducing human error and the cost of poor quality.

Cross-Case Analysis

Cross-Case Analysis of Companies A and B

Table 17 provides a comparison of the strategies companies A and B used to lower production cost. Figure 41 shows a high similarity index of the codes frequency and the overall codes pattern. Companies A seemed to place a high emphasis on three primary themes including (a) the raw material vertical integration, (b) energy efficiency and management, and (c) technological capabilities. Company B seemed to use sourcing strategy and partnership more intensively than company A did. The two companies shared a similar vision regarding productivity, plant utilization, and materials consumption efficiency. Nevertheless, company B had a balanced portfolio of strategies across the six core concepts. These concepts incorporated (a) energy management and price efficiency, (b) raw material integration, (c) productivity and plant utilization, (d) material consumption efficiency, (e) technological and R&D capabilities, and (f) purchasing strategies.

Table 17 also shows that the views of participants from the two companies converged significantly. I compared the aggregate frequency of participants and documents from the two companies to assess the thematic convergence. The only significant discrepancy observed was related to purchasing strategy, which seemed stronger in company B (75%) than company A (44%). Similarly, whereas the use of partnership in Company B was 88%, Company A exhibited only 31% of the documents reviewed and the senior managers who highlighted the use of this theme as an intervening concept to reduce production cost.

Table 17

Cross-Case Analysis of Companies A and B

	Total Code Occurrence Company_ A	Code Frequency Company_ A	Total Code Occurrence Company_ B	Code Frequency Company_ B	Frequency of Participants and Documents_ Company_A	Frequency of Participants and Documents_ Company_B
RQ1_Energy_Efficiency	29	23%	25	17%	94%	88%
RQ1_Raw Material Vertical Integration	29	23%	22	15%	81%	75%
RQ1_Productivity_Plant Utilization	15	12%	19	13%	81%	69%
RQ1_Purchasing Strategies	12	9%	16	11%	44%	75%
RQ1_Sourcing	7	5%	19	13%	56%	75%
RQ1_Strategic Partners	4	3%	17	11%	31%	88%
RQ1_Material Consumption Efficiency	12	9%	13	9%	56%	63%
RQ2_Capabilities (Technology/Design)	20	16%	18	12%	56%	88%
Totals:	128	100%	149	100%		

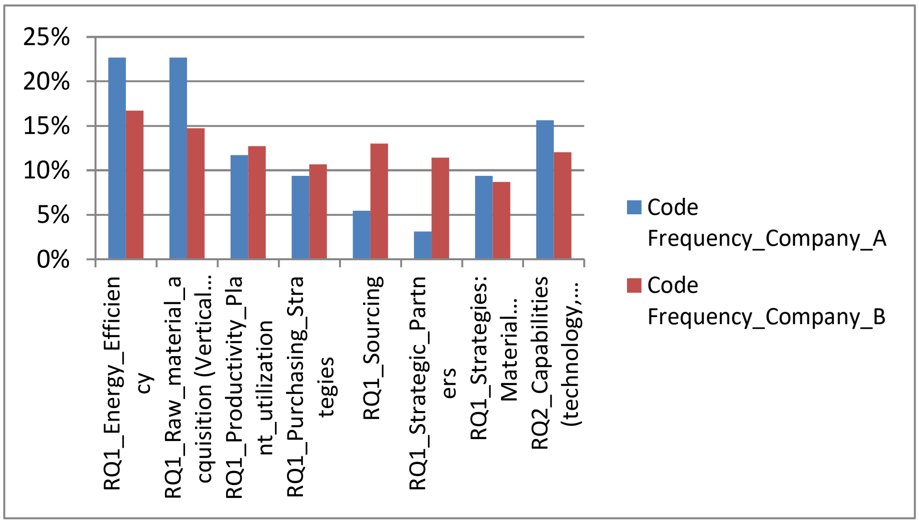


Figure 41. Codes frequency of Companies A and B

Cross-Case Analysis of Companies C and D

Table 18 exhibits the core themes that companies C and D used to reduce costs. The table also outlines causal conditions that led to high production costs. Figure 42 shows some similarity of the codes frequency and the overall codes pattern. Figure 42 reveals that two patterns were established: the first one was related to causal conditions that led to high production costs. These conditions were comprised of the lack of raw material integration, insufficient carbon anode manufacturing capacity, and energy consumption inefficiency. The European Commission (2013) found that these factors composed 70-75% of the production costs. Miltenburg (2005) cautioned that budgetary constraints and the lack of investments influence long-term decision-making and lead to a trade-off among options. Gallegos et al. (2012) discussed the ways that inappropriate investments are a risk for businesses. Limited investments in production systems may lead to insufficient production initiatives (Miltenburg, 2005). Gallegos et al. (2012) further discussed that although disinvestments can produce financial benefits in the short-term, the adverse consequences may be overwhelming should a manager fail to integrate market potential and variations to long-term production strategies.

The second pattern involved the concepts that companies C and D used intensively to reduce production costs. These Themes included operational excellence and plant productivity, environmental sustainability strategy, and sourcing strategy. Technology appeared a weak point in these two companies according to participants interviewed. Shepherd (2015) and Farrell (1957) cautioned that inadequate technological capabilities might lead to reduced technical efficiency, which has an impact on production cost.

Table 18 also shows the convergence of views based on the aggregate frequency of participants and documents that mentioned causal conditions leading to high production cost, and intervening conditions to reduce the costs. The only significant discrepancy observed was related to technological and R&D capabilities that seemed to show a higher weight in Company D (56%) than in Company C (31%).

Table 18

Cross-Case Analysis *of Companies C and D*

	Total Code Occurrence Company C	Code Frequency Company C	Total Code Occurrence Company D	Code Frequency Company D	Frequency of Participants and Documents Company C	Frequency of Participants and Documents Company D
RQ1_Missing Capability: Energy Efficiency	18	13%	14	11%	81%	81%
RQ1_Missing Capability: Raw Material Integration	26	19%	20	16%	94%	75%
RQ1_Operational Excellence/Productivity	16	12%	17	14%	63%	81%
RQ2_Limited Anode Manufacturing Capacity	15	11%	9	7%	88%	69%
RQ1_Purchasing_Strategies	8	6%	9	7%	50%	69%
RQ1_Sourcing	17	12%	21	17%	69%	94%
RQ1_Strategic_Partners	8	6%	3	2%	38%	31%
RQ1_Strategies Circular Economy	23	17%	22	18%	81%	88%
RQ2_Capability Technology/R&D	7	5%	8	7%	31%	56%
Totals:	138	100%	123	100%		

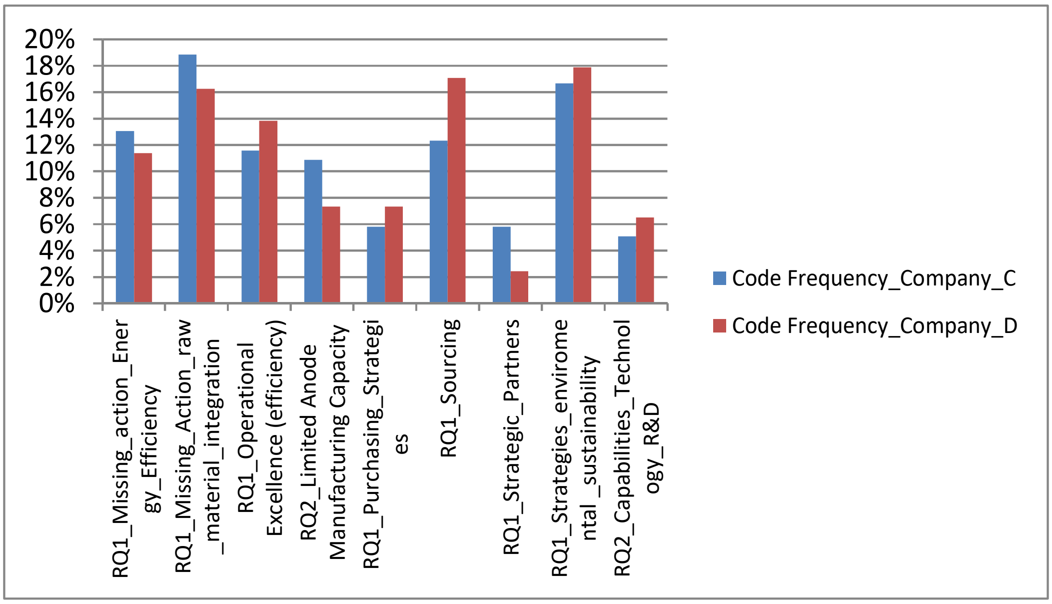


Figure 42. Codes Occurrence Companies C and D Compared.

Cross-Case Analysis: Companies A_B Compared to Companies C_D

Based on the analysis and the data interpretation outlined in the cross-case analysis section, no one strategy seemed to fit all requirements to reduce production costs. With increasing environmental challenges, alumina market fragmentation, energy costs, and the prices volatility of commodities, strategies to produce aluminum were expected to exhibit different patterns. In fact, believing that all primary aluminum producers are similar—and recommending a one-dimensional production strategy would be complicated, and potentially unrealistic. Tables 19 through 22 outline some of the strategies the companies used.

Table 19

Overview of the Companies' Strategies: Company A

Intervening Concepts	Production Function Components	Key Features	Company A
Geographical Location	Transportation Costs	Low Transportation Costs	The plant's facilities were located strategically and integrated with a port terminal in central Europe. The production units were close to its principal customer base. This location provided advantageous transportation costs compared to its competitors for the supply of the raw materials.
Energy Management and Modulation	Energy type and Contracts	Nuclear Energy is Carbon-Emission Free	The power source was nuclear-based. The company used long-term fixed contracts, which provided long-term cost visibility.
	Energy Efficiency	Price Efficiency	The Price efficiency of around USD 29.2/MW provided a competitive cost advantage (price or contract efficiency). This contract also provided competitive security of energy supplies. The company used energy modulation to increase efficiency.
		Technology and Operational Efficiency; Skilled Workforce	The specific energy consumption was 12.7 MWh/ton Al. The cost of inefficiency was USD 5/ ton Al compared to the observed benchmark. The energy gap compared to the theoretical requirement was 3.67 MWh/ton Al output, equivalent to USD 107/ ton Al. The technological capability supported high current creep and production volume (economies of scale), which resulted in reduced marginal fixed costs. The company used energy modulation to increase cash inflow.
Material and Technological Capabilities	Carbon Anode Manufacturing Capability and Efficiency	Cost Efficiency	The cost of carbon per ton of aluminum produced was USD 185. The company had a full capacity for the carbon anode in-house manufacturing. It optimized carbon anode life in electrolytic cells.
		Technology and Operational Efficiency	The company exhibited average performance for the carbon consumption intensity The carbon consumption efficiency was around 68 % compared to the theoretical requirements of 0.333 kg C/kg Al. The company derived productivity improvemen from operational excellence. Anodes requirement for its electrolysis were manufactured internally.
	Alumina Acquisition and Consumption Efficiency	Price Efficiency	Alumina supply: 100% mining ownership providing lower alumina costs than competitors. The cost incurred was around USD 371/ton alumina. The mining ownership provided a competitive security of supply. The company might not face the raw material prices volatility and pricing divergence from the traditional LME index.
		Technology and Operational Efficiency	The low-cost aluminum production technology increased the company's cash generation and profits. The alumina consumption inefficiency rate was only 0.02 kg/Kg of aluminum produced, corresponding to 7 USD/ton of aluminum output.
Circular Economy	Environmental Sustainability	Technology and Operational Efficiency	The company invested in breakthrough technologies for purifying and recycling gasses. It strived to reduce, recycle, and reuse solid materials of its process. The material to recycle was processed in specialized furnaces. The company used cathodic materials exhibiting specialized attributes. In addition, it had a clear strategy for SPL and residual aluminum management.

Note. This chart is a Bitmap picture; double click and expand to enhance the readability.

Table 20

Summary of the Companies' Strategies: Company B

Intervening Concepts	Production Function Components	Key Features	Company B
Geographical Location	Transportation Costs	Low-Transportation costs	The smelter was built next to massive hydroelectric plants; Energy and raw material transportation costs were reduced.
Energy Management and Modulation	Energy type and Contracts	Hydroelectricity/ Carbon-Emission Free	The company focused on renewable energy portfolio that provides clean and environmentally friendly energy. The high portion of power generation comes fror hydroelectricity and gas that provided low-cost, renewable, and emissions-free electricity compared to coal. A significant percentage of the energy is self-generated. The company engaged in long-term energy transactions rather spot prices.
	Energy efficiency	Price Efficiency	The company enjoyed the high-price efficiency of USD 29.7/MW. This price provided a competitive advantage compared to competitors. Hydropower might not experience volatile fuel costs.
		Technology and Operational Efficiency/ Skilled Workforce	The company realized 12.5 MWh/ ton of aluminum output in its new cells and reduced emissions to the atmosphere. The perfluorocarbon emissions were reduced due to a lower-anode effect rate. The energy gap, compared to the technical requirement was 3.47 MWh/ton Al output, equivalent to USD 103/ ton Al. The company used recycling as an option to lower energy costs. Recycling consumes only 5% of the energy required for the production of primary aluminum according to a participant interviewed.
Material and Technological Capabilities	Carbon Manufacturing Capability and Efficiency	Cost Efficiency	The cost of carbon per ton of aluminum produced was USD 177. This performanc is highly competitive compared to competitors.
		Technology and Operational Efficiency	The carbon consumption rate is 0.4 kg C/kg Al. The observed efficiency is 80%. A 20% inefficiency corresponds to USD 45 cash cost per ton of aluminum production. Anode coating in the prevention of oxidization was used. The company has the capability to manufacture the entire carbon anodes requirements in the production units. Although the carbon anode manufacturing was exposed to global oil and coal costs, internalized-anode manufacturing exhibited a competitiv price. Anodes recycling and an efficient-energy consumption process reduced the cost of manufacturing.
	Alumina Acquisition and Consumption Efficiency	Price Efficiency	The alumina cash cost is USD 377. The price efficiency is 24% greater than non-integrated companies are.
		Technology and Operational Efficiency	Low-cost aluminum production technology led the cash generation. The alumina consumption inefficiency was 0.03 kg/Kg of aluminum output, corresponding to USD 6/ton of aluminum. The inefficiency was compared to stoichiometric factors.
Circular Economy	Environmental Sustainability	Technology and Operational Efficiency	Significant investments were made in breakthrough technologies for purifying and recycling electrolytic gasses and filtering particles. The company has a clear strategy for SPL and residual aluminum management. Production expenses paid to governmental agencies have reduced in the last five years due to technological and operational improvements. The company recycled solid aluminum and cans to minimize energy consumption intensity.

Table 21

Overview of the Companies' Strategies: Company C

Intervening concepts	Production Function Components	Key Features	Company C
Geographical Location	Geographical Location	High-Transportation Costs	The company was located away from port terminals facilities and used road transportation for shifting the raw material. The raw material (RM) was delivered via ships. From the port facilities, the RM was transported to the smelter via a conveyor belt. Nevertheless, the company was located close to its leading customers' base.
Energy Management and Modulation	Energy type and Contracts	Hydroelectricity and nuclear power	The company used a mixed of nuclear and hydropower for its electrolytic cells. The power plant was connected to the public grid. The energy cost was proportional to electricity generation cost (variable prices contract). The cost was indexed based on the operating expenses of the nuclear power plant. The Company strived to reduce the prices through a public-private partnership (PPP) arrangement.
	Energy Efficiency	Price Efficiency	Energy accounted for 35% of the production cost and amounted USD 41.8/ MW. This price provided a competitive disadvantage compared to competitors. The cost inefficiency was 49% compared to a regional benchmark.
		Technology and Operational Efficiency; Skilled Workforce	The gap between the current energy consumption and the theoretical requirement was 5.7 MWh/ton Al. This gap incurred direct cash costs of USD 234/ton Al. The technological and operational inefficiencies caused 62.7% of the extra energy consumption.
Material Capabilities	Carbon Manufacturing Capability and Efficiency	Cost Efficiency	While in-house manufactured anodes generated direct cash costs of $217 USD, the similar anodes bought from China increased the direct cost by 22% due to transportation costs and the exposure to the raw material price volatility. Nevertheless, overhead, labor, and environmental expenses might offset these costs.
		Technology and Operational Efficiency	The company had a limited capability to manufacture carbon anodes for its electrolytic process. Only 60-65 % of the anodes were made in-house; the remainder was purchased from China. The Carbon Plant required retrofitting to meeting the energy efficiency and aluminum production requirements. The anode consumption ratio to aluminum output was 0.420 kg C/kg Al, 5% above the regional benchmark. The cost incurred was USD 13/ton aluminum production. Technological and operational efficiencies induced 27% of this additional cost compared to the theoretical requirements.
	Alumina Acquisition and Consumption Efficiency	Price Efficiency	The company purchased alumina at the market prices: These prices were confronted with uncertainty. The alumina cash cost was USD 456/ton Al. The price inefficiency was 26% higher than a low-cost company was (integrated upstream and midstream). The company lacked competitive security for the supply of the raw material in the long-term because it purchased the material at spot prices.
		Technology and Operational Efficiency	Observed alumina consumption inefficiency was 0.03 kg per kg of aluminum produced. The inefficiency induced additional cost of USD 7.5/ton Al. This inefficiency was related to lower current efficiency compared to technical expectations.

Table 21 continued

Circular Economy	Environmental Sustainability	Technology and Operational Efficiency	The company used a reliable and highly efficient alumina distribution system to minimize losses and to prevent environmental spillages. It also used the material anti-segregation system to reduce adverse impacts on process variables and performance. High-material segregation rate might lower the dissolution ability and increase anode effect and emissions. The company used solid aluminum recycling to reduce energy cost. It had a clear strategy for managing SPLM.		
Production Strategies	Production Cost Minimization	Productivity	The company faced low-capacity utilization of its assets due to high-energy cost. It also faced limited technological and design capability to enabling amperage creep. It used standard tools such as Lean Six Sigma and cost analysis that allowed minimizing waste and improving the bottom line performance. It prioritized projects based on criteria such as the business sustenance, critical to safety, needs, and the internal rate of return potential.	It outsourced 35 to 40% of the total carbon anodes manufacturing. It faced insufficient in-house anode manufacturing capacity and energy limitations. Purchasing manufactured carbon anode involved additional direct expenses, but indirect costs (e.g., overhead expenses) might offset the extra costs incurred. .	The company maximized the supply chain visibility and used strategic partners for critical supplies and services. It also streamlined the list of customers. The company employed 360 people including 19 % of contractor workers (sourcing strategies). Increased automation of the equipment led to a better control of the production process, inventories manageme and risk management.

Table 22

Overview of the Companies' Strategies: Company D

Intervening concepts	Production Function Components	Key Features	Company D
Geographical Location	Geographical Location	High-Transportation Costs	The company was located away from port terminal facilities. Imbalance of supplies for freight transportation services created additional inventories. This geographical location provided a disadvantageous position for transportation costs and inventories management.
Energy Management and Modulation	Energy type and Contracts	Hydroelectricity and nuclear power	The company was on variable power cost contracts with the electricity suppliers. The power suppliers were paid a fixed percentage of the world ingot price, which varied based macroeconomic factors such as the demand level and oil prices.
	Energy Efficiency	Price Efficiency	The technology was energy intensive. The power consumption rate was 14.5 MWh/ton aluminum output. The technological inefficiency impact on production expenses was 5.47 MWh/ton aluminum production. The energy price disadvantage was USD 238/ton Al, annualized to USD 55 million.
		Technology and Operational Efficiency; Skilled Workforce	The technology consumed 14.5 MWh/ton of aluminum produced. The energy consumption inefficiency was higher 16% and 60% compared to observed benchmark and the technical efficiency requirements respectively. The direct additional production cost involved due to operational or technological inefficiencies was USD 116/ton of aluminum output, annualized to USD 26.7 million.
Material Capabilities	Carbon Manufacturing Capability and Efficiency	Cost Efficiency	The Company signed a long-term supply contract for carbon anodes; the contract is renewed every two years. The cost of carbon per ton of aluminum produced was USD 274 compared to USD 177 for the high-performing company. Nevertheless, positive environmental impacts due to reduced emissions and energy use to manufacture carbon anode might offset the total costs. Net production cost, considering environmental benefits might be lower than the values mentioned thereof.
		Technology and Operational Efficiency	The carbon consumption ratio to aluminum output was about 0.417 kg C/kg, Al. The production process consumed 25% of additional material due to low technological and operational efficiencies. The technical and operational inefficiency impact corresponded to USD 11/ton aluminum output compared to the observed benchmark. This cost was annualized to USD 2.5 million.
	Alumina Acquisition and Consumption Efficiency	Price Efficiency	Alumina cash cost was around USD 460/ton. Extra cost incurred compared to the observed benchmark was USD 89/ton of aluminum produced, which can be annualized to USD 20 million.
		Technology and Operational Efficiency	Observed alumina inefficiency was 0.02 kg of alumina consumption per kg of aluminum produced equivalent to USD 7/ton of aluminum output, annualized to USD 1.6 million. The alumina consumption inefficiency was compared to the technical efficiency requirement

Table 22 continued

Circular Economy	Environmental Sustainability	Technology and Operational Efficiency	The company used the material attributes analysis to estimate the effect of its material potential in the business and the environment. For instance, the material properties allowed extending the cell lifespan and might also reduce capital costs. The management of SPL allowed overcoming environmental challenges and costs. The company used solid metal recycling to reduce energy use.		
Production Strategies	Production Cost Minimization	Productivity	The company employed 500 permanent employees and 140 contractor workers (sourcing strategies). The insourcing rate was 21%, higher than the competitors. The company insourced non-core activities. The company exhibited a low-asset utilization capacity restricted by the high energy costs and technological limits. The company used strategic partners in the cement industry to recycle the spent lining material (SPLM).	The company strived to negotiate energy contracts. Power modulation strategy was used to increase the cash inflow. Power modulation involved sound technical capability and skilled workforce. The company reduced cost through operational excellence and the productivity improvements. .	The company used strategic partners to optimize the supply chain performance. It produces high-quality aluminum, which provides premiums. The company established aluminum supplies to downstream business to minimize transportation costs. I used forward agreements to sell an amount of aluminum at a specified future date. A forward agreement protects the company from the risks of uncertainty in prices.

In mapping the themes based on data integration from the two primary sources and the cross-case analysis, six core concepts were isolated (see Figure 43). These six core concepts were the categories that exhibited a significant weight in the matrix of categories that unfolded. The repeated statements or viewpoints that were similar from all data sources (e.g., high frequency) denoted the weight. The six strategies, namely energy management and efficiency, raw material integration, circular economy, operational excellence and productivity, technological capability, and raw material consumption efficiency composed the concepts of interest.

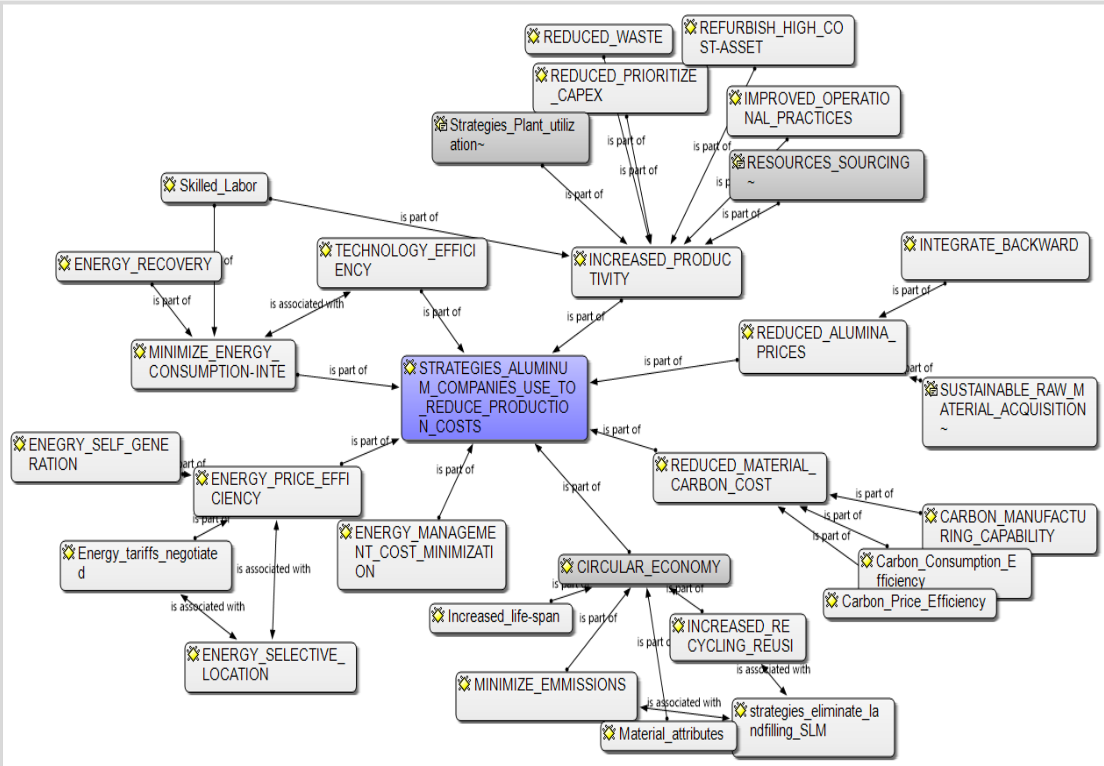


Figure 43. Production strategies aluminum companies use to reduce costs, derived from Atlas.ti.

Core Concept 1: Energy Consumption and Price Efficiency

The theme Energy consumption and price efficiency arose from the subthemes involving energy tariffs and contracts, energy-processing efficiency, energy self-generation, technological efficiency, and energy management options. Whereas participants from Companies C and D acknowledged the impacts of these elements on production costs, they also highlighted the deficiencies of these capabilities in their production functions. Similarly, most participants highlighted that technological and R&D capabilities influenced production costs. Nevertheless, companies C and D faced challenges to developing these core resources. Figure 44 shows the power consumption efficiency of all four companies investigated compared with the technical requirement.

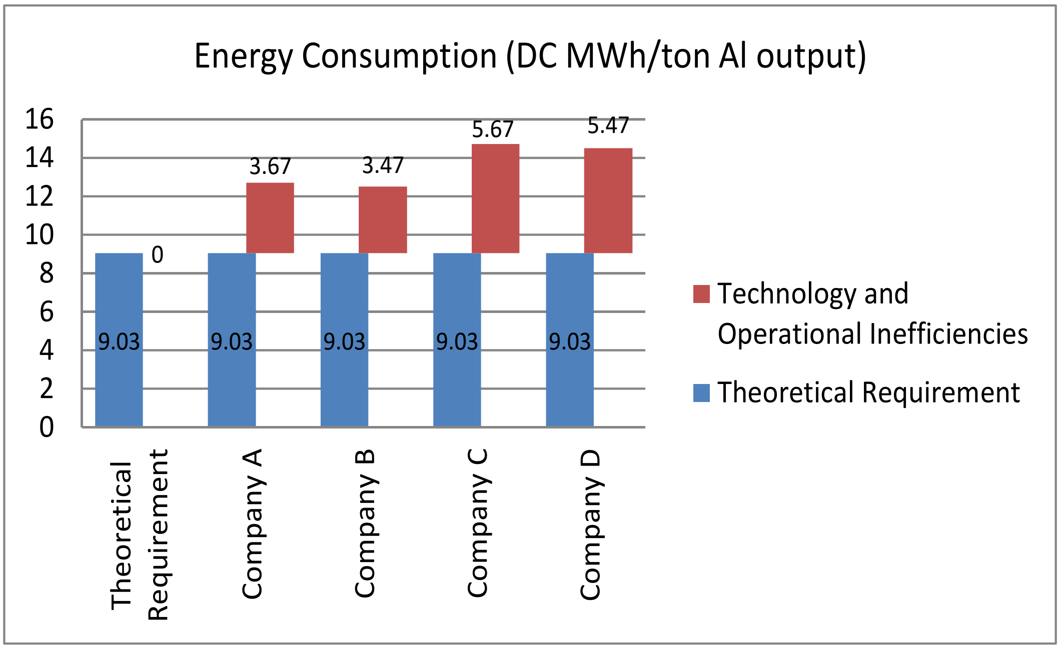


Figure 44. Energy efficiency of all four companies studied compared with the technical requirement.

Subtheme 1.1. Energy-processing efficiency.

Figure 44 shows that the minimum technical requirement for the energy consumption in the primary aluminum production, derived from the standard Gibbs free energy of heating and melting for alumina is 9.03 MWh/ton Al. The difference between actual energy consumed and the technical requirement was a measure of the improvement potential to minimize energy use toward thermodynamic limits. All observed companies experienced a significant gap in meeting the technical power consumption requirements, although the magnitude of the problem differed from one technology to another.

Whereas data revealed a constraining energy inefficiency gap for all companies, there was a difference between Companies (A and B) on the one side and Companies (C and D) on the other. Companies A and B consumed less energy than Companies C and D did by a magnitude of 16.7%. Part of this result was predictable because of two driving cost factors: (a) Companies A and B were modernized aluminum plants; whereas, Companies C and D were aging plants that required modernization. (b) Technological and operational capabilities also differed from these two groups of companies.

Subtheme 1.2: Energy management and price efficiency compared. Figure 45 outlines the energy cost components and the sources of inefficiencies. Two important concepts explained the observed pattern. These concepts were the basis for comparing aluminum company efficiency in buying and consuming energy: the energy price efficiency and the technological and operational efficiency. These important concepts were discussed in the literature that analyzed the implications of public information for cost efficiency and the costs of capital (Elliott, Hobson, & White, 2015; Han, Tang, & Yang, 2016).

The cost efficiency of energy and its consumption rate affected production costs, according to a participant interviewed. Contrary to inefficient markets in which energy prices may not always include all discounted values, in an efficient market, energy contracts and prices should be efficient because they reflect publicly available information. In an efficient market, aluminum companies that purchase electricity should determine the power contract portfolios that enable the maximum expected return (minimum production costs) for various levels of risk in their business model. Companies

C and D incurred an additional cost of USD184 and 254, respectively, because of the price inefficiencies. I compared the observed and benchmark prices in the same geographical location to determine the cost efficiency.

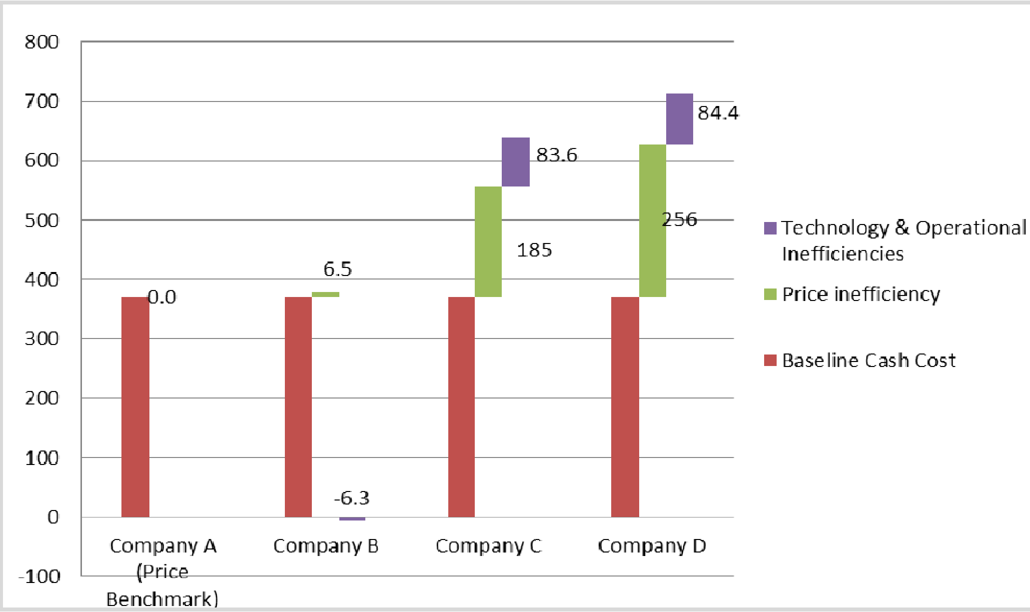


Figure 45. Energy cost efficiency of all four companies compared with a benchmark or baseline.

Subtheme 1.3: Energy type and emissions. Companies A and B used low-cost, renewable energy portfolios to capture midstream value such as low environmental and energy costs, according to participants interviewed and documents reviewed. All companies implemented electrolytic cell voltage reduction and the material attribute analysis to reduce electricity consumption intensity and environmental emissions.

Whereas the power consumption difference between the benchmark and the companies studied was a valuable measure of the opportunities of improvement for low-performing companies, the gap between the energy use and the theoretical minimum remained most compelling. Some sovereign governments have compounded the energy costs by emissions taxation on power producers. These costs were also charged to customers such as aluminum producers. The differences in energy consumption intensity among companies offered significant trade-offs regarding costs and the subsequent emission levels (carbon footprints), which were subject to national taxes. Examining the energy use difference between the two-paired samples would indicate where valuable technological and operational capabilities should be developed to reduce energy cost. Efficient technology and energy consumption, and the resulting carbon footprint would be the differentiator for corporations that wish to promote process quality and social responsibility.

Core Concept 2: Technological and Operational Efficiencies

Technical and operational inefficiencies were determined by using a similar approach as outlined previously. The technology and quality of operations influenced the production costs. Companies C and D incurred additional production costs of USD83 and 84, respectively, compared to the benchmark. The evidence that Company A curtailed and modernized most of its high-cost capacities, to deliver regional-leading performance through high-productive assets, might explain the performance observed. Company B also has upgraded most of its assets to target low-energy consumption assets.

Core Concept 3: Upstream Integration and Prices Efficiency

Backward alumina integration derived from the need to mitigate alumina supply uncertainty and companies' interdependence with dominant suppliers, and to protect companies from price volatility. An increased alumina price index not only influences production costs but also offsets gains on real aluminum prices because the alumina prices fluctuations have a double impact on the aluminum output cost based on stoichiometric factors. As most suppliers tend to link alumina index pricing to LME, this pricing strategy had disadvantageous economic costs for primary aluminum producers, according to a participant interviewed. Companies A and B exhibited lower alumina prices because they integrated their upstream activities. Mines ownership and alumina supplies security allowed the companies to drive low costs and generate cash. A strategic focus on low-cost capabilities, and upstream activities for obtaining alumina supplies were a fundamental pillar for Company A. One document reviewed highlighted that alumina ownership was a competitive security. Conversely, Companies C and D purchased alumina on the market and incurred additional production costs of USD94 and 102 per ton of product output, respectively. A fair comparison of costs opportunity, however, should include investment cost for producing alumina.

Core Concept 4: Material-Consumption Efficiency

Subtheme 4.1: Alumina consumption efficiency. Figure 44 indicates similarities among the four companies regarding the alumina consumption rate. Alumina was lost during aluminum processing through volatilization because of its fine particle size and high attrition rate during transportation and handling, necessitating tight controls and procedures to limit losses. Most companies have designed and built low maintenance, environmentally friendly systems for optimal material transportation and handling, from ships to in-plant systems incorporating conveying and pressure vessel capability, according to documents reviewed. The system was designed to minimize alumina attrition, which was the partial cause of waste. Overall, material heterogeneity influences material efficiency and environmental emissions when fine and coarse particles are segregated. The documents reviewed also indicated that anti-segregation technology for alumina storage maintained uniform grain-size distribution when materials were conveyed. When companies reduced attrition and increased homogenous material, they also reduced anode effects and greenhouse gas emissions and reduced energy use according to most participants interviewed.

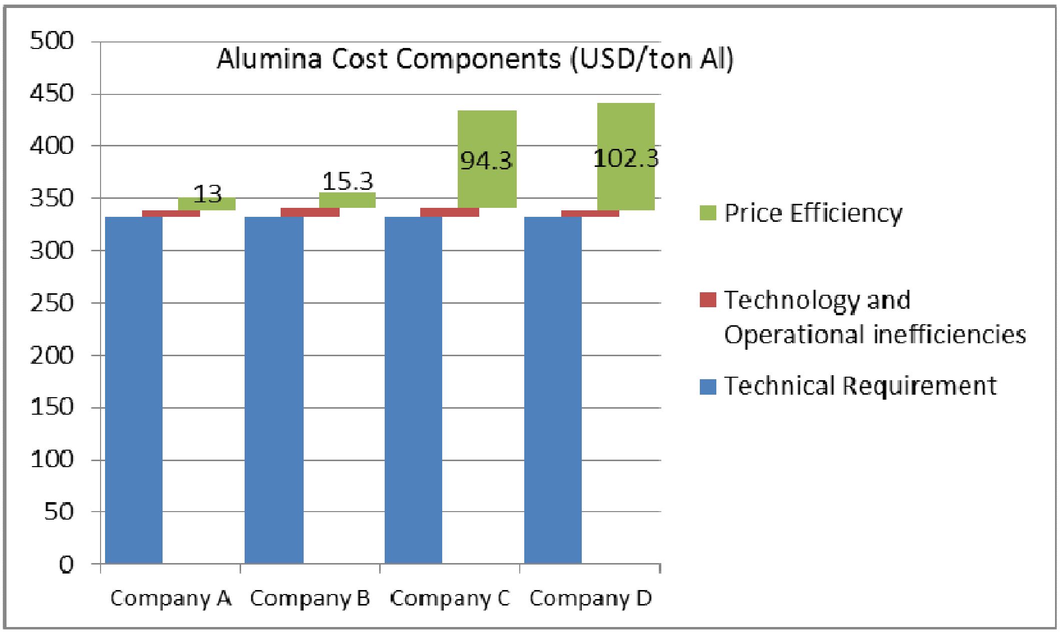


Figure 46. Alumina costs of all four companies compared with technical requirements.

Subtheme 4.2. Carbon-manufacturing capability and consumption.

Whereas Companies A and B could manufacture carbon anodes in their production plants, Companies C and D did so only partially. The latter group purchased some carbon anodes already made from China. This strategy had significant direct impacts on production costs. The total additional production costs incurred equal to USD31 and 89 per ton of aluminum output for companies C and D, respectively. Figure 45 (left) indicates that carbon anode consumption efficiency was 30–36% lower than the stoichiometric requirement for all companies. Companies C and D exhibited the lowest carbon utilization efficiency. Participants related this factor to technological and operational capabilities.

Although the carbon consumption showed a similar pattern among all four companies, the difference still, was observed vis-à-vis the technical requirements and the observed performance as well as the price efficiency. Carbon-consumption efficiency depended on the quantity of material used, its quality, recyclability, and its reusability. From the environmental standpoint, improving the material efficiency enabled the greenhouse gas reduction, which had significant impacts on production costs.

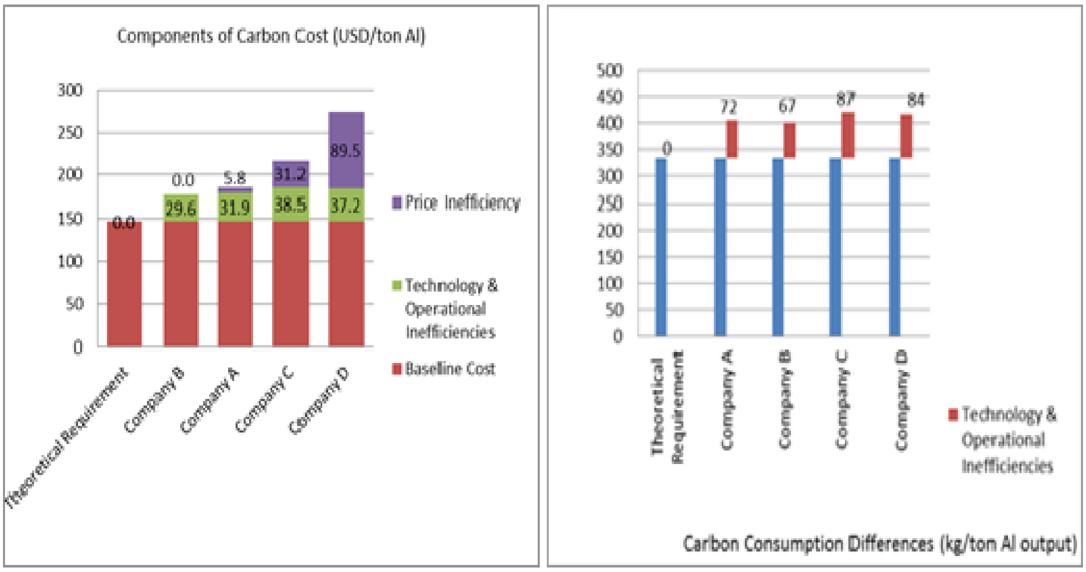


Figure 47. Carbon expenses of all four companies compared: components of carbon cost (left); the difference between the theoretical and observed consumption (right).

Anode-material quality is of paramount importance because its consumption rate affects the production cost per ton Al. The material quality influenced not only use efficiency, but it also was a determinant of the energy efficiency and productivity of the electrolytic process.

Core Concept 5: Sustainable Operation and Productivity Improvements

Increased productivity and operational excellence were the core concepts implemented across the four aluminum plants. This critical concept derived from seven subthemes: (a) plant utilization, (b) sourcing, (c) waste minimization, (d) refurbishing high-cost assets, (e) improving operational practices, (f) prioritizing capital expenses, and (g) skilled labor. Company A increased productivity through the material and inventory management increased the asset lifecycle and consolidated the performance. For example, in the electrolytic process, increased anode size allowed the company to increase the current input and the production volume, according to a participant interviewed.

Although current creep allowed aluminum producers to reduce the fixed cost-per-unit output, production could not increase relentlessly because the law of diminishing marginal returns might be applicable. According to Ellington et al. (2014), for a given combination of inputs, most optimization processes face depreciating efficiencies. When a production unit nears the maximum, its profitability decreases because its marginal production costs tend to increase (Ellington et al., 2014). Participants stated that Company A considered all direct and indirect costs that contributed to the plant efficiency to evaluate net present value analysis (the cumulative difference between the current value of cash inflows and outflows of an option). The company also assessed the capacity utilization to estimate the maximum amount of output potential given existing resources.

In turn, Company B focused on the efficiency of resources and innovative processes that minimized waste and material use. Its profitability margins were also supported by a highly automated and innovative technology, a substantial technical expertise, and customer experience, according to documents reviewed. Documents reviewed also indicated that experienced management teams enabled and drove the value creation and maximization at all levels of the production chain. An example of the value maximization was increased production volumes while maintaining input quasi-constants and reducing working capital. Both Companies A and B maximized value creation by increasing asset utilization.

The workforce-sourcing rate for these companies was in the ranges of 10–15% for Companies A and B and 17–21% for Companies C and D (see Figure 48). Insourcing involved bringing in contractors to accomplish temporary activities or non-core tasks that a manager would otherwise outsource. Insourcing or Outsourcing strategy was used to reduce fixed costs and increase flexibility (Porter, 1980). On a unit of material output basis, Companies C and D incurred higher person-hours than Companies A and B (Figure 48, left), revealing a higher full-time equivalent (FTE). Companies C and D attempted to intensify insourcing strategy to balance the high-FTE effect on production costs.

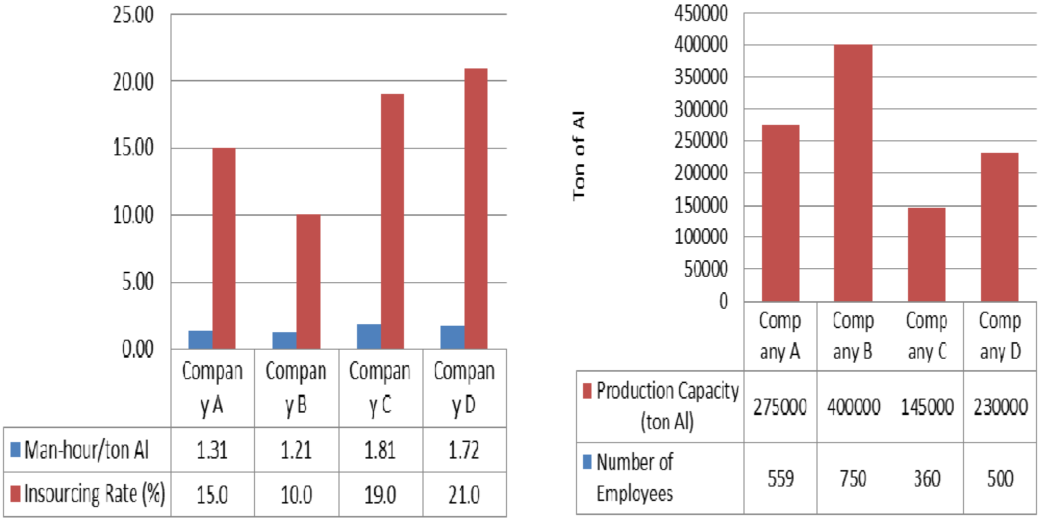


Figure 48. Productive hour (left) and production capacity (right) of all four companies compared.

Crespi and Zuniga (2012) found that innovative firms have higher labor productivity when compared with noncreative companies. Applying technological capabilities can enable producers to use resources efficiently, providing an economic advantage (Crespi & Zuniga, 2012; Dosi et al., 2015). Innovativeness can be linked to the ability to adjust the methods and techniques or to engineer a production process to increase its efficiency.

Core Concept 6: Sustainable Environment and Circular Economy

The circular economy also received a definite consensus because most participants highlighted the benefits regarding the energy minimization and material use, reduced governmental taxes and emissions, and the protection of the natural resources. The lifespan of an electrolytic cell ranged from 5 to 7 years, depending on the technological capability and electronic density crossing a cell cathode, according to a participant interviewed. At the end of its life, companies demolished the electrolytic cell, and the SPLMs, which were polluted with various chemicals, such as aluminum carbide, sodium, toxic fluoride, and cyanide compounds. The SPLM must be recycled using a proper safety protocol to minimize waste and environmental contamination. Holywell and Breault (2013) found that most companies often confine SPLMs at the production sites, placed in landfills or containers, or employed in other industries as raw material. Holywell and Breault also found that many environmental institutions list the SPLM generated in the aluminum electrolytic process as hazardous waste. This dangerous material requires companies to implement rigorous operational safety, not only by the supplying company for shifting and storing but also by the buying company in storing and processing the material. Recovery and recycling techniques for SPLM exist but are expensive to implement given their uneconomic returns, according to a participant interviewed. The process of decontaminating and recycling these corrosive materials can be a source of significant expenses from both the operationalization and the national taxes standpoints. The European Commission (2014a) found that environmental costs in the production of primary aluminum account for approximately 8–13% of the production costs, evidencing disparities among companies.

Because the SPLM is an end-of-life product; as such, its potential value might not cover the costs of decontamination, transportation, and processing. Because of this effect, companies must conduct net present value analysis to decide the best financial options for handling the SPLM. In either case, the company must either invest in internal capabilities for decontaminating and processing the material or pay costs associated with the elimination of SPLM pollution when the responsibility for processing is outsourced. Most companies found local partners for handling and processing the SPLM. National governments no longer accept inaction vis-à-vis the management of the SPLM, and the failure to handle the materials appropriately might result in financial liabilities from a regulatory standpoint and a reputational perspective—both of which affect production costs.

Literature review Analysis

I used the economic theory of production and production costs as the conceptual framework to provide a foundational scheme for analyzing the data and comparing the strategies the four aluminum production companies implemented to reduce production costs. The economic theory of production and production costs includes four significant concepts related to a production system's performance: (a) technical efficiency, (b) factors of production, (c) production costs, and (d) the rate of technological substitution (Cobb & Douglas, 1928). Factors that affect production costs include machine and technical capabilities, labor skills (Chauhan & Singh, 2013), quality (Herrmann & Kayasa, 2012), processing efficiency (Farrell, 1957), and resource allocation and use (Bartelsman et al., 2013; Cobb & Douglass, 1928). Casadesus and Zhu (2013) found that technological superiority and innovative business models are critical factors of business performance to reduce production costs.

Shepherd (2015) and Wicksteed (1894) defined the production function as a combination of factors used in a process to yield outputs. Cobb and Douglas (1928) and Wicksteed (1894) found that each production function consists of different stages.

Production managers may adjust input utilization to increase or decrease outputs. Notwithstanding, a manager may face increasing returns to scale (IRS), constant returns to scale (CRS), or diminishing returns to scale (DRS; Restuccia & Rogerson, 2013). CRS and DRS may arise in cases where management does not control input levels adequately—in such circumstances production costs might increase (Cook et al., 2014).

Miltenburg (2005) and Oke (2013) found that a production system provides many outputs against which to measure performance. These outputs include production costs, flexibility, quality, efficiency, and innovation. Restuccia and Rogerson (2013) and Jones (2011) found that the optimal combination of production factors depends on the effectiveness of the allocative resources at each operational level and the alignment among organizational units. With this understanding, a complete analysis of a production-function efficiency to reduce costs includes two principal components: (a) allocative efficiency and (b) technical efficiency (Haelermans & Ruggiero, 2013; Jones, 2011; Restuccia & Rogerson, 2013). Farrell (1957) further divided technical efficiency into two distinct elemental constituents: input and output efficiency. Input-output efficiency is the ratio of the total value of the products and services obtained from a production process to the set of resources used given technological capabilities (Fang et al., 2013). Jones (2011), Farrell (1957), and Fang et al. (2013) found that a higher input-output efficiency refers to an efficient allocation and a rational use of inputs. The frontier method also termed the "directional distance function" (Tovar & Wall, 2015) can be suitable for comparing the production performance of different companies. The frontier analysis helps to determine the extent to which a production manager can stretch inputs and yield allocative resources to reduce production costs.

The energy use of production implies both high power usage and high carbon dioxide concentration (Gutowski et al., 2013). High energy and material consumption affect production costs and incur additional environmental taxes, should a company fail to address regulatory requirements. According to technical efficiency paradigms (Farrell, 1957), companies may adjust their energy and raw material usages to minimize the costs of inputs (input efficiency). Reh (2013) idealized the concept of reducing, recycling, and reusing (RRR) as a circular economy—a practice that can affect not only production outputs but also material inputs. Regarding resource capacity constraints, circular economies might make sense as a strategy for reducing production costs in resource-intensive industries.

Applications to Professional Practice

The network exhibited in Figure 47 outlines the strategies that the four companies used to reduce production costs. Companies A and B (blue rectangles) were those that lower costs and Companies C and D (orange boxes) did not. I coded different and similar strategies the companies use in the diagram. This network was a type of Venn diagram, consisting of multiple overlapping concepts that the companies used to reduce cost. The overlapping areas were intersection points or areas of partial convergence. The domains of total convergence were in the middle of the chart. I outlined the areas of discordance or singularity separately near the rectangle representing each company. I positioned similar strategies between the two codes of the companies. For instance, Companies D and C faced similar challenges, limiting their ability to reduce costs. These challenges included limited technological capabilities to increase production, high prices of raw material, and energy cost and processing inefficiencies. In addition, because market dynamics tend to drive commodity prices, Companies C and D that did not own bauxite mines, faced price pressure of the raw-material prices volatility.

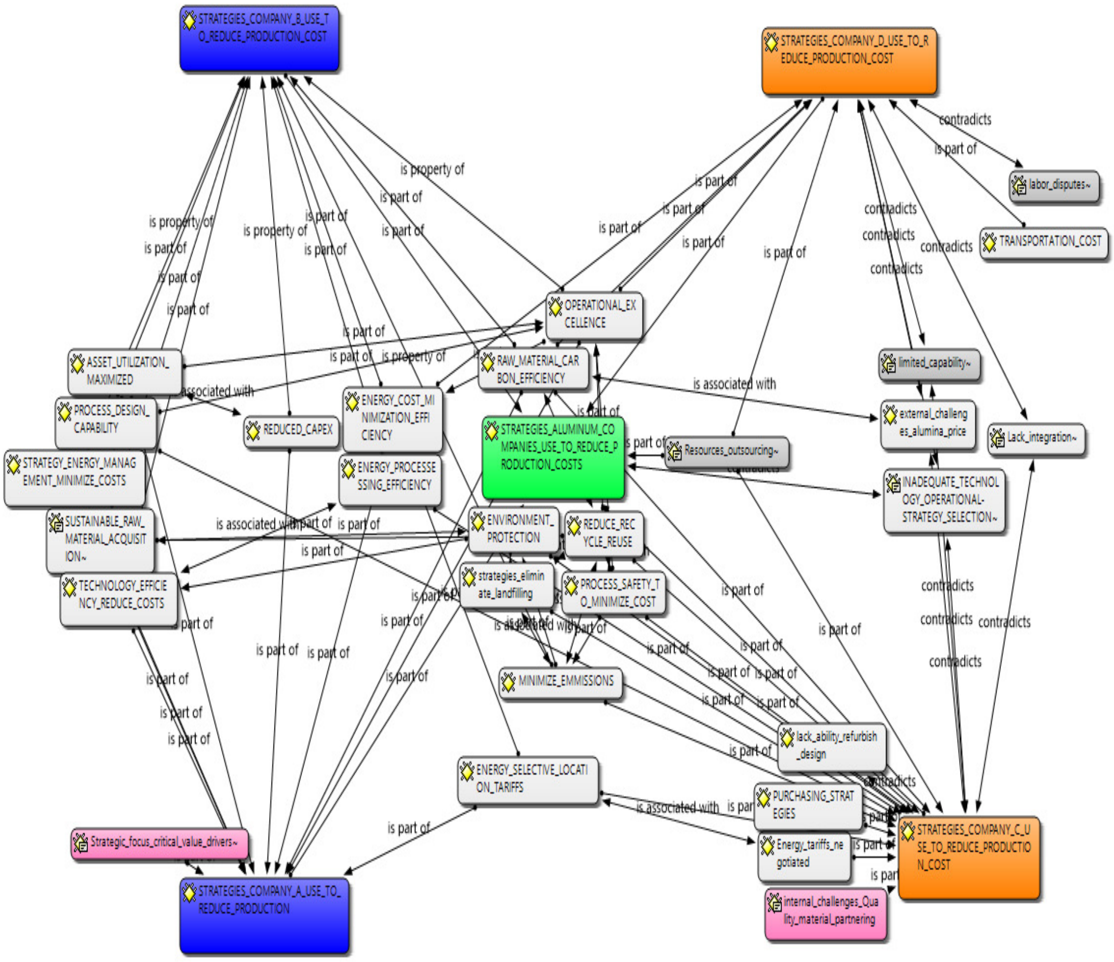


Figure 49. Aggregate strategies of all four companies, as derived from Atlas.ti.

Conversely, most businesses used operational excellence, production capacity creep, environmental emissions minimization, and plant utilization as core strategies to reduce cost. A particularity of Companies A and B was that they integrated the alumina supply activities. Besides, their technologies appeared to exhibit a high level of energy efficiency, which could be symbolized on the left side of the diagram. These two companies used the technologies to their fullest to maximize business impact and value creation. The companies had a clear strategic focus on low-cost assets that maximized the returns. On the contrary, Companies C and D faced different challenges—in particular, rising alumina prices, energy costs, and a shortage of capabilities to manufacture carbon anodes.

Vertical Integration and Prices Efficiency

Aluminum businesses faced challenges unique to their models of activities and contexts as well as regarding their energy and alumina contracts. For example, the lack of upstream and midstream integration affected the production costs of Companies C and D. Blair and Kaserman (2014) found that price variations in resource acquisition have an impact on a company's production cost structure; nevertheless, the effect might reduce when the resources are integrated. Miltenburg (2005) and Porter (1980) identified the conditions under which suppliers may affect the production costs of buying companies. First, the industry downstream is disintegrated; that is, the supplier-to-downstream concentration ratio is high (Radetzki, 2013). Second, no substitute products are available for the buyers. Finally, the supplier's product is critical for the industry downstream. Integrating the upstream activities influences vertical and horizontal competition as well as the price structure of the product under consideration (Glock & Kim, 2015).

Backward integration occurs when a company in the downstream of a given supply chain decides to integrate upstream activities in its business (Lin et al., 2014). Backward integration can allow convenient access to the strategic raw material while improving purchasing activities, production coordination (Miltenburg, 2005; Porter, 1980), and price efficiency. Price efficiency allows a company to reduce the cost of inputs and is part of a firm's technical efficiency (Farrell, 1957). Vertical integration provides benefits such as enhanced planning, improved forecasting predictability, and replenishment quality (Glock & Kim, 2015; Jin et al., 2013). Backward integration also allows an aluminum company to bypass dominant suppliers in the industry upstream and the alumina-pricing index based on the LME. Ping et al. (2013) argued that because raw material prices for nonferrous metals have been rising worldwide, upstream integration in this industry could make sense. According to Lin et al. (2014), however, upstream and downstream integrations tend to intensify competition.

Technological and R&D Capabilities and Capacity Utilization

Technical capabilities provided a competitive advantage to Companies A and B and restricted Companies C and D from increasing the production capacity. Although a more revolutionary technology for producing primary aluminum is needed in today's competitive environment to curb production costs, Companies A and B demonstrated some advances with their designs to provide sustainable prices, at least in the middle term. For instance, the R&D activities in Companies A and B promoted technological learning, derived from firms' engagement in networking of relations with other aluminum companies in the same field (Participants 1A, 2A, 2B, & 4B, March 2017). The networking also promoted training and problem-solving opportunities that were factors in the cost minimization.

Miltenburg (2005) and Porter (1980) found that capacity utilization was of paramount importance in high capital-intensive businesses with high fixed costs. Farrell (1957) argued that technological capability was a factor in capacity utilization. In

Companies A and B, R&D was an enabler to provide knowledge to drive technical process abilities and capacity utilization (D1A & 2B, March 2017). Capacity can improve economies of scale (increased volumes), increase productivity, and spread fixed costs. Candelise, Winskel, and Gross (2013) found that production costs decreased significantly in systems in which the production doubled given the technology and quasi-fixed inputs.

Jones (2011) found that the misallocation of core resources leads to revenue differences among companies. Furthermore, Jones maintained that aligning appropriate technologies to business realities might allow a company to develop a competitive edge rapidly. Restuccia and Rogerson (2013) showed that many firms lose money because they fail to produce at optimum efficiency. The knowledge of the production frontier based on the factors of production such as energy, labor, raw material, capital, and technological capabilities, could allow enhancing the plant and resources utilization. Scholars agree that differences in technical efficiency emerge from the misallocation of core resources and technology insufficiencies, both of which affect production costs (Baik et al., 2013; Moll, 2014; Restuccia & Rogerson, 2013).

Energy Management and Efficiency

Companies A and B modulated the energy usage by operating production systems with nonlinear energy input. The decision to shift from the linear energy input to a nonlinear model was based on the average price realized and the internal rate of return of options. These companies were competitive regarding power costs and electricity contracts. In the aluminum industry, energy costs range from 25–45% of the total aluminum output costs; for Companies A and B, power prices ranged from 28–30%. The companies' energy efficiency was approximately 60% from the theoretical baseline. Gutowski et al. (2013) found that implementing low-cost capacity machines or replacing high-cost technologies might provide high-energy efficiency. Companies A and B divested or curtailed high-cost assets. Lucio et al. (2013) found that energy self-generation in the primary aluminum business is a competitive factor. Lucio et al. also found that strategic energy management in a production system contributes to improving electricity consumption through the flexible operation and option-pricing methods (Liu et al., 2014).

Companies consider two demand curves in energy management: one for peak and the other for off-peak periods (Gaudard & Romerio, 2014). In Western Europe, public electricity demand is higher in winter than in summer. Given the periodic availability and temperature-dependent capacity profiles (Gils, 2014), many power producers face challenges responding to the market demand for electricity in winters. The energy deficit and its substantial pricing implications in wintertime in urban areas provide an opportunity for many aluminum companies to improve the plant performance. The seasonal implementation of imports or exports could allow balancing or offsetting high production costs in the context of slumping aluminum prices. The internal rate of return must be assessed precisely by identifying all direct and indirect costs of options as well as their technical implications for the business. For example, some companies negotiate contractual terms in such a way that electricity providers carefully schedule periodic maintenance from soaring electricity demand to lower demand periods. From the perspective of an electricity provider, demand response through import and export strategies on the power grid is a mechanism to overcome stringent planning of network reinforcement.

Based on the real options model for value developed by Dockendorf and Paxson (2013), and given the complexity of the aluminum electrolytic process, companies might interrupt part of the production for exporting energy should the internal return of the option exhibit a desirable behavior. Notwithstanding, interrupting the process might entail significant structural and infrastructural costs. For instance, when a company curtails a production line and endeavors to restore it, people and assets face operational risks (Bastian-Pinto et al., 2015). Skilled workers are needed to provide high-quality conditioning, retrofitting, and re-energizing of the cells. Technically, it is possible for aluminum producers to minimize losses by reducing a percentage of the current input while maintaining a reasonable thermal balance in the electrolytic cells. Figure 48 shows a conceptual pattern for seasonal energy management in aluminum production. Nevertheless, this option is only available in a short-term; companies should consider additional technological and operational efficiencies for reducing energy use.

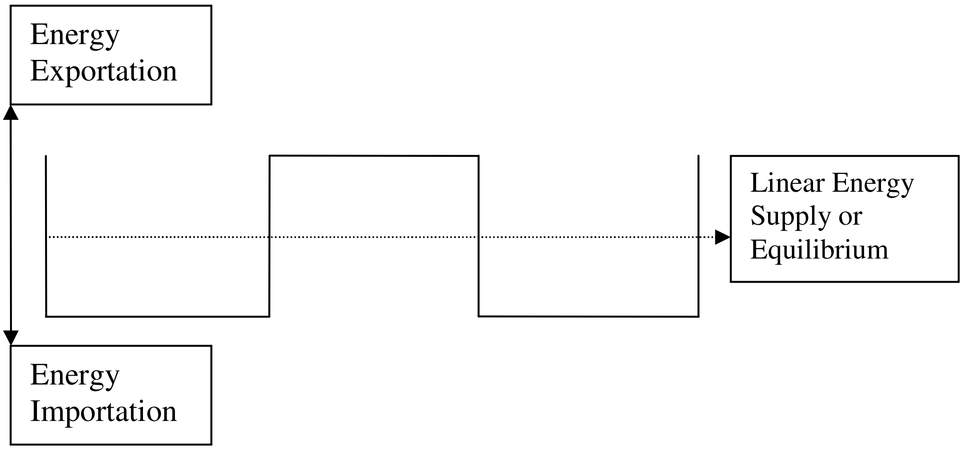


Figure 50. Seasonal energy management/modulation for aluminum producers.

Energy Tariffs and Contracts

Energy tariffs and the type of contracts aluminum companies used varied widely in price. Prices efficiency depended on the electricity contract type (e.g., fixed-power price contracts, variable-power price contracts, or other contracts), for which prices varied significantly from one company to another. Fixed-rate contracts remained constant for the contractual period and provided long-term visibility of production costs. In variable-power price contracts, the electric companies were paid a fixed percentage of the aluminum commodity price (LME). In this arrangement, energy costs decreased when aluminum prices decreased; reciprocally when aluminum increased energy prices increased. In the other types of contracts, the aluminum producer refunded the amount proportional to the expenses incurred to produce electricity. This kind of arrangement presented different levels of uncertainty, including a dependence on the energy supplier's business model and context, which might be disconnected from the aluminum-commodity pricing mechanism on the LME. The cost of electricity also varied according to the primary energy source used (coal, nuclear, fuel, hydroelectricity), because most European countries have integrated carbon and energy prices since 2008 (Ahamada & Kirat, 2015). Coal and fuel were the most expensive energy sources. Aluminum companies that used nuclear or hydropower had a competitive advantage in energy prices.

Focusing on High-Returning Assets

Companies A and B used similar strategies focusing on high-economic returning assets. Whereas Companies A and B were in the lowest quartile in the industry cost curve, Companies C and D were in the highest quartile. Being a low-cost producer was a key driver for sustaining the commodity price pressure. Companies C and D might face significant challenges in a falling aluminum price context. These two companies incurred significant costs because they failed to retrofit high-cost technologies adequately or efficiently (Participants 1C, 2C, 2D, & 5D, March 2017). Given that energy contributed to approximately 40% of the production costs, technologies for which energy efficiency was below 45% from the theoretical baseline should be retrofitted given the small return. The return on assets is a gauge of the assets' profitability, which is an indication of its quality, and how well a production manager can utilize the asset to make a profit. The higher the return, the more cost efficient the asset is in earnings generation and reducing production cost. High-returning capabilities that supported low production costs comprised upstream integration, carbon-manufacturing capability, energy efficiency, Low-cost assets, and long-life cell lining.

Operational Excellence and Productivity

Most companies considered operational excellence (OE) and environmental sustainability as the baseline for sustaining and consolidating performance. Operational excellence is a practice that business people use to maximize quality while minimizing waste. The OE is implemented through a robust problem-solving ability involving the optimization of existing production processes, which results in a continuous improvement (Tsiotras, 2014). Operational excellence stresses the application of a variety of tools and principles with the aim of developing a culture that yields sustainable improvements. Another attribute of operational excellence is high information–capability systems (Youn, Yang, Kim, & Hong, 2014). These attributes apply to aluminum production given its resource-intensive characteristic.

Information capability can allow a company to reduce operating costs along the value chain through purchasing strategies. The information capability also allows a company to enhance its relationship with strategic suppliers, mitigate supply chain risks, and learn continually. Chopra and Sodhi (2014) found that supply-chain risk is associated with cost efficiency. A high-quality information system in the supply chain network facilitates knowledge acquisition, which is linked to cycle times and supply chain costs. The quality of information promotes innovation and enhances responsiveness (Suresh, 2014).

Real-time data transmission from an electrolytic cell to the control room operator was another information capability that could permit the acknowledgment of problems and a timely diagnosis. A high level of automation also provided operational resilience and the additional ability for operational risk management. Aluminum production managers might use these practices to enable asset reliability, resulting in increased lifespan of critical assets, and reduced capital expenses. Finally, Tate, Ellram, Schoenherr, and Petersen (2014) found that skilled labor was a critical competitive factor driving operational excellence and business sustainability.

Circular Economy

Product end-of-life management was a significant challenge for most aluminum producers. Business leaders should begin financing R&D for alternative scenarios in the future era of the industrial ecology. Most companies started thinking about the material attributes or breakthroughs in materials science to capture the value-added and to implement designs that enhance the recyclability and reusability of the material input into the aluminum smelting process. Alternative scenarios of standards for energy and material efficiencies and reusability criteria must be produced (Niero, Hauschild, Hoffmeyer, & Olsen, 2017) for further generation of electrolytic cells. Health, recyclability, and reusability are challenges facing not only the aluminum industry but also the general community and policymakers.

Most aluminum companies that were studied had a transparent approach to managing the sector's end-of-life material, the SPLM. The strategy consisted of working with strategic partners in the cement industry to decontaminating, recycling, and reusing the SPLM. Some companies set aggressive targets for increasing the recycling rate of waste while reducing landfilling. These actions not only create value for stakeholders but also reduce production and environmental costs.

Implications for Social Change

This research has implications for positive social changes because companies can implement a circular rather than a linear economy to reduce costs while maintaining the biodiversity prosperity. Reducing waste, energy, and emissions—recycling solid aluminum and the derivative process waste, and reusing these materials are approaches strongly supported in the circular–economy model. Primary aluminum production is a resource- material- and energy-intensive process that generates a significant amount of greenhouse gases and solid waste. This process causes extraction of large quantities of raw materials and uses millions of megawatts of electricity.

For industrial ecology, the current production model requires a strong commitment from business owners to minimize operational and technological impacts. This research provided a comprehensive framework of discussion and paved the path for exploration of alternatives solutions of production because it outlined the technical gap among technologies. The circular economy approach applied in aluminum production is a necessary, sustainable alternative to its linear counterpart.

The circular-economy paradigm implemented in this study referred to a business model that generated minimum waste and pollution and that used minimum amounts of materials and energy. It is a model in which technological and operational practices must be crafted to restoring and regenerating resources through material substitution and recycling. Aluminum producers should embrace this model for an apparent reason associated with growing solid-waste management and emissions burdens. In implementing the circular economy approach, a company might realize greater productivity through a more sustainable resource use and decreased environmental impacts. For example, Company B used internal capabilities (furnaces) for recycling the solid metal collected from the casting process. Besides, Companies B and C intensified solid-aluminum recycling to minimize the use of material and energy. These strategies not only reduced costs paid to governmental agencies but also contributed to the prosperity of the ecosystem.

Recommendations for Action

The data of this study indicated that low-cost aluminum producers had a balanced portfolio of strategies for most of the industry's production cost drivers. These companies also had a focused strategy for each cost driver (energy, raw material, carbon, environmental sustainability, and low-cost assets). Data indicated that energy and material use mainly affected production costs. Businesses that integrated alumina supplies (backward integration) appeared more cost effective than those that purchased alumina at spot prices. A balanced alumina position or self-supply seemed to provide competitive supply security and a certainty of cost visibility (long-term action).

Critical components of energy costs comprised price efficiency, energy management or modulation, operational efficiency, and energy self-generation. Price efficiency depended on the electricity contract type (e.g., fixed-power price contracts, variable-power price contracts, or other contracts), for which prices varied significantly from one company to another. Fixed-rate contracts remained constant for the contractual period and provided long-term visibility of production costs. In variable-power price contracts, the electric companies were paid a fixed percentage of the aluminum commodity price (LME). In this arrangement, energy costs varied proportionally to aluminum prices. In other types of contracts, the aluminum producer refunded the amount proportional to the expenses incurred to produce electricity. This contractual arrangement presented different levels of uncertainty, including a dependence on the energy supplier's business model and context, which might be disconnected from the aluminum commodity pricing mechanism on the LME.

Companies should use long-term market outlook to analyze various market options to select the option that maximizes the return (minimum prices) and yields minimal risk. In conclusion, companies must be well versed in the tactics of leveraging the best choice through a public-private partnership in a liberalized energy market (short-term action). Ultimately, aluminum companies should negotiate long-term power deals that provide stable energy costs. Operational practices and technological capabilities allow the company to minimize energy consumption and to implement a circular economy. Companies need to set aggressive annual targets to reduce energy use considering the theoretical minima and the thermodynamic limits as the long-term goal. For example, increased energy efficiency by 1–2% annually might allow significant cost reduction. This realistic goal would foster research breakthroughs and disruptive technologies (medium-term action). Companies should import or export energy to the grid depending on the attractiveness and the net present value of options to improve price efficiency. Companies may conduct internal rate of returns analyses to ensuring efficient value creation (short-term action). Aluminum companies can use the highly productive circular economy and minimize energy consumption, waste, and environmental emissions to reduce environmental costs. This shift of activity is expected to boost a company's competitiveness while focusing on business economics and fostering sustainable environmental benefits. Aggressive targets are needed to strengthen resource efficiency, minimize waste, and grow the recyclability. For instance, goals should include (a) reuse 90% of the process waste, (b) recycle and reuse 100% of the solid aluminum waste, and (c) reduce SPLM landfilling to a maximum of 5% by 2025.

Companies can generate cash using selective assets with higher returns. High-cost assets might be retrofitted to minimize energy consumption and increase production capacity, which allows improving plant productivity (medium-term action). Finally, operational excellence provides a robust problem-solving ability involving the optimization and consolidation of existing production processes that often result in continuous improvements. Operational excellence emphasizes the application of a variety of tools and principles with the aim of developing a culture that yields sustainable improvements.

Stakeholders who might benefit from this research include primary aluminum producers in Western Europe, academic practitioners, and business consultants. Policymakers also might be interested in the findings regarding natural resource preservation and regulation, energy use minimization, and the benefits of the circular economy. By exploring technologies that minimize the resources and energy use intensity, companies might contribute to environmental protections that support sovereign states' energy and resources policies. Future research may use these findings to test hypotheses and add to the body of knowledge. This research will be communicated beyond the conventional medium of academic journals. Initially, I will disseminate the research results in context, building trust incrementally, and then I will move to broader channels such as seminars, international aluminum conferences, and business workshops.

Recommendations for Further Research

Despite the current technological advances in operating standards, aluminum producers must still maintain a clear focus on sustainable values that are central industrial problems. Apparently, the most significant opportunities for productivity improvement include (a) minimizing energy and material use (alumina, cathodes, and carbon), (b) developing an efficient circular economic model that integrates the material properties to expand the recyclability of waste, and (c) increasing electrolytic cell life cycle. Heterogeneous current distribution across the cathodic surface drives the heterogeneous erosion of the cathodic material. Cathode lining material, as input in the Hall–Héroult process, has always been a capital-intensive component. Too often, when the cathodic material fails in running cells, only 30-40% of the material is used; the remainder is treated and handled as waste. New generations of technologies should provide optimal solutions to increasing cathode lifespan while maintaining the homogeneous erosion across its surface. This performance might improve the aluminum cell life, productivity, energy efficiency, and could lower capital cost. Regarding the energy efficiency, new long-term technological capabilities should consider energy recovery and storage to slash overall carbon emissions. Storage capacity, coupled with smart demand management, might allow companies to absorb and reuse the excess energy wasted during processing. Finally, R&D teams should answer the following question: what material attributes can enable aluminum producers to meet stringent environmental and efficiency standards while reducing production costs. The new breakthroughs in materials science should achieve the trifecta of conductivity, durability, and sustainability.

Reflections

A highly productive circular economy is the path to which aluminum companies might need to move the business forward to curb the current linear production model that generates excess waste and emissions, and which uses material and energy intensively. The current aluminum production model induces a significant pressure on finite resources and increases the problem of resource depletion. The circular economy model may allow aluminum producers to curb environmental burdens. The benefit of the circular economy model is the sustainability of the aluminum production process. As companies are becoming increasingly concerned regarding waste generation as well as increasing emissions and their long-lasting effects on the world's ecosystem, aluminum producers have the opportunity to advance the material attributes to meeting these challenges. The aluminum energy-processing and material consumption efficiencies ranged from 45–60% and 70–80% respectively; energy waste as heat loss from the electrolytic cells was over 40-45%. The carbon wasted (20-30%) was oxidized during the electrolytic process, resulting in greenhouse gases. If the heat lost from the electrolytic cells, which is estimated to exceed millions of megawatt hours annually could be recovered or reused upstream or downstream, significant advances in energy use would result.

The Hall-Héroult electrolysis is an energy-intensive process; notwithstanding, companies can still innovate beyond the traditional model of operation and push the boundaries of energy consumption efficiency. The levels of efficiency exhibited previously offer a scope for potential gains given the gaps between the current performance of 13.3 MWh/ton Al and the theoretical and thermodynamic limits of 9.03. Notwithstanding the performance achieved so far in high-performing companies, production managers must overcome multiple technical barriers before the industry reaches sustainable performance. Still, the economic gain potential, including cost reduction and environmental benefits for both the aluminum companies and their communities, are worth funding the R&D. In the future, companies might maximize productivity through regenerative resources (energies and materials) and sustainable environments (zero landfilling and minimal emissions to the atmosphere). Improvements expected in the future include the following: (a) Technological progress—the discovery of a breakthrough technology that will revolutionize aluminum production to minimize energy and material intensities. (b) Waste minimization—a continuous challenge for aluminum producers; (c) Increased electrolytic cell lifespan, (d) Product end-of-life management—implementing aluminum post-sale tracking with the aim of developing a recycling system and maximizing its benefits.

Regarding the energy management and modulation, switching between production options (e.g., suspending part of operations based on energy price incentives) requires a company to develop strategic technical flexibility. Scholars describe strategic flexibility as the ability to acknowledge a change in the marketplace, adapt production systems, and allocate resources for new directions to realize higher performance (Zhang, Juan, & Xiao, 2015).

Summary and Study Conclusion

This study allowed identifying the strategies aluminum companies might use to reduce production costs. I found that low-cost aluminum producers had a balanced portfolio of strategies for most production cost drivers and a focused strategy for each cost driver. No cost driver was left out, and no driver dominated. Reducing production costs requires a company to promoting technical efficiency capabilities, a state of production that necessitates a clear vision and an efficient allocation of resources at distinct levels of the production system. The study indicates that aluminum production is a resource-intensive process; companies should aim to be technically efficient, by operating the production functions near the production limits of the core resources. The production frontier is the maximum output achievable with minimum resources use. The technical efficiency measures the ability of an aluminum company to maximize outputs for a given set of inputs. Production managers might use the production-function analysis method to monitor the firm's efficiency.

I also found that material consumption and acquisition mainly influenced production costs. Businesses that integrated alumina supplies (backward integration) were more cost effective than those that purchased alumina at spot prices. A balanced alumina position or self-supply might provide a competitive supply security and the certainty of price visibility. Cost optimization depends not only on the proper selection of production capabilities but also on the access to the raw material and energy at efficient prices.

Price efficiency of energy depended on the electricity contract type (e.g., fixed-power price contracts, variable-power price contracts, other contracts), for which prices varied significantly from one company to another. Competitive power rates are the basis for a sound primary aluminum business plan. Without a competitive electricity price, primary aluminum producers might lack competitiveness. Prices inefficiency might result from distortions in the supply-demand dynamism, influencing the cost of input. A firm's internal characteristics (information capability, highly trained and experienced workforce, continuing technological adaptation to new stringent shareholders' expectations) might allow mitigating buying costs.

Notwithstanding, some companies lack a measurement system of production frontier, technical efficiency, and allocative efficiency to assess accurately to what extent a manager can make improvements to production factors utilization to drive cost-saving opportunities. The knowledge of these measurements might permit to determine different stages of production: increasing returns to scale (IRS), constant returns to scale (CRS), or diminishing returns to scale (DRS). DRS may arise in cases of high consumption of inputs, an overuse of resources, and a misallocation of resources that can lead to increased marginal unit cost.

Operational practices and technological capabilities allow a company to minimize energy consumption. Companies might set aggressive annual targets for reducing energy use, considering the theoretical minima and thermodynamic limits as a long-term goal. For example, increasing energy efficiency by 1–2% annually might provide a significant cost reduction. Raising the energy efficiency requirement would foster research breakthroughs and disruptive technologies.

From the methodological standpoint, the qualitative method was appropriate to explore the portfolio of strategies to reduce production cost. The methodology, which was based on the constructivist and interpretivism worldview, empowered the data collection and analysis and provided a thick and rich description of different and contrasting production strategies. According to interpretivism, individuals and companies are each different, and reality is complicated to apprehend; people understand reality in a variety of ways. The flexibility of the qualitative research method allowed close interactions with participants. The quality of the documents reviewed enhanced the information quality.

The qualitative method provided the flexibility of the data collection based on new insights that some senior managers suggested. Without these insights, I could not have covered the aluminum production strategies at a granular level and from various angles. The multiple comparative case study design was beneficial for three essential case study characteristics: (a) it allowed the application of different data-gathering strategies to permit in-depth inquiry about complex issues. (b) It allowed the analysis of four different strategies developed in the companies' economic contexts. Finally, (c) the purposeful sampling maximized the information strength and provided an extended range of perspectives that allowed analyzing and understanding competing explanations. The business and economic context influenced the companies' performance. Most companies adopted production strategies based on internal and external factors. Given the sampling size and characteristics, this multiple case study design can provide both critical and theoretical transferability of the findings. Some limitation nevertheless affected the data collection quality, because I could not negotiate the permission for entry to perform site observations. Most companies were reluctant about issues of confidentiality. These restrictions limited the possibility to observe core process and assets, although the participants and documents provided a wealth of information to overcome such shortcomings.

References

Achtenhagen, L., Melin, L., & Naldi, L. (2013). Dynamics of business models: Strategizing, critical capabilities and activities for sustained value creation. *Long Range Planning, 46*, 427–442. doi:10.1016/j.lrp.2013.04.002

Adamczak, M., Domanski, R., Hadas, L., Cyplik, P. (2016, June). *The integration between the production-logistics system and its task environment: Chosen aspects.* Proceedings of the 8th IFAC Conference on Manufacturing Modelling, Management and Control MIM 2016: Troyes, France. doi:10.1016/j.ifacol.2016.07.771

Addington, D., McKenzie, E., Addington, J., Patten, S., Smith, H., & Adair, C. (2014). Performance measures for early psychosis treatment services. *Psychiatric Services*. doi:10.1176/appi.ps.56.12.1570

Ahamada, I., & Kirat, D. (2015). The impact of phase II of the EU ETS on wholesale electricity prices. *Revue d'économie Politique, 125,* 887–908. Retrieved from https://www.cairn.info/revue-d-economie-politique.htm

Ahmed, M. U., Kristal, M. M., & Pagell, M. (2014). Impact of operational and marketing capabilities on firm performance: Evidence from economic growth and downturns. *International Journal of Production Economics, 154*, 59–71. doi.10.1016/j.ijpe.2014.03.025.

Ajmal, M., Hussain, M., Kristianto, Y., & Tenkorang, A. R. (2012). A study of technology adoption in manufacturing firms. *Journal of Manufacturing and Technology Management, 23*, 198–211. doi:10.1108/17410381211202197

Alborzi, M., Nazemi, J., Salimian, H., & Shavarini, K. S. (2013). Operations strategy and business strategy alignment model (case of Iranian industries). *International Journal of Operations and Production Management*, *33*, 1108–1130. doi:10.1108/ijopm-12-2011-0467

Allen, C. R., Fontaine, J. J., Pope, K. L., & Garmestani, A. S. (2011). Adaptive management for a turbulent future. *Journal of Environmental Management*, *92*, 1339–1345. doi:10.1016/j.jenvman.2010.11.019

Amini, S., Kazemi, N., & Marzban, A. (2015). Energy optimization of traditional and modern farms of broiler production using data envelopment analysis approach. *Elixir Agriculture 81,* 32005–32010. Retrieved from https://www.researchgate.net/profile/Sherwin Amini2/publication/283090795 Energy Optimization of Traditional and Modern Farms of Broiler Production using Data Envelopment Analysis Approach/links/562a894d08ae04c2aeb1aaf9.pdf

Anyan, F. (2013). The influence of power shifts in data collection and analysis stages: A focus on qualitative research interview. *The Qualitative Report, 18*, 1–9. Retrieved from http://www.nova.edu/sss/QR/index.html

Aristovnik, A., Seljak, J., & Mencinger, J. (2013). Relative efficiency of police directorates in Slovenia: A non-parametric analysis. *Expert Systems with Applications*, *40*, 820–827. doi:10.1016/j.eswa.2012.08.027

Aristovnik, A., Seljak, J., & Mencinger, J. (2014). Performance measurement of police forces at the local level: A non-parametric mathematical programming approach. *Expert Systems with Applications*, *41*, 1647–1653. doi:10.1016/j.eswa.2013.08.061

Ashton, S. (2014). Researcher or nurse? Difficulties of undertaking semi-structured interviews on sensitive topics. *Nurse Researcher, 22*, 27–31. doi:10.7748/nr.22.1.27.e1255

Atici, K. B., & Podinovski, V. V. (2015). Using data envelopment analysis for the assessment of the technical efficiency of units with different specializations: An application to agriculture. *Omega*, *54*, 72–83. doi:10.1016/j.omega.2015.01.015

Bach, S., & Bordogna, L. (2013). Reframing public service employment relations: The impact of economic crisis and the new EU economic governance. *European Journal of Industrial Relations*, *19*, 279–294. doi:10.1177/0959680113505031

Baik, B., Chae, J., Choi, S., & Farber, D. B. (2013). Changes in operational efficiency and firm performance: A frontier analysis approach. *Contemporary Accounting Research*, *30*, 996–1026. doi:10.1111/j.1911-3846.2012.01179.x

Ballot, G., Fakhfakh, F., Galia, F., & Salter, A. (2014). The fateful triangle: Complementarities in performance between product, process and organizational innovation in France and the UK. *Research Policy*, *44*, 217–232. doi:10.1016/j.respol.2014.07.003

Bardou, P., Mariette, J., Escudié, F., Djemiel, C., & Klopp, C. (2014). Jvenn: An interactive Venn diagram viewer. *BMC Bioinformatics, 15*, 1. doi:10.1186/1471-2105-15-293

Bartelsman, E., Haltiwanger, J., & Scarpetta, S. (2013). Cross-country differences in productivity: The role of allocation and selection. *The American Economic Review, 103*, 305–334. doi:10.1257/aer.103.1.305

Baškarada, S. (2014). Qualitative case study guidelines. *Qualitative Report, 19,* 1–25. Retrieved from www.tqr.nova.edu

Bastian-Pinto, C. D. L., Brandão, L. E. T., & Ozório, L. D. M. (2015). Valuing flexibility in electro-intensive industries: The case of an aluminum smelter. *Production*, *(AHEAD)*. doi:10.1590/0103-6513.174214

Bastič, M., Ivanišević, A., Leber, M., & Mavrič, M. (2014). Value analysis as an integral part of new product development. *Procedia Engineering, 69*, 90–98. doi:10.1016/j.proeng.2014.02.207

Behmiri, N. B., & Manera, M. (2015). The role of outliers and oil price shocks on the volatility of metal prices. *Resources Policy, 46,* 139–150. doi:10.1016/j.resourpol.2015.09.004

Bennett, D. L., & Vedder, R. K. (2014). Public policy, higher education, and income inequality in the US: Have we reached diminishing returns? *Social Philosophy & Policy, 31*, 252–280. doi:10.13140/RG.2.1.3519.3763

Bianxia, S., Sharon, X. L., & Zesheng, S. (2013). The impact of monetary liquidity on Chinese aluminum prices. *Resources Policy, 38*, 512–522. doi:10.1016/j.resourpol.2013.08.002

Birchall, S. J., Murphy, M., & Milne, M. (2016). Mixed methods research: A comprehensive approach for study into the New Zealand Voluntary Carbon

Market. *The Qualitative Report, 21*, 1351–1365. Retrieved from http://nsuworks.nova.edu/tqr/vol21/ iss7/11

Blair, R. D., & Kaserman, D. L. (2014). *Law and economics of vertical integration and control.* New York, NY*:* Academic Press.

Blom, H., Gustavsson, C., & Sundler, A. J. (2013). Participation and support in intensive care as experienced by close relatives of patients: A phenomenological study. *Intensive and Critical Care Nursing, 29*, 1–8. doi:10.1016/j.iccn.2012.04.002

Blomberg, J., & Söderholm, P. (2011). Factor demand flexibility in the primary aluminum industry: Evidence from stagnating and expanding regions. *Resources Policy*, *36*, 238–248. doi:10.1016/j.resourpol.2011.03.002

Bonevski, B., Randell, M., Paul, C., Chapman, K., Twyman, L., Bryant, J.,…Hughes, C. (2014). Reaching the hard-to-reach: A systematic review of strategies for improving health and medical research with socially disadvantaged groups. *BMC Medical Research Methodology, 14,* 1–29. doi:10.1186/1471-2288-14-42

Bornstein, M. H., Jager, J., & Putnick, D. L. (2013). Sampling in developmental science: Situations, shortcomings, solutions, and standards. *Developmental Review, 33,* 357–370. doi:10.1016/j.dr.2013.08.003

Bouchard, K. L. (2016). Anonymity as a double-edged sword: Reflecting on the implications of online qualitative research in studying sensitive topics. *The Qualitative Report*, *21*, 59–67. Retrieved from http://nsuworks.nova.edu/tqr/vol21/iss1/5

Boulamanti, A., & Moya, J. A. (2016). Production costs of the non-ferrous metals in the EU and other countries: Copper and zinc. *Resources Policy, 49,* 112–118. doi:10.1016/j.resourpol.2016.04.011

Bourne, A. H., & Robson, M. A. (2015). Participants' reflections on being interviewed about risk and sexual behavior: Implications for collection of qualitative data on sensitive topics. *International Journal of Social Research Methodology, 18*, 105–116. doi:10.1080/13645579.2013.860747

Brailas, A. V. (2014). Networked grounded theory. *The Qualitative Report*, *19*, 1–16. Retrieved from http://nsuworks.nova.edu/tqr/vol19/iss8/3

Bray, E. L. (2013). *Metal prices in the United States through 2010* (Scientific Investigations Report 2012–5188). Retrieved from http://pubs.usgs.gov/sir/2012/5188/sir2012-5188.pdf

Brown, G., Greaney, A. M., Heffernan, C., Heffernan, E., Mhaolrúnaigh, S. N., Murphy, J., & Sheehy, A., (2012). Research ethics application: A guide for the novice researcher. *British Journal of Nursing*, *21*, 38–40. doi:10.12968/bjon.2012.21.1.38

Burian, P. E., & Maffei, F. R. (2013). Operations strategy: A broader view of threading the vision to the customer. *The International Business and Economics Research Journal (Online)*, *12*, 1513–1520. Retrieved from http://www.cluteinstitute.com/ojs/index.php/IBER/article/viewFile/8637/8634

Cai, H., Chen, H., Yi, T., Daimon, C. M., Boyle, J. P., Peers, C., ... & Martin, B. (2013). VennPlex: A novel Venn diagram program for comparing and visualizing datasets with differentially regulated datapoints. *PLoS One*, *8*, e53388. doi:10.1371/journal.pone.0053388

Camuffo, A., & Wilhelm, M. (2013). Between internal and external misfit: A configurational perspective on the Toyota crisis. *Academy of Management Proceedings*, *1*. doi:10.5465/AMBPP.2013.16246a

Candelise, C., Winskel, M., & Gross, R. J. (2013). The dynamics of solar PV costs and prices as a challenge for technology forecasting. *Renewable and Sustainable Energy Reviews*, *26*, 96–107. doi:10.1016/j.rser.2013.05.012

Caniëls, M. C., & Rietzschel, E. F. (2015). Organizing creativity: Creativity and innovation under constraints. *Creativity and Innovation Management*, *24*, 184–196. doi:10.1111/caim.12123

Cant, M. C., Wiid, J. A., & Kallier, S. M. (2015). Product strategy: Factors that influence product strategy decisions of SMEs in South Africa. *Journal of Applied Business Research*, *31*, 621–630. Retrieved from http://cluteinstitute.com/ojs/index.php/JABR/article/viewFile/9158/9148

Cardoso, S.R., Ana Paula, F.D., Barbosa-Povoa, A.P.F.D., & Relvas S. (2013). Design and planning of supply chains with the integration of reverse logistics activities under demand uncertainty. *European Journal of Operational Research, 226*, 436–451. doi:10.1016/j.ejor.2012.11.035

Caruth, G. D. (2013). Demystifying mixed methods research design: A review of the literature. *Online Submission, 3*, 112–122. doi:10.13054/mije.13.35.3.2

Carvalho, P., & Marques, R. C. (2014). Computing economies of vertical integration, economies of scope and economies of scale using partial frontier nonparametric methods. *European Journal of Operational Research*, *234*, 292–307. doi:10.1016/j.ejor.2013.09.022

Casadesus, M. R., & Zhu, F. (2013). Business model innovation and competitive imitation: The case of sponsor-based business models. *Strategic Management Journal*, *34*, 464–482. doi:10.1002/smj.2022

Castillo-Montoya, M. (2016). Preparing for interview research: The interview protocol refinement framework. *The Qualitative Report, 21*, 811–831. Retrieved from http://nsuworks.nova.edu/tqr/vol21/iss5/2

Chan, Z. C., Fung, Y., & Chien, W. (2013). Bracketing in phenomenology: Only undertaken in the data collection and analysis process. *The Qualitative Report, 18*, 1–9. Retrieved from http://nsuworks.nova.edu/tqr/vol18/iss30/1

Chatfield, S. L., Cooper, R., Holden, E., & Macias, K. (2014). Enhancing the experience: A multiple case study of students' experiences using arts-based techniques in learning qualitative research. *The Qualitative Report*, *19*, 1–13. Retrieved from http://nsuworks.nova.edu/tqr/vol19/iss41/3

Chauhan, G., & Singh, T. P. (2013). Resource flexibility for lean manufacturing: SAP-LAP analysis of a case study. *International Journal of Lean Six Sigma, 4*, 370–388. doi:10.1108/IJLSS-10-2012-0010

Chevarin, F., Azari, K., Ziegler, D., Gauvin, R., Fafard, M., & Alamdari, H. (2016). Substrate effect of coke particles on the structure and reactivity of coke/pitch mixtures in carbon anodes. Fuel, 183, 123-131. doi:10.1016/j.fuel.2016.06.070

Chian, K. (2013). Dynamic data envelopment analysis: A relational analysis. *European Journal of Operational Research, 227,* 325–330. doi:10.1016/j.ejor.2012.12.012

Chiang, Y. H., Li, J., Choi, N. Y. T., & Man, K. F. (2012). Comparing China mainland and China Hong Kong contractors' productive efficiency: A DEA-Malmquist Productivity Index approach. *Journal of Facilities Management*, *10*, 179–197. doi:10.1108/14725961211245992

Chopra, S., & Sodhi, M. S. (2014). Reducing the risk of supply chain disruptions. *MIT Sloan Management Review*, *55*(3), 73. Retrieved from http://sloanreview.mit.edu/

Cleary, M., Horsfall, J., & Hayter, M. (2014). Data collection and sampling in qualitative research: Does size matter? *Journal of Advanced Nursing, 70*, 473–475. doi:10.1111/jan.1216

Cobb, C. W., & Douglas, P. H. (1928). A theory of production. *The American Economic Review*, 139–165. Retrieved from http://www.jstor.org/

Coker, E., Ploeg, J., Kaasalainen, S., & Fisher, A. (2013). Assessment of rigor in published nursing intervention studies that use observational methods. *The Qualitative Report*, *18*, 1–23. Retrieved from http://nsuworks.nova.edu/tqr/vol18/iss34/1

Compton, M. & Barrett, S. (2016). A brush with research: Teaching grounded theory in the art and design classroom. *Universal Journal of Educational Research, 4,* 335–348. doi:10.13189/ujer.2016.040204

Connelly, L. M. (2013). Limitation section. *Medsurg Nursing, 22*, 325. Retrieved from http://www.medsurgnursing.net/cgi-bin/WebObjects/MSNJournal.woa

Cook, W. D., Tone, K., & Zhu, J. (2014). Data envelopment analysis: Prior to choosing a model. *OMEGA, 44,* 1–4. doi:10.1016/j.omega.2013.09.004

Cope, D. G. (2014). Methods and meanings: Credibility and trustworthiness of qualitative research. *Oncology Nursing Forum, 41*, 89–91. doi:10.1188/14.ONF.

Corbin, J., & Strauss, A. (2014). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Thousand Oaks, CA: Sage.

Cornish, F., Gillespie, A., & Zittoun, T. (2013). *Collaborative analysis of qualitative data*. Thousand Oaks, CA: Sage.

Council on Population, Social Sciences, & National Research. (2014). *Determining minimal risk in social and behavioral research.* Retrieved from http://www.ncbi.nlm.nih.gov/books/NBK217972/

Crespi, G., & Zuniga, P. (2012). Innovation and productivity: Evidence from six Latin American countries. *World Development, 40*, 273–290. Retrieved from http://www.econstor.eu/bitstream/10419/89026/1/IDB-WP-218.pdf

Croskerry, P. (2013). From mindless to mindful practice: Cognitive bias and clinical decision making. *N Engl J Med*, *368*, 2445–2448. Retrieved from http://www.girardslaw.com/library/from mindless to mindful practice cognitive bias and clinical decision making redacted.pdf

Cruz, L. (2015). Self-reflexivity as an ethical instrument to give full play to our explicit and implicit subjectivity as qualitative researchers. *The Qualitative Report*, *20*, 1723–1735. Retrieved from http://nsuworks.nova.edu/tqr/vol20/iss10/13

Davenport, T. H. (2013). *Process innovation: reengineering work through information technology.* New York, NY: Harvard Business Press.

Denzin, N. K. (2012). Triangulation 2.0. *Journal of Mixed Methods Research, 6*, 80–88. doi:10.1177?1558689812437186

Ding, D. X. (2014). The effect of experience, ownership, and focus on productive efficiency: A longitudinal study of US hospitals. *Journal of Operations Management*, *32*, 1-14. doi:10.1016/j.jom.2013.10.002

Dockendorf, J. & Paxson, D. (2013). Continuous rainbow options on commodity outputs: what is the real value of switching facilities? *The European Journal of Finance 19*, 645–673. doi:10.1080/1351847X.2011.601663

Doody, O., & Noonan, M. (2013). Preparing and conducting interviews to collect data. *Nurse Researcher*, *20*, 28–32. doi:10.7748/nr2013.05.20.5.28.e327

Dosi, G., Grazzi, M., Moschella, D. (2015). Technology and costs in international competitiveness: From countries and sectors to firms. *Research Policy, 44,* 1795–1814. doi:10.1016/j.respol.2015.05.012

Earley, M. A. (2014). A synthesis of the literature on research methods education. *Teaching in Higher Education, 19,* 242–253. doi:10.1080/13562517.2013.860105

Eckel, C., Iacovone, L., Javorcik, B., & Neary, J. P. (2015). Multi-product firms at home and away: Cost-versus quality-based competence. *Journal of International Economics*, *95*, 216–232. doi:10.1016/j.jinteco.2014.12.012

Ellington, J. K., Dierdorff, E. C., & Rubin, R. S. (2014). Decelerating the diminishing returns of citizenship on task performance: The role of social context and interpersonal skill. *Journal of Applied Psychology, 99*, 748–758. doi:10.1037/a0036102

Elliott, W. B., Hobson, J. L., & White, B. J. (2015). Earnings metrics, information processing, and price efficiency in laboratory markets. *Journal of Accounting Research, 53,* 555–592. doi:10.1111/1475-679X.12080

Elo, S., Kaariainen, M., Kanste, O., Polkki, T., Utriainen, K., & Kyngas, H. (2014). Qualitative content analysis: A focus on trustworthiness. *SAGE Open*, 1–10. doi:10.1177/2158244014522633

Esmaeilikia, M., Fahimnia, B., Sarkis, J., Govindan, K., Kumar, A., & Mo, J. (2014). Tactical supply chain planning models with inherent flexibility: Definition and review. *Annals of Operations Research*, 1–21. doi:10.1007/s10479-014-1544-3

European Commission. (2013). *The state of aluminum production in Europe (MEMO/13/954).* Retrieved from http://europa.eu/rapid/press-release MEMO-13-954 en.htm

European Commission. (2014a). *DG enterprise and industry: Short-term industrial outlook (Ref. Ares (2014)3536116 - 24/10/2014).* Retrieved from http://ec.europa.eu/geninfo/query/resultaction.jsp

European Commission. (2014b). *Best available techniques (BAT) reference document for the non-ferrous metals industries: Final draft, JRC Institute for Prospective Technological Studies Sustainable Production and Consumption Unit (European IPPC Bureau, October).* Retrieved from http://eippcb.jrc.ec.europa.eu/reference/BREF/NFM Final Draft 10 2014.pdf

Fang, C., Guan, X., Lu, S., Zhou, M., & Deng, Y. (2013). Input-output efficiency of urban agglomerations in China: An application of data envelopment analysis (DEA). *Urban Studies, 0042098013477707*. doi:10.1177/0042098013477707

Farahani, M. A., Mohammadi, E., Ahmadi, F., & Mohammadi, N. (2013). Factors influencing the patient education: A qualitative research. *Iranian Journal of Nursing and Midwifery Research*, *18*, 133–138. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3748569/

Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society. Series A (General)*, 253–290. Retrieved from https://www.jstor.org/journal/jroyastatsociser

Fielding, N. G. (2012). Triangulation and mixed methods design: Data integration with new research technologies. *Journal of Mixed Methods Research*, *6*, 124–136. doi:10.1177/1558689812437101

Fram, S. M. (2013). The constant comparative analysis method outside of Grounded Theory. *The Qualitative Report, 18*, 1–25. Retrieved from http://nsuworks.nova.edu/tqr/vol18/iss1/1

Franzén, C., & Brown, G. (2013). Undergraduate degree projects in the Swedish dental schools: A documentary analysis. *European Journal of Dental Education*, *17*, 122–126. doi:10.1111/eje.12022

Frels, R. K., & Onwuegbuzie, A. J. (2013). Administering quantitative instruments with qualitative interviews: A mixed research approach. *Journal of Counseling & Development, 91,* 184–194. doi:10.1002/j.1556-6676.2013.00085.x

Friese, S. (2014). *Qualitative data analysis with Atlas.ti.* Los Angeles, CA: Sage.

Fusch, P. I., & Ness, L. R. (2015). Are we there yet? Data saturation in qualitative research. *The Qualitative Report*, *20*(9), 1408–1416. Retrieved from http://www.nova.edu/ssss/QR/QR20/9/fusch1.pdf

Gale, N. K., Heath, G., Cameron, E., Rashid, S., & Redwood, S. (2013). Using the framework method for the analysis of qualitative data in multi-disciplinary health research. *BMC Medical Research Methodology*, *13*, 117. doi:10.1186/1471-2288-13-117

Gallegos, D., Giskes, K., Ramsey, R., & Turrell, G. (2012). Food insecurity among adults residing in disadvantaged urban areas: Potential health and dietary consequences. *Public Health Nutrition, 15*, 227–237. doi:10.1017/S1368980011001996

Gaudard, L., & Romerio, F. (2014). The future of hydropower in Europe: Interconnecting climate, markets, and policies. *Environmental Science & Policy*, *37*, 172–181. doi:10.1016/j.envsci.2013.09.008

Gibbins, J., Bhatia, R., Forbes, K., & Reid, C. M. (2014). What do patients with advanced incurable cancer want from the management of their pain? A qualitative study. *Palliative Medicine, 28*, 71–78. doi:10.1177/0269216313486310

Gils, H. C. (2014). Assessment of the theoretical demand response potential in Europe. Energy, 67, 1–18. doi:10.1016/j.energy.2014.02.019

Gioia, D. A., Corley, K. G., & Hamilton, A. L. (2013). Seeking qualitative rigor in inductive research notes on the Gioia methodology. *Organizational Research Methods, 16*, 15–31. doi:10.1177/1094428112452151

Glaser, B. G., & Strauss, A. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Chicago, IL: Aldine.

Gläser, J., & Laudel, G. (2013). Life with and without coding: Two methods for early-stage data analysis in qualitative research aiming at causal explanations. *Qualitative Social Research*, *14*. Retrieved from http://www.qualitative-research.net/index.php/fqs/article/view/1886/3528>

Glock, C, H., & Kim, T. (2015). The effect of forward integration on a single-vendor–multi-retailer supply chain under retailer competition. *International Journal of Production Economics, 164,* 179–192. doi:10.1016/j.ijpe.2015.03.009

Gorski, P. S. (2013). What is critical realism? And why should you care? *Contemporary Sociology: A Journal of Reviews, 42,* 658–670. doi:10.1177/0094306113499533

Götz, G. (2014). Stop de-industrialization: Concrete proposals from the European aluminum Industry. *Aluminium International Today*, *26*, 14. Retrieved from http://search.proquest.com/openview/5dc346e68bcc594c422921f315ec6d21/1?pq

Govindan, K., Khodaverdi, R., & Jafarian, A. (2013). A fuzzy multi-criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach. *Journal of Cleaner Production*, *47*, 345–354. doi:10.1016/j.jclepro.2012.04.014

Graham, A., Powell, M. A., & Taylor, N. (2014). Ethical research involving children: Encouraging reflexive engagement in research with children and young people. *Children and Society, 29*, 331–343. doi:10.1111/chso.12089

Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of Qualitative Research* (pp. 105–117). Thousand Oaks, CA: Sage. Retrieved from https://www.uncg.edu/hdf/facultystaff/Tudge/Guba%20&%20Lincoln%201994.pdf

Guest, G., Bunce, A., & Johnson, L. (2006). How many interviews are enough? An experiment with data saturation and variability. *Field Methods, 18*, 59–82. doi:10.1177/1525822X05279903

Gunasekaran, A., Irani, Z., Choy, K. L., Filippi, L., & Papadopoulos, T. (2015). Performance measures and metrics in outsourcing decisions: A review of research and applications. *International Journal of Production Economics*, *161*, 153-166. doi.10.1016/j.ijpe.2014.12.021

Gutowski, T. G., Sahni, S., Allwood, J. M., Ashby, M. F., & Worrell, E. (2013). The energy required to produce materials: Constraints on energy-intensity improvements, parameters of demand. *Philosophical Transactions of the Royal*

Society of London A: Mathematical, Physical and Engineering Sciences, *371*, 20120003. doi:10.1098/rsta.2012.0003

Haahr, A., Norlyk, A., & Hall, E. O. C. (2014). Ethical challenges embedded in qualitative research interviews with close relatives. *Nursing Ethics, 21*, 6–15. doi:10.1177/0969733013486370.

Haas, B. K., Hermanns, M., & Melin-Johansson, C. (2016). Case study of persons with cancer participating in a community-based exercise program: An exploration of meaning and change. *The Qualitative Report*, *21*, 1409–1424. Retrieved from http://nsuworks.nova.edu/tqr/vol21/iss8/5

Hadas, L., Cyplik, P., Adamczak, M. (2014). Integration level measurement system in modeling forward and backward supply chain. In P. Golinska (Ed.), *Logistics Operations, Supply Chain Management, and Sustainability* (pp. 47–58). New York, NY: Springer. doi:10.1016/j.ifacol.2016.07.771

Haelermans, C., & Ruggiero, J. (2013). Estimating technical and allocative efficiency in the public sector: A nonparametric analysis of Dutch schools. *European Journal of Operational Research, 227*, 174–181. doi:10.1016/j.ejor.2012.12.004

Hall, W., Prichard, J., Voogt, P., & Zuccato, E. (2014). Sewage epidemiology and illicit drug research: The development of ethical research guidelines, *Science of The Total Environment*, *472*, 550–555. doi:10.1016/j.scitotenv.2013.11.039

Han, B., Tang, Y., & Yang, L. (2016). Public information and uninformed trading: Implications for market liquidity and price- efficiency. *Journal of Economic Theory*, *163*, 604–643. doi.10.1016/j.jet.2016.02.012

Hanna, P. (2012). Using internet technologies (such as Skype) as a research medium: A research note. *Qualitative Research, 12,* 239–242. doi:10.1177/1468794111426607

Hannes, K., & Parylo, O. (2014). Let's play it safe: Ethical considerations from participants in a photo voice research project. *International Journal of Qualitative Methods*, *13*, 255–274. Retrieved from http://ejournals.library.ualberta.ca/index.php/IJQM/article/view/21243/16897

Hao, H., Geng, Y., & Hang, W. (2016). GHG emissions from the production of primary aluminum in China: Regional disparity and policy implications. *Applied Energy*, *166*, 264–272. doi:10.1016/j.apenergy.2015.05.056

Harper, M., & Cole, P. (2012). Member checking: Can benefits be gained similar to group therapy? *The Qualitative Report, 17,* 510–517. Retrieved from http://www.nova.edu/ssss/QR/QR17-2/harper.pdf

Hazzan, O., & Nutov, L. (2014). Teaching and learning qualitative research: Conducting qualitative research. *Qualitative Report, 19*, 1–29. Retrieved from www.nova.edu

Helm, R., & Conrad, D. (2015). The impact of customer-specific and market-related variables on the preference for highly innovative products. *Review of Managerial Science*, *9*, 61–88. doi:10.1007/s11846-014-0123-y

Herrmann, C., & Kayasa, M. J. (2012). A simulation-based evaluation of selective and adaptive production systems (SAPS) supported by quality strategy in production. *Procedia CIRP, 3*, 14–19. doi:10.1016/j.procir.2012.07.004

Higginbottom, G. M. A., Pillay, J. J., & Boadu. N.Y. (2013). Guidance on performing focused ethnographies with an emphasis on healthcare research. *The Qualitative Report , 18,* 1–16. Retrieved from http://www.nova.edu/ssss/QR/QR18/higginbottom17.pdf

Holliday, R. E., Humphries, J. E., Milne, R., Memon, A., Houlder, L., Lyons, A., & Bull, R. (2012). Reducing misinformation effects in older adults with cognitive interview mnemonics. *Psychology and Aging*, *27*, 1191. doi:10.1037/a0022031

Holloway, I., & Wheeler, S. (2013). *Qualitative research in nursing and healthcare.* Chichester, UK: John Wiley & Sons.

Holywell, G., & Breault, R. (2013). An overview of useful methods to treat, recover or recycle spent pot lining. *JOM, 65,* 1443. doi:10.1007/s11837-013-0769-y

Hook, G. (2015). Plugging in epistemology: A theoretical and methodological maneuver in qualitative research. *The Qualitative Report*, *20*, 982–995. Retrieved from http://nsuworks.nova.edu/tqr/vol20/iss7/3

Hoon, C. (2013). Meta-synthesis of qualitative case studies: An approach to theory building. *Organizational Research Methods, 16,* 522–556. doi:10.1177/1094428113484969

Hoskins, M. L., & White, J. (2013). Relational inquiries and the research interview: Mentoring future researchers . *Qualitative Inquiry, 19,* 179–188. doi:10.1177/1077800412466224

Houghton, C., Casey, D., Shaw, D., & Murphy, K. (2013). Rigor in qualitative case-study research. *Nurse Researcher, 20,* 12–17. doi:10.7748/nr2013.03.20.4.12.e326

Hua, N., & Lee, S. (2014). Benchmarking firm capabilities for sustained financial performance in the U.S. restaurant industry. *International Journal of Hospitality Management*, *36*, 137–144. doi:10.1016/j.ijhm.2013.08.012

Huang, C. W., Ho, F. N., & Chiu, Y. H. (2014). Measurement of tourist hotels′ productive efficiency, occupancy, and catering service effectiveness using a modified two-stage DEA model in Taiwan. *Omega*, *48*, 49–59. doi:10.1016/j.omega.2014.02.005

Huberman, A. M., & Miles, M. B. (1994). Data management and analysis methods. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 428–44). Thousand Oaks, CA: Sage.

Hyett, N., Kenny, A., & Dickson-Swift, D. V (2014). Methodology or method? A critical review of qualitative case study reports. *International Journal of Qualitative Studies on Health and Well-being*, *9.* doi:10.3402/qhw.v9.23606

Irvine, A., Drew, P., & Sainsbury, R. (2012). Am I not answering your questions properly? Clarification, adequacy, and responsiveness in semi-structured telephone and face-to-face interviews. *Qualitative Research, 13*, 87–106. doi:10.1177/1468794112439086

Jean-François, H., Boiral, O., Marie-Josee, & Roy. (2016). Strategic cost management and performance: The case of environmental costs. *The British Accounting Review, 48,* 269-282. doi:10.1016/j.bar.2015.01.001

Jeong, H., & Othman, J. (2016). Using Interpretative phenomenological analysis from a realist perspective. *The Qualitative Report, 21,* 558–570. Retrieved from http://nsuworks.nova.edu/tqr/vol21/iss3/9

Jin, Y, H., Amydee, M, F, & Fawcett, S, E. (2013). Awareness is not enough: Commitment and performance implications of supply chain integration. *International Journal of Physical Distribution & Logistics Management, 43*, 205–230. doi:10.1108/IJPDLM-10-2011-0169

Jones, C. I. (2011). Intermediate goods and weak links in the theory of economic development. *American Economic Journal*: *Macroeconomics, 3*, 1–28. Retrieved from http://www.aeaweb.org/aej-macro/index.php

KC, D., Staats, B. R., & Gino, F. (2013). Learning from my success and from others' failure: Evidence from minimally invasive cardiac surgery. *Management Science*, *59*, 2435–2449. doi:10.1287/mnsc.2013.1720

Kelly, C. A., Soler-Hampejsek, E., Mensch, B. S., & Hewett, P. C. (2013). Social desirability bias in sexual behavior reporting: Evidence from an interview mode experiment in rural Malawi. *International Perspectives on Sexual and Reproductive Health*, *39*, 14. doi:10.1363/3901413

Kirkwood, A., & Price, L. (2013). Examining some assumptions and limitations of research on the effects of emerging technologies for teaching and learning in higher education. *British Journal of Educational Technology, 44*, 536–543. doi:10.1111/bjet.12049

Klein, H. K., & Myers, M. D. (1999). A set of principles for conducting and evaluating interpretive field studies in information systems. *MIS Quarterly,* 67–93. Retrieved from http://www.misq.org/

Koopmans, T. C. (1951). *Analysis of production as an efficient combination of activities.* New York, NY: Wiley.

Kortmann, S., Gelhard, C., Zimmermann, C., & Piller, F. T. (2014). Linking strategic flexibility and operational efficiency: The mediating role of ambidextrous operational capabilities. *Journal of Operations Management*, *32*, 475–490. doi:10.1016/j.jom.2014.09.007

Kvande, H. (2015). Occurrence and production of aluminum. *Encyclopedia of Inorganic and Bioinorganic Chemistry*. doi:10.1002/9781119951438.eibc2350

Kvande, H., & Drabløs, P. A. (2014). The aluminum smelting process and innovative alternative technologies. *Journal of Occupational and Environmental Medicine*, *56.* doi:10.1097/JOM.0000000000000062

Lahiri, N., & Narayanan, S. (2013). Vertical integration, innovation, and alliance portfolio size: Implications for firm performance. *Strategic Management Journal, 34,* 1042–1064. doi:10.1002/smj.2045

Latham, J. R. (2013). A framework for leading the transformation to performance excellence part I: CEO perspectives on forces, facilitators, and strategic leadership systems. *Quality Management Journal*, *20*, 12–29. Retrieved from http://www.asq.org/pub/qmj/

Lee, C. J. G. (2012). Reconsidering constructivism in qualitative research. *Educational Philosophy and Theory*, *44*, 403–412. doi:10.1111/j.1469-5812.2010.00720.x

Leedy, P. D., & Ormrod, J. E. (2013). *Practical research: Planning and design* (10th ed.). Upper Saddle River, NJ: Pearson Education.

Lin, Y. T., Parlaktürk, A. K., & Swaminathan, J. M. (2014). Vertical integration under competition: Forward, backward, or no integration? *Production and Operations Management, 23*, 19–35. doi:10.1111/poms.12030

Liu, Y., Dong, H., Lohse, N., Petrovic, S., & Gindy, N. (2014). An investigation into minimising total energy consumption and total weighted tardiness in job shops. *Journal of Cleaner Production*, *65*, 87–96. doi:10.1016/j.jclepro.2013.07.060

Loh, J. (2013). Inquiry into issues of trustworthiness and quality in narrative studies: A perspective. *The Qualitative Report*, *18*, 1. Retrieved from http://nsuworks.nova.edu/tqr/vol18/iss33/1

Lohri, C. R., Camenzind, E. J., & Zurbrügg, C. (2014). Financial sustainability in municipal solid waste management: Costs and revenues in Bahir Dar, Ethiopia. *Waste Management, 34*, 542–552. doi:10.1016/j.wasman.2013.10.014

Lucas, S. R. (2014). An inconvenient data set: Bias and inappropriate inference in the multilevel model. *Quality & Quantity, 48*, 1619–1649. doi:10.1007/s11135-013-9865-x

Lucic, L., Daiute, C., & Khan, A. (2015). Narrative exploration of social cognition in adults hospitalized due to symptoms of schizophrenia. *European Psychiatry*, *30*, 1282. doi:10.1016/S0924-9338(15)31004-X

Lucio, N. R., Wendell de Queiroz, L., & Rubens de Camargo, J. (2013). Strategic energy management in the primary aluminum industry: Self-generation as a competitive factor, *Energy Policy, 59*, 182–188. doi:10.1016/j.enpol.2013.03.021

Ma, D., Chang, C. C., & Hung, S. W. (2013). The selection of technology for late-starters: A case study of the energy-smart photovoltaic industry. *Economic Modelling*, *35*, 10-20.doi:10.1016/j.econmod.2013.06.030

Malterud, K., Siersma, V. D., & Guassora, A. D. (2016). Sample size in qualitative interview studies: Guided by information power. *Qualitative Health Research*, *26*, 1753–1760. doi:10.1177/1049732315617444

MacGillivray, A., Jeffrey, H., Winskel, M., & Bryden, I. (2014). Innovation and cost reduction for marine renewable energy: A learning investment sensitivity analysis. *Technological Forecasting and Social Change, 87*, 108–124. doi:10.1016/j.techfore.2013.11.005

Marsillac, E., & Jungbae, R. J. (2014). Connecting product design, process, and supply chain decisions to strengthen global supply chain capabilities. *International Journal of Production Economics*, *147*, 317–329. doi:10.1016/j.ijpe.2013.04.011

McAreavey, R., & Das, C. (2013). A delicate balancing act: Negotiating with gatekeepers for ethical research when researching minority communities. *International Journal of Qualitative Methods, 12*, 113–131. doi:10.1177/160940691301200102

Merriam, S. B. (2014). *Qualitative research: A guide to design and implementation*. San Francisco, CA: John Wiley & Sons.

Miltenburg, J. (2005). *Manufacturing strategy: How to formulate and implement a winning plan*. New York, NY: Taylor and Francis Group.

Mitchell, K. R., & Wellings, K. (2013). Measuring sexual function in community surveys: Development of a conceptual framework. *Journal of Sex Research, 50,* 17–28. doi:10.1080/00224499.2011.621038

Moll, B. (2014). Productivity losses from financial frictions: Can self-financing undo capital misallocation? *American Economic Review, 104,* 3186–3221. doi:10.1257/aer.104.10.3186

Mollick, E. (2014). The dynamics of crowdfunding: An exploratory study. *Journal of Business Venturing*, *29*, 1–16. doi:10.1016/j.jbusvent.2013.06.005

Molnár, G., Greiff, S., & Csapó, B. (2013). Inductive reasoning, domain specific and complex problem solving: Relations and development. *Thinking Skills and Creativity*, *9*, 35-45. doi:10.1016/j.tsc.2013.03.002

Morse, A., & McEvoy, C. D. (2014). Qualitative research in sports management: Case study as a methodological approach. *The Qualitative Report*, *19*, 1–13. Retrieved from http://nsuworks.nova.edu/tqr/vol19/iss31/3

Munn, Z., Porritt, K., Lockwood, C., Aromataris, E., & Pearson, A. (2014). Establishing confidence in the output of qualitative research synthesis: The ConQual approach. *BMC Medical Research Methodology, 14.* 1–7. doi:10.1186/1471-2288-14-108

Namageyo-Funa, A., Rimando, M., Brace, A., Fowles, T., Christiana, R., Davis, T. L., Martinez, L., Sealy, D. (2014). Recruitment in qualitative public health research:

Lessons learned during dissertation sample recruitment. *The Qualitative Report, 19*, 1–17. Retrieved from http://nsuworks.nova.edu/tqr/vol19/iss4/3

Neri de Souza, F., Neri, D. C., & Costa, A. P. (2016). Asking questions in the qualitative research context. *The Qualitative Report*, *21*, 6–18. Retrieved from http://nsuworks.nova.edu/tqr/vol21/iss13/2

Niero, M., Hauschild, M. Z., Hoffmeyer, S. B., & Olsen, S. I. (2017). Combining eco-efficiency and eco-effectiveness for continuous loop beverage packaging systems: Lessons from the Carlsberg Circular Community. *Journal of Industrial Ecology*. doi:10.1111/jiec.12554

Noble, H. & Smith, J. (2015). Issues of validity and reliability in qualitative research. *Evidence-Based Nursing, 18*, 34–35. doi:10.1136/eb-2015-102054

Nolte, S., Elsworth, G. R., & Osborne, R. H. (2013). The absence of social desirability bias in the evaluation of chronic disease self-management interventions. *Health and Quality of Life Outcomes*, *11*, 1. doi:10.1186/1477-7525-11-114

Novy-Marx, R. (2013). The other side of value: The gross profitability premium. *Journal of Financial Economics*, *108*, 1–28. doi:10.1016/j.jfineco.2013.01.003

The Office for Human Research Protections. (2005). The Nuremberg code. *Trials of War Criminals before the Nuremberg Military Tribunals under Control Council Law*, *10*, 181–182. Retrieved from http://www.hhs.gov/ohrp/archive/nurcode.html

Oke, A. (2013). Linking manufacturing flexibility to innovation performance in manufacturing plants. *International Journal of Production Economics*, *143*, 242–247. doi:10.1016/j.ijpe.2011.09.014

Olausson, S., Lindahl, B., & Ekebergh, M. (2013). A phenomenological study of experiences of being cared for in a critical care setting: The meanings of the patient room as a place of care. *Intensive and Critical Care Nursing, 29*, 234–243. doi:10.1016/j.iccn.2013.02.002

Olesen, O. B., & Petersen, N. C. (2016). Stochastic data envelopment analysis: A review. *European Journal of Operational Research*, *251*, 2–21. doi:10.1016/j.ejor.2015.07.058

Olson, J. D., McAllister, C., Grinnell, L. D., Gehrke-Walters, K., & Appunn, F. (2016). Applying constant comparative method with multiple investigators and inter-coder reliability. *The Qualitative Report, 21*, 26–42. Retrieved from http://nsuworks.nova.edu/ tqr/vol21/iss1/3

Onwuegbuzie, A. J., & Byers, V. T. (2014). An exemplary for combining the collection, analysis, and interpretation of verbal and nonverbal data in qualitative research. *International Journal of Education, 6*, 183–246. doi:10.5296/ije.v6i1.4399

Oquendo, M. A., Stanley, B., Ellis, S. P., & Mann, J. J. (2014). Protection of human subjects in intervention research for suicidal behavior. *American Journal of Psychiatry, 161*, 1558–1563. doi:10.1176/appi.ajp.161.9.1558

O'Reilly, M., & Parker, N. (2012, May). Unsatisfactory saturation: A critical exploration of the notion of saturated sample sizes in qualitative research. *Qualitative Research*, 1–8. doi:10.1177/1468794112446106

Owen, G. T. (2014). Qualitative methods in higher education policy analysis: Using interviews and document analysis. *The Qualitative Report*, *19*, 1–19. Retrieved from http://nsuworks.nova.edu/tqr/vol19/iss26/2

Ozorio, L., Bastian-Pinto, C. L., Baidya, T. K. N., & Brandão, L. E. T. (2013). Investment decision in integrated steel plants under uncertainty. *International Review of Financial Analysis, 27,* 55–64. doi:10.1016/j.irfa.2012.06.003

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and Policy in Mental Health and Mental Health Services Research*, 1–12. doi:10.1007/s10488-013-0528-y

Palmer, J., Fam, D., Smith, T., & Kilham, S. (2014). Ethics in fieldwork: Reflections on the unexpected. *The Qualitative Report*, *19*, 1–13. Retrieved from http://nsuworks.nova.edu/tqr/vol19/iss28/3

Park, B. L., Simar, P., & Zelenyuk, V. (2015). Categorical data in local maximum likelihood: Theory and applications to productivity analysis. *Journal of Productivity Analysis, 43*, 199–214. doi:10.1007/s11123-014-0394-y

Pearson, M. L., Albon, S. P., & Hubball, H. (2015). Case study methodology: Flexibility, rigor, and ethical considerations for the scholarship of teaching and learning. *The Canadian Journal for the Scholarship of Teaching and Learning, 6*(12). Retrieved from http://ir.lib.uwo.ca/cjsotl rcacea/vol6/iss3/12

Perkins, A., Burton, L., Dray, B., & Elcock, K. (2013). Evaluation of a multiple-mini-interview protocol used as a selection tool for entry to an undergraduate nursing program. *Nurse Education Today*, *33*, 465–469. doi:10.1016/j.nedt.2012.04.023

Pernecky, T. (2012). Constructionism: Critical pointers for tourism studies. *Annals of Tourism Research, 39*, 1116–1137. doi:10.1016/j.annals.2011.12.010

Petty, N. J., Thomson, O. P., & Stew, G. (2012). Ready for a paradigm shift? Part 2: Introducing qualitative research methodologies and methods. *Manual Therapy*, *17*, 378-384. doi:10.1016/j.math.2012.03.004

Pierre, E. A. S., & Jackson, A. Y. (2014). Qualitative data analysis after coding. *Qualitative Inquiry*, *20*, 715–719. doi:10.1177/1077800414532435

Ping, W. E. I., Tang, H. Q., Yao, C. H. E. N., & Chen, X. H. (2013). Measuring technical efficiency of Chinese nonferrous metals enterprises on a background of industry consolidation. *Transactions of Nonferrous Metals Society of China, 23*, 2797–2806. doi:10.1016/S1003-6326(13)62800-9

Pinto, A. D., Manson, H., Pauly, B., Thanos, J., Parks, A., & Cox, A. (2012). Equity in public health standards: A qualitative document analysis of policies from two Canadian provinces. *International Journal for Equity in Health*, *11*, 28. doi:10.1186/1475-9276-11-28

Pogue, A. I., & Lukiw, W. J. (2014). The mobilization of aluminum into the biosphere. *Frontiers in Neurology*, *5*. doi:10.3389/fneur.2014.00262

Polansky, A. M. (2014). Assessing the capability of a manufacturing process using nonparametric Bayesian density estimation. *Journal of Quality Technology*, *5*, 150–170. Retrieved from http://www.asq.org/pub/jqt

Porter, M. E. (1980). *Competitive Strategy*: *Techniques for analyzing industries and competitors*. New York, NY: The Free Press.

Potter, S. (2013). Learning to value stories: A review of narrative inquiry. *Qualitative Report, 18*, 1–3. Retrieved from www.nova.edu

Radetzki, M. (2013). The relentless progress of commodity exchanges in the establishment of primary commodity prices. *Resources Policy*, *38*, 266–277. doi:10.1016%2Fj.resourpol.2013.04.001

Ramanathan, U. (2014). Performance of supply chain collaboration–A simulation study. *Expert Systems with Applications*, *41*(1), 210. doi:10.1016/j.eswa.2013.07.022

Ravenek, M. J., & Rudman, D. L. (2013). Bridging conceptions of quality in moments of qualitative research. *International Journal of Qualitative Methods, 12,* 436–456. doi:10.1177/160940691301200122

Ray, C. S. (2015). Nonparametric measures of scale economies and capacity utilization: An application to U.S. manufacturing. *European Journal of Operational Research, 245,* 602–611. doi:10.1016/j.ejor.2015.03.024

Reh, L. (2013). Process engineering in circular economy. *Particuology*, *11*, 119–133. doi:10.1016/j.partic.2012.11.001

Reinartz, S. J., & Schmid, T. (2015). Production flexibility, product markets, and capital structure decisions [Abstract]. *Review of Financial Studies*, hhv126. doi:10.1093/rfs/hhv126

Restuccia, D., & Rogerson, R. (2013). Misallocation and productivity. *Review of Economic Dynamics*, *16*, 1–10. doi:10.1016/j.red.2012.11.003.

Rimando, M., Brace, A. M., Namageyo-Funa, A., Parr, T. L., Sealy, D., Davis, T. L., Martinez, L. M., & Christiana, R. W. (2015). Data collection challenges and recommendations for early career researchers. *The Qualitative Report*, *20*, 2025–2036. Retrieved from http://nsuworks.nova.edu/tqr/vol20/iss12/8

Ritchie, J., Lewis, J., Nicholls, C. M., & Ormston, R. (Eds.). (2013). *Qualitative research practice: A guide for social science students and researchers*. Thousand Oaks, CA: Sage.

Robert, D., & Shenhav, S. (2014). Fundamental assumptions in the narrative analysis: Mapping the field. *The Qualitative Report, 19*, 1–17. Retrieved from http://nsuworks.nova.edu/tqr/vol19/iss38/3

Rosenthal, M. (2016). Qualitative research methods: Why, when, and how to conduct interviews and focus groups in pharmacy research. *Currents in Pharmacy Teaching and Learning, 8,* 509–516. doi.org/10.1016/j.cptl.2016.03.021

Sáenz, V. B., Bukoski, B. E., Lu, C., & Rodriguez, S. (2013). Latino males in Texas community colleges: A phenomenological study of masculinity constructs and their effect on college experiences. *Journal of African American Males in Education, 4,* 82–102. Retrieved from http://journalofafricanamericanmales.com

Schraw, G. (2013). Conceptual integration and measurement of epistemological and ontological beliefs in educational research. *ISRN Education*. doi:10.1155/2013/327680

Scopelliti, I., Cillo, P., Busacca, B., & Mazursky, D. (2014). How do financial constraints affect creativity? *Journal of Product Innovation Management*, *31*, 880–893. doi:10.1111/jpim.12129

Shepherd, R. W. (2015). *Theory of cost and production functions*. Princeton, NJ: Princeton University Press.

Sherman, H. D., & Zhu, J. (2013). Analyzing performance in service organizations. *MIT Sloan Management Review, 54*, 37–42. Retrieved from http://sloanreview.mit.edu/article/analyzing-performance-in-service-organizations/

Shrouf, F., Ordieres-Meré, J., García-Sánchez, A., & Ortega-Mier, M. (2014). Optimizing the production scheduling of a single machine to minimize total energy consumption costs. *Journal of Cleaner Production*, *67*, 197–207. doi:10.1016/j.jclepro.2013.12.024

Silva, J. A., Abellán-Nebot, J. V., Siller, H. R., & Guedea-Elizalde, F. (2014). Adaptive control optimization system for minimizing production cost in hard milling operations. *International Journal of Computer Integrated Manufacturing*, *27*, 348–360. doi:10.1080/0951192X.2012.749535

Simpson, A., & Quigley, C. F. (2016). Member checking process with adolescent students: Not just reading a transcript. *The Qualitative Report, 21*, 376–392. Retrieved from http://nsuworks.nova.edu/tqr/vol21/iss2/12

Singh, D., Oberoi, J. S., & Ahuja, I. S. (2014). A rule-based fuzzy-logic approach for evaluating the strategic flexibility in manufacturing organizations. *International Journal of Strategic Change Management*, *5*, 281–296. doi:10.1504/IJSCM.2014.067284

Stacey, A. & Stacey, J. (2012). *Research ethics for sustainable development.* Paper presented at the 391-XV European Conference on Research for Methodology for Business Management. Retrieved from http://www.ejbrm.com/front/search/index.html

Stake, R. (1995). *The art of case study research*. Thousand Oaks, CA: Sage.

Stanko, M. A., Molina-Castillo, F. J., & Harmancioglu, N. (2015). It won't fit! For innovative products, sometimes that's for the best. *Journal of Product Innovation Management, 32*, 122–137. doi:10.1111/jpim.12238

Strauss, A., & Corbin. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Thousand Oaks, CA: Sage.

Suresh, A. (2014). Synthesis of knowledge through responsiveness, recognition, formation, attraction, and retention: An empirical approach. *IUP Journal of Knowledge Management*, *12*, 53. Retrieved from https://www.coursehero.com/file/p45f9v9/2014-Synthesis-of-Knowledge-Through-Responsiveness-Recognition-Formation/

Sverdrupa, H. U, Ragnarsdottirb, K, V., Kocac, D. (2015). Aluminium for the future: Modelling the global production, market supply, demand, price and long term development of the global reserves. *Resources, Conservation and Recycling, 103.* 139–154. doi:10.1016/j.resconrec.2015.06.008

Tabereaux, A. T., & Peterson, R. D. (2014). Chapter 2.5 - Aluminum production. In S. Seetharaman (Ed.), *Treatise on Process Metallurgy* (pp. 839–917). Boston, MA: Elsevier. doi:10.1016/B978-0-08-096988-6.00023-7

Taheri, M., Moghaddam, M. R. A., & Arami, M. (2015). Improvement of the/Taguchi/design optimization using artificial intelligence in three acid azo dyes removal by electrocoagulation. *Environmental Progress and Sustainable Energy*, *34*, 1568–1575. doi:10.1002/ep.12145

Tarrozzi, M. (2013). How does my research question come about? The impact of funding agencies in formulating research questions. *The Qualitative Report*, *18*, 1–11. Retrieved from http://nsuworks.nova.edu/tqr/vol18/iss51/2

Tate, W. L., Ellram, L. M., Schoenherr, T., & Petersen, K. J. (2014). Global competitive conditions driving the manufacturing location decision. *Business Horizons*, *57*(3), 381–390. doi:10.1016/j.bushor.2013.12.010

Teddlie, C., & Tashakkori, A. (2012). Common core characteristics of mixed methods research: A review of critical issues and call for greater convergence. *American Behavioral Scientist, 56,* 774-788. doi:10.1177/0002764211433795

Torrie, R. D., Stone, C., & Layzell, D. B. (2016). Understanding energy systems change in Canada: Decomposition of total energy intensity. *Energy Economics*, *56*, 101–106. doi:10.1016/j.eneco.2016.03.012

Tovar, B. & Wall, A. (2015). Can ports increase traffic while reducing inputs? Technical efficiency of Spanish Port Authorities using a directional distance function approach. *Transportation Research Part A.* doi:10.1016/j.tra.2014.11.003

Trench, A., Sykes, J., & Robinson, P. (2015). Edge of tomorrow: A tour of 2016–2020 mineral commodity markets. In *Proceedings AusIMM New Zealand Branch Annual Conference* (pp. 481–494). Retrieved from https://www.researchgate.net/profile/John_Sykes4/publication/299584077_Edge_of_tomorrow_A_tour_of_2016-2020_mineral_commodity_markets/links/5700b67108aea6b77469bae0.pdf

Tribedy, P., & Venugopalan, R. (2012). QCD saturation at the LHC: Comparisons of models to p+ p and A+ A data and predictions for p+ Pb collisions. *Physics Letters B, 710*, 125–133. Retrieved from http://www.worldscinet.com/mplb

Tsiotras, G. D. (2014). Operational excellence in the Greek brewing industry. *Global Business and Organizational Excellence*. doi: 10.1002/joe.2153

Tukker, A. (2015). Product services for a resource-efficient and circular economy: A review. *Journal of Cleaner Production*, *97*, 7691. doi:10.1016/j.jclepro.2013.11.049

Tummons, J. (2014). Using software for qualitative data analysis: Research outside paradigmatic boundaries. *Big Data,* 155–177. doi:10.1108/S1042-319220140000013010

U.S. Department of Health. (2014). The Belmont Report: Ethical principles and guidelines for the protection of human subjects of research. *The Journal of the American College of Dentists*, *81*, 4. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/25951677

U.S. Energy Information Administration. (2012). *Energy needed to produce aluminum.* Retrieved from https://www.eia.gov/todayinenergy/detail.cfm?id=7570

U.S. Geological Survey. (2013). *Metal prices in the United States through 2010*. Washington, DC: U.S. Government Printing Office.

U.S. Geological Survey. (2014). *Mineral commodity summaries 2014*. Washington, DC: U.S. Government Printing Office.

Valero, A., Valero, A., & Calvo, G. (2015). Using thermodynamics to improve the resource efficiency indicator GDP/DMC. *Resources, Conservation and Recycling*, *94*, 110–117 doi:10.1016/j.resconrec.2014.12.001

Van Wijk, E. (2014). Recruitment and retention of vulnerable populations: Lessons learned from a longitudinal qualitative study. *The Qualitative Report*, *19*, 1–21. Retrieved from http://nsuworks.nova.edu/tqr/vol19/iss28/2

Varabyova, Y. & Schreyögg, J. (2013). International comparisons of the technical efficiency of the hospital sector: Panel data analysis of OECD countries using parametric and non-parametric approaches. *Health System Performance*

Comparison: New Directions in Research and Policy, 112, 70–79. doi:10.1016/j.healthpol.2013.03.003

Venkatesh, V., Brown, S. A., & Bala, H. (2013). Bridging the qualitative-quantitative divide: Guidelines for conducting mixed methods research in information systems. *MIS Quarterly*, *37*, 21–54. Retrieved from http://www.misq.org

Wei-Qiang, C., & Lei Shi. (2012). Analysis of aluminum stocks and flows in mainland China from 1950 to 2009: Exploring the dynamics driving the rapid increase in China's aluminum production. *Resources, Conservation and Recycling, 65*, 18–28. doi.10.1016/j.resconrec.2012.05.003.

Weishaar, H., Collin, J., Smith, K., Grüning, T., Mandal, S., & Gilmore, A. (2012). Global health governance and the commercial sector: A documentary analysis of tobacco company strategies to influence the WHO framework convention on tobacco control. *PLoS Medecine*, *9*. doi:10.1371/journal.pmed.1001249

White, P. (2013). Who’s afraid of research questions? The neglect of research questions in the methods literature and a call for question-led methods teaching. *International Journal of Research & Method in Education, 36*, 213–227. doi:10.1080/17437 27X.2013.809413

Wicksteed, P. H. (1894). An essay on the co-ordination of the laws of distribution. Journal of the *History of economic thought*. Retrieved from http://cepa.newschool.edu/het/texts/wicksteed/wickess.pdf

Wiengarten, F., Humphreys, P., Cao, G., & McHugh, M. (2013). Exploring the important role of organizational factors in IT business value: Taking a contingency perspective on the resource-based view. *International Journal of Management Reviews, 15*, 30–46. doi:10.1111/j.1468-2370.2012.00332.x

Williams, A. D., Blackwell, S. E., Mackenzie, A., Holmes, E. A., & Andrews, G. (2013). Combining imagination and reason in the treatment of depression: A randomized controlled trial of internet-based cognitive-bias modification and internet-CBT for depression. *Journal of Consulting and Clinical Psychology*, *81*, 793. Retrieved from http://psycnet.apa.org/journals/ccp/81/5/793.html

Wirshing, D. A., Wirshing, W. C., Marder, S. R., Liberman, R. P., & Mintz, J. (2014). Informed consent: Assessment of comprehension. *The American Journal of Psychiatry*, *155*, 1508–1511. doi:10.1176/ajp.155.11.1508

World Bank. (2013). Commodity market outlook. *Global Economic Prospect.* Retrieved from http://www.wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2013/02/05/00042596220130205142844/Rendered/PDF/750590WP0Box370ties2013A0FullReport.pdf

Yang, W., Shi, J., Qiao, H., Shao, Y., & Wang, S. (2016). Regional technical efficiency of Chinese Iron and steel industry based on bootstrap network data envelopment analysis. *Socio-Economic Planning Sciences*. *In Press, Corrected Proof,* doi:10.1016/j.seps.2016.07.003

Yao, S., & Liu, Z. (1998). Determinants of grain production and technical efficiency in China. *Journal of Agricultural Economics, 49*, 171-184. doi:10.1111/j.1477-9552.1998.tb01262.x

Yazan, B. (2015). Three approaches to case study methods in education: Yin, Merriam, and Stake. *The Qualitative Report*, *20*, 134–152. Retrieved from http://nsuworks.nova.edu/tqr/vol20/iss2/12

Yilmaz, K. (2013). Comparison of quantitative and qualitative research: Traditions: epistemological, theoretical, and methodological differences. *European Journal of Education*, *48*, 311–325. doi:10.1111/ejed.12014

Yin, R. K. (2012). *Application of case study research* (3rd ed.). Thousand Oaks, CA: Sage.

Yin, R. K. (2013). Validity and generalization in future case study evaluations. *Evaluation, 19,* 321–332. doi:10.1177/1356389013497081

Youn, S. H., Yang, M. G. M., Kim, J. H., & Hong, P. (2014). Supply chain information capabilities and performance outcomes: An empirical study of Korean steel suppliers. *International Journal of Information Management*, *34*(3), 369–380. doi:10.1016/j.ijinfomgt.2014.01.008

Zelenyuk, V. (2015). Aggregation of scale efficiency. *European Journal of Operational Research, 240,* 269–277. doi:10.1016/j.ejor.2014.06.038

Zhang, C., Juan, Z., & Xiao, G. (2015). Do contractual practices affect technical efficiency? Evidence from public transport operators in China. *Transportation Research Part E: Logistics and Transportation Review, 80,* 39–55. doi:10.1016/j.tre.2015.05.001

Appendix A: Interview Protocol Form

Aluminum Production Profitability: A Comparative Case Study of Production Strategy

by

Joseph Nloga Ndjebayi

Walden University

Doctoral Proposal: A Comparative Case Study of Production Strategy in the Primary-Aluminum Production

Date

Time

Location

Interviewer Joseph Ndjebayi

Interviewee "X1 "

Release informed consent.

Interview Background

Thank you for your participation in this explorative research. The purpose of this study is to identify strategies that some producers use to reduce production costs. You have been selected as a participant because of your experience and the important role you play in developing production strategies. In this doctoral research, I place a particular interest in understanding the production strategy as deployed in your company. I would like to identify the strategies your business uses to increase business profitability by decreasing production costs. I believe your contribution will shed light on the purpose of this research by helping to identify strategies to reduce costs.

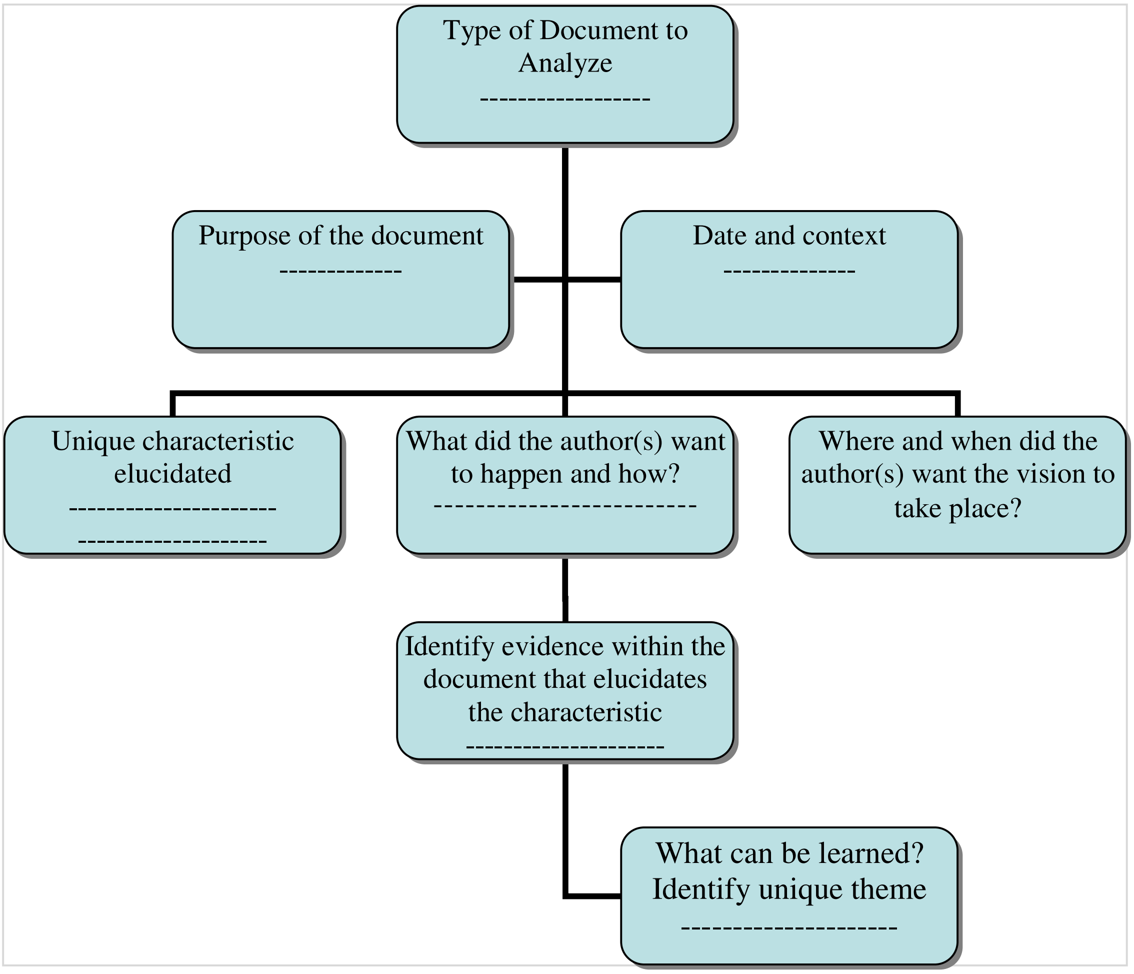
Please note that the IRB has approved this study; therefore, I will guarantee that all the requirements for ethical research are met. Specifically, I will anonymize your details and those of your company. Is that ok with you? To avoid losing valuable information, I will also audiotape this interview; is that also ok with you? The approximate length of the interview is no more than 50 minutes for 10 primary questions. Please feel free to seek clarification to any questions that may be ambiguous. The following serves as the line of questioning:

1. What are resources of production necessary for reducing production costs?
2. How do you combine the resources of production to reduce production costs?
3. What strategy of production related to production costs does your company use to minimize resource utilization?
4. What approach does your company use to maximize the production output while reducing resource utilization?
5. In line with production cost minimization, by what measurement do you consider that you have reached the maximum limit attainable for resource utilization?
6. In line with production cost minimization, what strategy does your company use to allocate resources?
7. What material-management strategy does your company use to reduce production costs?

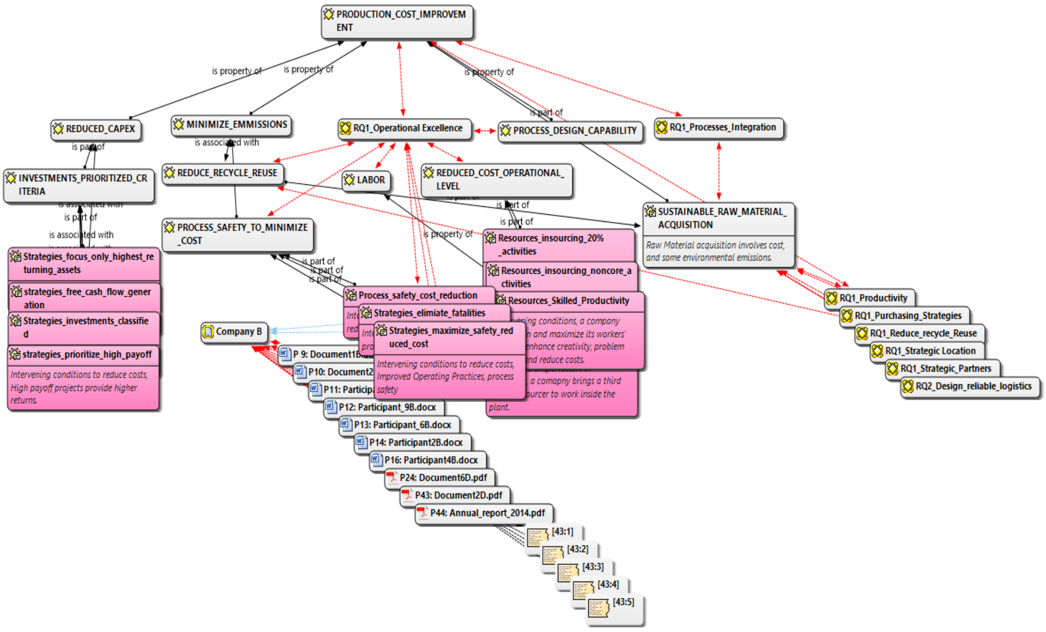
8. What are your purchasing and procurement strategies to reduce production costs?
9. What level of technology do you use to minimize production costs?
10. What level of process engineering does your company use to reduce production costs?
11. What other production capability do you use to help your business reduce its production costs?

Reflection by Interviewer:

Appendix B: Documentary Analysis Process



Appendix C: Within-Case Analysis Network



Appendix D: Between-Case Analysis Network