Chapter 6
Sustainable Development Partnerships: Development of an Estimation Model of CO_2 and Cost-Saving Potentials in German Foundry Value Chains

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Abstract This paper presents an evaluation model of CO_2 and cost-saving potentials, which could be realised by early supplier integration. By analysing serval factors, this paper explores how CO_2 emissions and cost effects are realised by cast development partnerships. Based on the results of the analysis presented, an estimation model to forecast the CO_2 emissions and cost effects of early supplier involvement is shown. Finally, the paper presents a multiple case study analysis, covering 41 cast product development projects of one German iron foundry which were realised together with 27 different customers.

Keywords Sustainable development partnerships • Early supplier integration • CO_2 and cost-saving potentials • Foundry value chain

6.1 Introduction

In the context of ecology and environmental friendliness, there is a growing focus on emissions of carbon dioxide (CO_2), which is by far the most important of the greenhouse gases. This trend can also be seen in the foundry industry. There is growing customer demand for "ecological castings", or at least for products whose CO_2 footprints have been measured and published and are therefore comparable. Foundries are, among other things, known for their high rates of recycling (e.g. 90% of cast parts are produced from melting down scrap metal) (Sturm 2011). However, the melting process requires a considerable energy input. Hence, the foundry industry has the highest energy costs by percentage of total costs of all metal-processing

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sectors. That is why energy efficiency in the foundry industry (in the casting process) has for decades been a subject of debate and discussion (see, e.g. Lownie 1978; Herfurth 1991; Ketscher and Herfurth 1997; Huppertz 2000; Wagner and Enzler 2006). For cast products, the focus has been on achieving energy savings by assessing and optimising casting processes rather than on potential improvements centred on the casting itself (Huppertz 2000; Kuchenbuch 2006; Institute of Foundry Technology 2013).

A number of methods have been developed over the years for assessing, selecting and involving suppliers in the product development process (e.g. Ellram 1987; Kamath and Liker 1994; Peter 1996; Petersen et al. 2005; Kirst 2008; John 2010). These methods consider factors such as project timeline, product quality and project costs. However, there has not been a sufficiently robust theory-based investigation of energy efficiency aspects (in particular reductions in CO_2 emissions) either in cross-company casting development partnerships or within the foundry sector itself.

6.2 Theory and Case Study for Calculating Potential CO_2 Emissions and Production Cost Savings

6.2.1 Ecological Casting Development

Many publications address product development (Pahl et al. 2007; Ehrlenspiel 2009; Schäppi 2005), and many focus specifically on casting development (Richter 1984; Hasse 2007; Roller et al. 2013). There is, however, relatively little material available on cross-company cast product development; there are only brief reports from industrial practice (Hespers 2000; Vollrath 2004; duMaire 2003; Becker 2002). The projects run in this area over recent years such as the BMBF project “Wachstumskern Precision Cast – Verbundprojekt: Entwicklung einer virtuellen, integrierten Technologieplattform für Guss-Konstruktion und –Fertigung (viTeG)” [“Deployment of a virtual and integrated technology platform for construction and manufacturing of castings (viTeG), subproject: precision cast – development process for foundry network”] have addressed the development of computer-aided design guidelines and explored casting simulation (Getzlaff 2010). They have not focused on integrated business processes and the specific ecological implications of casting development.

A wide range of terms and methodological approaches are used in the field of ecological product development, for example, design for sustainability (Jaafar et al. 2007), design for the environment (Ashley 1993), life-cycle design (Kölscheid 1999), eco-design (Fuad-Lake 2002), environmentally conscious design (Myer 2007), design for environmentability (Navinchandra 1991), eco-effectiveness in product development [öko-effektive Produktentwicklung] (Frei 1999), sustainable value engineering (Stahlmann 2006) and green design (Mackenzie 1991). These terms and approaches are all closely related and offer many potential starting points for optimisation, in particular if they are employed at an early stage in the product development process across roles and companies (Clarke and Gershenson 2007, pp. 70; McDonough and Braungart 2006, pp. 39; Giudice et al. 2006). Around 80% of a product's environmental impact depends on decisions taken at the start of the product creation phase (Jaafar et al. 2007, pp. 33; Clarke and Gershenson 2007, pp. 88; Caduff 1999, pp. 55; Atik 2001). The particular environmental significance of the early product development phases and their increasingly scientific analysis has been explored by authors including Zhou and Schoenung (2009), Kölscheid (1999), Alting et al. (2007), and Baumann et al. (2002). One aspect of particular relevance to cast parts is the attempt to produce less mass-intensive products ("light-weight components") (on "demassification", compare e.g. Fiskel 2009; Hitchcock and Willard 2009). Less mass-intensive products mean, for example, less energy for preparing the smaller amounts of raw materials, less energy for melting, more environmentally friendly transport and a lower environmental impact after the (initial) use phase, i.e. reducing mass and weight generally offers benefits at all stages of the life cycle (Fiskel 2009). Reducing energy consumption also reduces emissions, in particular CO_2 emissions.

6.2.2 The Increasing Importance of Energy Consumption and CO_2 Emissions in the Foundry Industry

Increasing attention has been paid over recent decades to the serious effects to be expected from global warming (WMO 2014). Investigations have focused on global changes in greenhouse gas emissions, and in particular emissions of carbon dioxide (CO_2). Growing concerns not least in the fact of a rise in natural disasters (storm tides, droughts, etc.) are increasing pressure on companies to reduce their environmental impact, and that not just for a specific sector, but along the entire value chain (UNEP 2012). Companies are increasingly also taking responsibility for the environmental problems of their suppliers (Koplin et al. 2007). A number of studies and company surveys, for example, "Nachhaltigkeitsmanagement in Unternehmen" ["Sustainability management in businesses"], conducted by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, have shown that companies are increasingly recognising the economic benefits of sustainable processes (German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety 2007). A study by the German Engineering Federation states that the German mechanical engineering sector alone could achieve a reduction in CO_2 emissions of 198 million tonnes over 10 years through the increased use of innovative processes and methods (VDMA 2009).

According to the World Energy Council, energy costs currently account for a global average of 10% of production costs; this percentage is forecast to rise to over 25% over the next 10–15 years (Robison 2011). In Germany, industry is responsible for more than 40% of total energy consumption (Neugebauer 2008), and the foundry

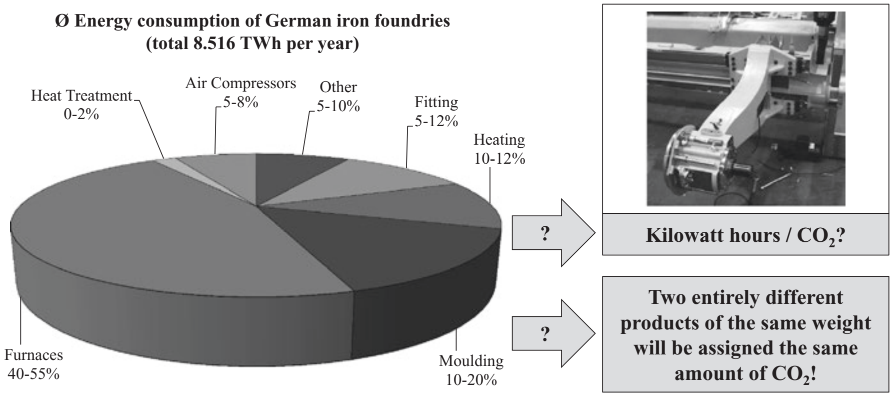


Fig. 6.1 Energy consumption of German foundries for cast iron materials (Fandl et al. 2014a; Picture: Heidenreich & Harbeck GmbH)

industry is particularly energy intensive. Energy savings are therefore an important factor in profitability and sustainability for German foundries (Trauzeddel 2009). Energy consumption in foundries varies significantly depending on the material cast, the process and the measuring methods and specifically also on the defined areas for measurement (cf. Figure 6.1).

Significant differences in consumption strongly indicate that considerable potential remains (Coss et al. 2015). On average, e.g. 60–70% of a foundry's total energy consumption is in the melting process (Bührig-Polaczek et al. 2014). German iron foundries use an average of 40–55% of total energy on melting (Bosse 2012). An assessment of the energy consumption of an iron foundry should not be limited to the melting process, as around half of the total energy is used in upstream and downstream processes in a foundry (Spall 1997). A standard, consistent and quality-assured tool is needed for measuring and evaluating energy and cost effects in casting development.

6.2.3 *Case Study of an IT Tool for Early Assessment of CO_2 Emissions and Production Costs*

A review of the available literature offered a number of aspects to explore in terms of how foundries could address environmental issues (e.g. Spall 1997; Huppertz 2000; Kuchenbuch 2006). None of the studies, however, directly addressed the CO_2 emissions in the casting process that are directly connected to the cast parts themselves. Building on the previous work in the field, a detailed process analysis was conducted for a German iron foundry (Fandl et al. 2014a, b). In line with the defined areas of measurement, detailed material and energy flow data were collected as inputs and outputs of the various steps in the production process and clearly distinguished from nonintegrated material and energy flows. Data were collected in part on the basis of ISO 14040 (life cycle assessment) and VDI 4600 (cumulated energy demand), with additional data where required. Information on the energy consumption of all machines and technical equipment in the case study foundry was collected (a total of 282 items of equipment) (Fandl et al. 2014a, b).

A more in-depth process cost analysis was required in certain areas for an analysis of production costs (Kuchenbuch 2006). The IT tool developed on the basis of this analysis allows the development and design department of the iron foundry in question to assess both CO_2 emissions and production costs systematically. The difference in emissions between customer specifications and finalised development can be established by calculating the CO_2 emissions and production costs for a casting both on the basis of specifications from the customer (e.g. using customer 2D/3D models) and after conclusion of the joint, cross-company development process. As far as the authors are aware, the tool is the first to allow CO_2 emissions to be calculated specifically for castings without using an extremely simplified breakdown of total company emissions. It was found that castings of a similar mass can produce very different levels of CO_2 emissions and that previous breakdowns, for example, of energy consumption on the basis of component weight, are an oversimplification. Using a sample casting (support arm for a paper rolling machine), Fig. 6.2 shows how the IT tool offers considerable potential for reducing CO_2 emissions by drawing on casting development expertise. Production costs were also reduced by around 24% in this development project.

In the course of development of the IT tool, it became clear that there are many potentially important factors effecting cross-company product development part-

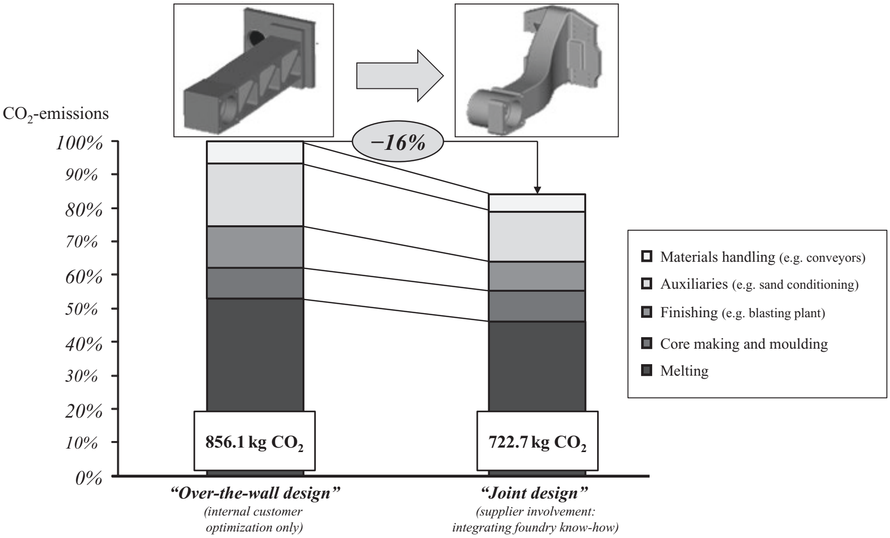


Fig. 6.2 Functionally identical castings: product development by the customer only (on the *left*) and with collaborative optimization (on the *right*) (Pictures: Heidenreich & Harbeck GmbH)

nerships. Further analysis was then required to identify what factors significantly affect a product development partnership and their impact on potential for CO_2 emissions and production cost reductions (Fandl and Held 2015a).

6.3 Design of the Study

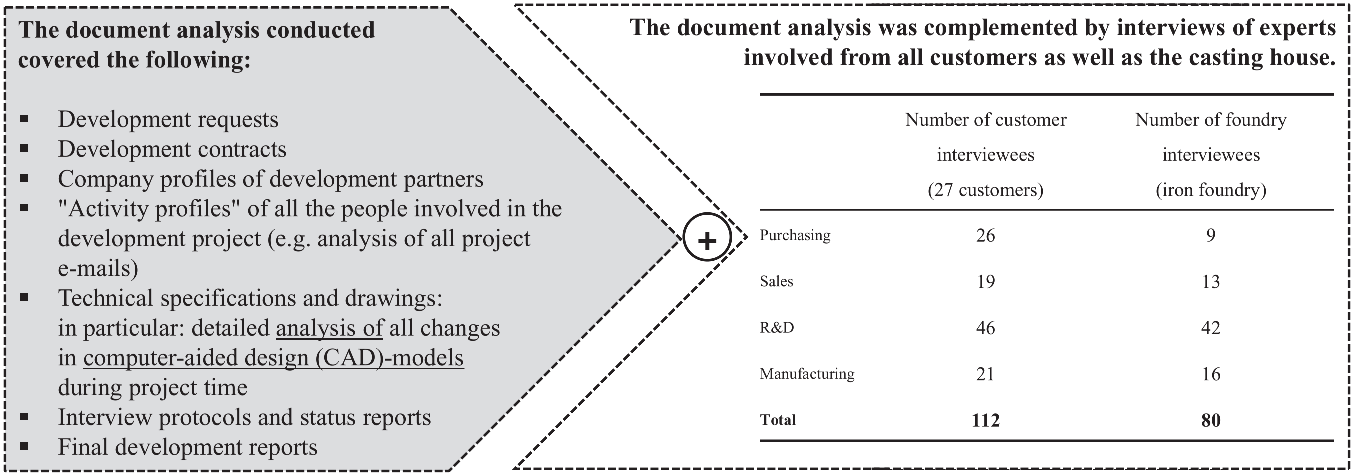
6.3.1 Scope of the Study

A case study is a useful way to analyse cross-company development partnerships in the context in question here (Yin 2003). The case study discussed below allowed in-depth analysis and theoretical replication (Eisenhardt 1989; McDonough 2000; Lamnek 2005; Miles and Huberman 2014). As shown in Fig. 6.3, the present study used guided expert interviews (on the right) with staff at the iron foundry in question and its customers, as well as document analysis (on the left) as data collection methods (e.g. Mayer 2013; Prior 2003). Cross-company casting development was defined as follows for the analysis: it starts when a customer first informs the foundry of a new development project and ends when the foundry hands over the development report with the final technical drawings and specifications to the customer.

The documents analysed (all e-mail communication, all CAD models in various stages of development, specifications, etc.) were supplemented with semi-structured interviews with experts involved in the relevant development projects at the customer end. One hundred ninety-two customers and foundry workers from purchasing, sales, research and development and production were interviewed face to face, and the interviews were then transcribed (Rubin et al. 1995).

The iron foundry in question is a medium-sized company in northern Germany. Its core business is the production of cast components for the mechanical engineering industry. The foundry currently supplies cast components developed and casts to high-quality standards, which are in some cases provided ready for installation. Materials are cast in weights of, e.g. 50–8000 kg in small-scale and medium-scale series production in accordance with DIN EN 1561 and DIN EN 1563. The iron foundry is certified in accordance with DIN EN ISO 9001 and DIN EN ISO 50001. The research and development (R&D) department uses 3D CAD software, finite element method (FEM) calculation tools and development tools for topology optimisation and casting simulation.

All development projects in the iron foundry in question for the period from 2006 up to and including July 2014 were recorded. There were a total of 78 development projects in this period. Restrictions, for example, on the basic material (the iron foundry casts materials in accordance with DIN EN 1561 and DIN EN 1563), production processes (only sand cast products) and project type (this study only covers new development projects), meant however that 39 development projects were excluded from further analysis. An analysis was conducted to determine the



The document analysis conducted covered the following:

- Development requests
- Development contracts
- Company profiles of development partners
- "Activity profiles" of all the people involved in the development project (e.g. analysis of all project e-mails)
- Technical specifications and drawings: in particular: detailed analysis of all changes in computer-aided design (CAD)-models during project time
- Interview protocols and status reports
- Final development reports

The document analysis was complemented by interviews of experts involved from all customers as well as the casting house.

	Number of customer interviewees (27 customers)	Number of foundry interviewees (iron foundry)
Purchasing	26	9
Sales	19	13
R&D	46	42
Manufacturing	21	16
Total	**112**	**80**

Fig. 6.3 Data collection methods

change in CO_2 emissions and production costs for cross-company casting development for the remaining 39 new development projects at the iron foundry.

The 39 case studies cover a total of 27 large- and medium-sized customer companies in the mechanical engineering industry that all operate German R&D departments.

6.3.2 Analysis of Data

In the light of the challenges outlined at the beginning, the aim of the study was to establish which factors could improve sustainability in cooperation between casting suppliers and buyers (primarily CO_2 and cost savings). This article therefore aims to answer the following two research questions (RQ):

- RQ A: What factors influence casting development partnerships?
- RQ B: How could an evaluation method for casting development partnerships be designed?

A combination of qualitative and quantitative methods (mixed method research design; see, e.g. Schreier and Odag 2010 pp. 271) particularly suited to exploratory questions was used to answer these research questions (Foscht et al. 2009 pp. 256).

First, the qualitative data (from the expert interviews, document analysis and literature research) was coded and converted to quantitative data. Thereby, the data collected were collected in figures and mapped using statistics software SPSS 22 (Schendera 2014; Field 2005). For a better understanding of the available data on cross-company casting development, the absolute frequency and percentage for each factor in the 39 development projects were then mapped with univariate statistics (Mayer 2013; Rasch et al. 2014). Factors were categorised as either customer or project factors; the project factors were then broken down further (e.g. characterisation of castings developed in partnership, communication and information).

The relationships between factors and changes in CO_2 emissions/production costs were then examined using bivariate analysis. A particular focus was on the strength of the relationship, for example, to changes in CO_2 emissions. On the basis of the information obtained from the univariate and bivariate analyses, an explanatory model was then developed for predicting future CO_2 savings [and production costs] in cross-company casting development, using, among other things, multiple analytical methods (e.g. univariate and multiple regression).

6.4 Development of a Method for Early Assessment of Potential CO_2 and Cost Savings in Cross-Company Casting Development

6.4.1 *Findings of the First Statistical Analyses*

The IT tool (see Sect. 2.3) was used to calculate both changes in CO_2 emissions and changes in production costs for all development projects analysed (cf. Fig. 6.4). Cross-company development partnerships had overall a significant positive effect on CO_2 emissions. The average change in CO_2 emissions for all development projects analysed was −14.39% (median −11.61% CO_2 emissions); the standard deviation was s = 14.81. The changes in production costs amounted on average to −23.18% (median of −20.94% production costs); the standard deviation was s = 21.78. The IT tool developed was used to calculate the changes in CO_2 emissions and production costs in the development projects analysed, which were implemented in a development partnership involving the iron foundry. A number of other measurements were also made, including the change in weight for the castings evaluated. It was found that this figure was not identical to the CO_2 savings or cost savings; a more detailed examination of individual design drivers and factors was therefore essential.

First, factors potentially affecting cross-company casting development and CO_2 emissions [and production costs] were identified and derived. A total of 48 such factors were identified (using, among other things, four case studies and a comprehensive

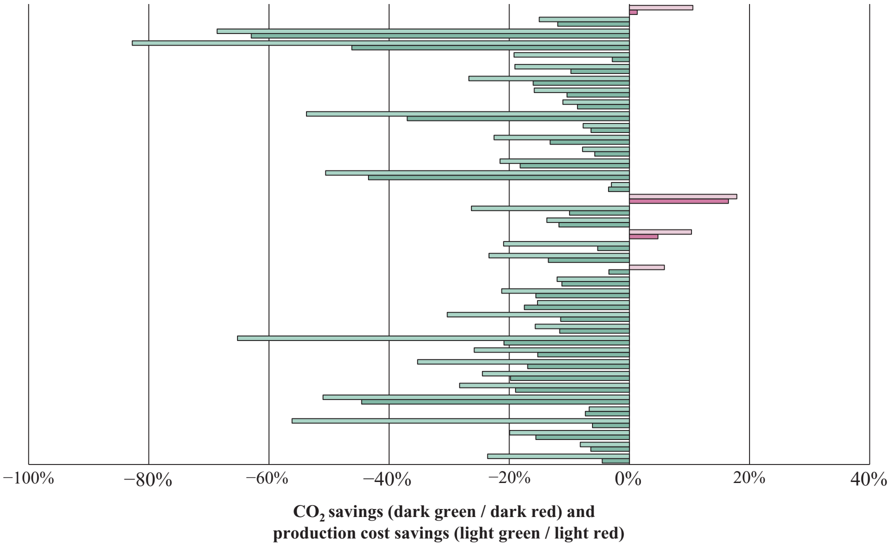


Fig. 6.4 Changes in CO_2 emissions and production costs in the cross-company development projects analysed

and more in-depth study of the literature). A top-down approach was used to narrow down these factors, for example, through interviews with over 100 experts from industry and research (Fandl and Held 2015b). In this way, 34 factors affecting cross-company casting development were identified for further analysis. Univariate analysis of the individual factors was then conducted, in part to better understand the available sample and to restrict further factors.

For the subsequent bivariate analysis of relevant factors, hypotheses were developed on the basis of the expert interviews and a comprehensive document analysis. For example, the following hypotheses (H) were formed: “The higher the number of full-time staff at the customer, the lower the potential CO_2 savings in cross-company casting development (H_3)”; “The earlier casting supplier is involved in the casting development process, the higher the potential CO_2 savings in cross-company casting development (H_{20})”. Figure 6.5 below gives an overview of the hypotheses formed on the factors affecting the change in CO_2 emissions.

The next step was in-depth analysis of the relationships between influencing factors and CO_2 reductions. An initial, “simple” binary analysis showed that the CO_2 reductions achieved with customer companies “with fewer than 250 full-time staff” were on average −16.63%, in other words greater than customer companies “with more than 250 full-time staff” (average of −12.09% reduction in CO_2). Table 6.1 below gives examples of four more of the 27 factors investigated for cross-company casting development.

Building on the results above, boxplot and scatter diagrams were used to visualise more detailed bivariate relationships between the relevant factors and the change

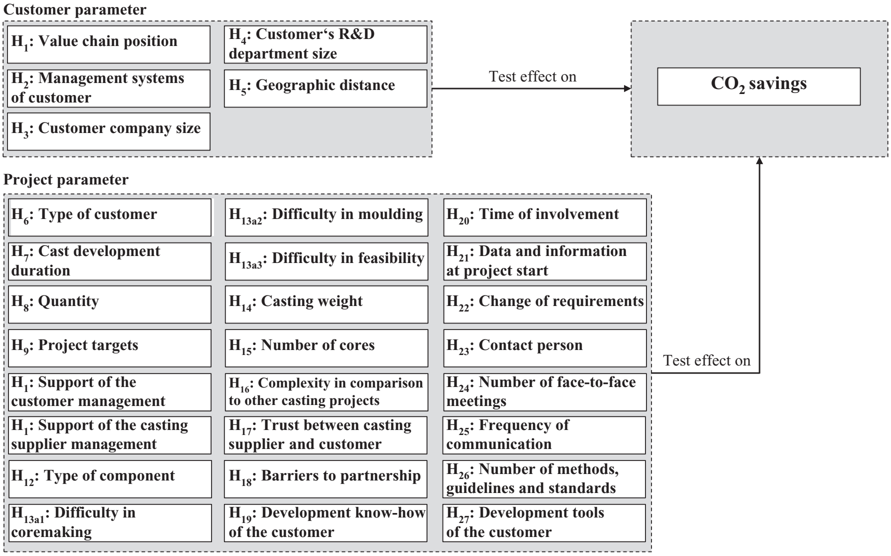


Fig. 6.5 Cross-company parameters with a potential impact on CO_2 savings when foundries are involved in cross-company casting development

Table 6.1 Simplified presentation of CO_2 emissions reductions with selected factors

H_{14}: **Casting weight**		
Average of CO_2 savings	Castings with “low mass” (<2000 kg)	Castings with “high mass” (≥2000 kg)
	−11,25%	**−17,09%**
H_{20}: **Time of involvement**		
Average of CO_2 savings	Idea phase	Design phase
	−21,52%	**−8,23%**
H_{24}: **Number of face-to-face meetings**		
Average ofCO_2 savings	“Without” face-to-face meetings during cross-company casting development	“Starring” face-to-face meetings during cross-company casting development
	−9,39%	**−23,59%**
H_{25}: Frequency of communication		
Average of CO_2 savings	“Scarce” project communication between the customer and the foundry (<15 interactions)	“Frequent” project communication between the customer and the foundry (≥15 interactions)
	−8,75%	**−16,06%**

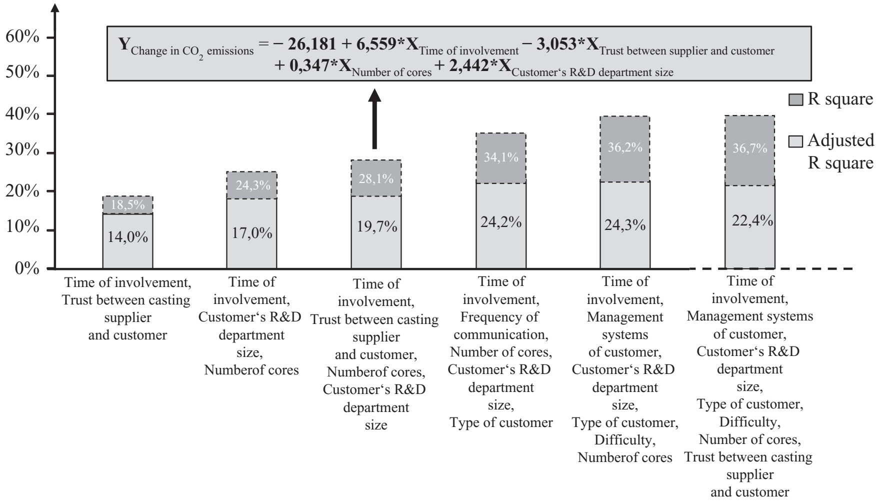


Fig. 6.6 “Combinatorics” of factors affecting cross-company casting development with the best degree of explanation

in CO_2 emissions. The hypotheses formed were tested (see above); and, e.g. hypothesis 3 was confirmed by comprehensive binary analysis. A subsequent analysis of the relationships between all influencing factors found largely (in 92.3% of cases) “very low” to “low” correlations between the individual factors. Only in 5.9% of cases there were “moderate” correlations, and in only 1.7% of cases, the correlation coefficients were greater than 0.6.

To summarise, many factors affected cross-company casting development, but only 27 were suitable for in-depth analysis of their impact on changes in CO_2 and cost savings (response to research question A). The change in CO_2 emissions found in the bivariate analysis gave a clear initial indication of potential factors impacting on sustainable cross-company casting development.

6.4.2 Full-Model Regression

A number of different models were then developed to explain the change in CO_2 emissions overall. The factors with the highest adjusted R squared were mapped starting with the first model (cf. Fig. 6.6).

The influencing factors examined in the univariate regression analyses were first correlated using “all-subset selection” (Albers et al. 2009, pp. 225; Field 2005, pp. 169ff.). Following the best model in each case with the highest adjusted R squared, further models were then also calculated.

On the basis of the requirements for regression analyses (see, e.g. Albers and Skiera 2000; Jann 2005), the fourth model was selected as the most suitable (cf. Fig. 6.6). This significant ($p < 0.05$) model covers four factors and shows that earlier involvement, a high level of mutual trust, the number of cores and a smaller customer R&D department in particular can have a positive effect on cross-company casting development. However, only the relationship for the time of involvement was individually significant at the 5% level. The relationships for the size of the R&D department and the number of cores had a tendency to significance at the 10% level. The model explained over 28% of total variance in CO_2 reductions through cross-company casting development (cf. Fig. 6.6, equation above).

The explanatory model then underwent another correlation analysis, and multicollinearity was examined. The relationship between the factors was examined first; no increased positive or negative correlation was found. A number of methods were used to test for multicollinearity; there was no multicollinearity.

6.4.3 Limitations of the Model for Predicting Future CO_2 Reductions

This section reflects critically on a number of aspects, such as the method applied, the factors affecting the empirical study and the robustness of the findings. The definition of the evaluation period and evaluation method was examined. The evaluation period ran from 2006 to 2014. Both shortening the evaluation period and extending the evaluation period by several years could have led to different results. The study considered all development projects at the case study foundry: complete data were not available for development projects prior to 2006.

There were various aspects to be considered in terms of the number of factors. The study started by addressing a wide range of possible factors affecting cross-company casting development. The large number of factors was due in part to the many expert interviews conducted. Other interesting potential factors were ruled out of the study in subsequent qualitative and quantitative analysis. There were many factors other than those discussed here which could be investigated in research in this field.

A comprehensive inductive statistical analysis was conducted to analyse the robustness of the results of the empirical study. Studies on heteroscedasticity and on special cases were also carried out as part of this process with outlier analyses. The findings of the regression analyses were found to be extremely useful and, in line with the scope of the sample, reliable.

6.5 Practical Implementation and Summary

On the basis of the method developed (see Sect. 4.2), an IT tool was created for the evaluation model. This tool was designed to assess the scope of possible ecological potential – i.e. changes in CO_2 emissions – offered by changing cross-company casting development. Design was followed by operational implementation of the IT tool using MS Excel.

The IT tool was then used by the head of the development and design department at the iron foundry on the basis of the data from two verification development projects. Table 6.2 shows the results of the ex ante forecast of changes in CO_2 emissions in cross-company casting development at the start of the verification development projects. The findings of the forecast with the evaluation model were then compared with those from an evaluation of the actual castings (cf. Table 6.2).

Table 6.2 above shows a −1.26% deviation between the forecast and the actual change in CO_2 emissions at a "base frame development project". The CO_2 savings of just under −11.29% mean that a total reduction of 2.3 tonnes of CO_2 emissions could be achieved with the number of castings planned. The verification development project "machine base unit" showed a +1.45% deviation in the difference. In the light of total output, this means savings of nearly 1 tonne of CO_2 emissions.

Testing the IT tool developed allowed an ex ante forecast of the CO_2 emissions saved by cross-company casting development (response to research question B). Collecting comprehensive data on material and energy flows in the various steps in

Table 6.2 Forecast quality assessment for verification development projects

Verification development project	Forecast of changes in CO_2 in cross-company casting development [%]	Actual saving [%]	Difference in [%]
Base frame	−8,98	−10,24	−1,26
Machine base unit	−11,29	−9,87	+1,45

the production process at a German iron foundry provided the basis for the development and implementation of an IT tool to assess energy consumption/CO_2 emissions and production costs (see Sect. 2.3). This IT tool was then used to assess the changes in CO_2 emissions [and production costs] in 39 cross-company development projects using the expertise of the foundry. The first step towards evaluation was a qualitative study of influencing factors in case studies and a preliminary bivariate quantitative analysis at a German foundry (see Sect. 4.1). The multivariate analyses presented (see Sect. 4.2), supported by the statistical analysis conducted and based on a large number of expert interviews and extensive document analysis, found that the main factors affecting changes in CO_2 emissions at the iron foundry investigated were as follows:

- The time at which a foundry's customers involve it in cast part development
- The level of trust between cast part customer and foundry
- The number of cores at the start of development
- The size of the cast part customers' R&D department

This set of factors is both customer related and project related and interacts with other factors. A final decision on long-term collaboration or on the scale of and resources provided for a cross-company product development partnership should always be taken on a situational basis for each individual development project; the assessment model developed can be used as a supporting tool. In the future, we can expect the German foundry industry to seek to investigate and evaluate the entire life cycle of its cast parts in the light of continuing competitive pressures and the growing importance of material and resource efficiency. The assessment of large-scale series production, for example, for the automotive industry, is not the only focus here. Another important area is single and large cast parts, in which the requirements are becoming ever more complex.

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