Including Multi-Objective Game Theory in complex decision making

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July 6, 2020

Abstract

Strategic decisions have to be made in virtually all organizations, and often they involve multiple criteria or objectives. Two frequently used methods in the field of management to describe and analyse complex decisions are Game Theory and Multi-Criteria Decision Analysis (MCDA). This thesis aimed to expand the game theoretical field as it was currently known to management and integrate it with MCDA. The multi-objective game has been presented in managerial terms and its use has been proposed in a process that incorporates both MCDA and Game Theory. Adopting a mixed methods design, this thesis was completed in three phases. The first phase focused on the theoretical contribution of this thesis: developing the multi-objective game for the field of management and integrating the game in the MCDA process. In the second phase the game developed in phase 1 was empirically tested by means of an online experiment in order to observe peoples' behaviour when they play the game. In the third phase, the researcher performed a meta analysis in order to compare theory and empirical evidence. It was found that the use of the multi-objective game could lead to new insights in the decision making process. In order to identify the true value of the multi-objective game, directions for future research are proposed.

Contents

1 Introduction

Strategic decisions have to be made in virtually all organizations, and often they involve multiple criteria or objectives. Strategic decisions can be characterized as complex because they are made infrequently, even though they are critical for organizational survival (Eisenhardt & Zbaracki, 1992). In the process of a complex decision multiple options, stakeholders and objectives are involved (Montibeller & Franco, 2010). Strategic decisions can be (and often are) complex and vice versa, but the two terms refer to different phenomena. This thesis focuses on complex decisions with the central topic understanding and supporting the process of decision making. The process of making a decision has been investigated before. Calabretta, Gemser and Wijnberg (2017) for example made a difference between rational and intuitive decision making. Even though no choice is made regarding which process will lead to better decisions, this study will focus on the more analytical, structured decision making processes.

Multi-criteria decision analysis (MCDA) is an analytical technique used for analyzing and understanding complex decisions. MCDA makes it possible for the user to analyze various courses of action based on qualitative and quantitative criteria (Goodwin and Wright (2014) provide an exemplary overview of different MCDA techniques). MCDA requires judgement when it comes to determining uncertainties and stating preferences. Managers are often undecided about their own preferences, especially in the early stages of a decision problem (Eisenstadt & Moshaiov, 2018). Next to that MCDA looks at only one organization or decision maker at a time. However, it is argued that complex decision-making is also characterized by the involvement of multiple decision makers who are mutually dependent (Wernz & Deshmukh, 2010).

Another method that is used in the field of strategic decision making is game theory. Game theory is a mathematical tool that can be used to model and analyse situations that involve two or more decision makers or agents (Bacci, Lasaulce, Saad & Sanguinetti, 2015; Coimbra & Correia, 2017). By modeling the decision problem as a game such that the outcome of one player depends on the choice of the other players interdependencies become apparent (see for example Carmichael (2005) for an overview of different games). As a result, the players in the game take into account possible actions of the other players while making decisions (Camerer, 2010). Even though game theory is viewed from a rational perspective, the outcomes can conflict with actual human behaviour on a structural basis (Tversky & Kahneman, 1989). Most games are used to describe situations which involve only one outcome for each player in the game (Bacci et al., 2015; Camerer, 2010; Coimbra & Correia, 2017). This means that these games inevitably take into account only one objective.

Recent work has made a start taking into account both issues: the lack of multi-player relationships (MCDA) and the impossibility to model multiple objectives simultaneously (Game Theory),

which resulted in a new type of game: the multi-objective game (Eisenstadt & Moshaiov, 2018; Lee, 2012; Noguchi, Miyamoto, & Matsutomo, 2014). The multi-objective game analyses multiple conflicting objectives and its results are aimed at identifying a range of 'acceptable' solutions (Eisenstadt & Moshaiov, 2018). An example of the multi-objective game in practice is found in Lee (2012). The problem involves reservoir watershed management. Different economic options are available to exploit the area (hence multi-objective) while at the same time there are environmental agencies that want to minimize the pollution in the area. Because the economic results are not only influenced by economic choices (for example residential or recreational buildings) but also by the activities of the environmental agencies this problem can be modeled as a game. The multi-objective game is explained in great detail in section 2.4. The example taken from Lee (2012) or solutions for network processing (Bacci et al., 2015; Coimbra & Correia, 2015) search for the optimal solution, also referred to as multi-objective optimization. The solutions in these studies are of such complexity that little contribution to the understanding of the decision process is made. Other research regarding the multi-objective game finds its origin in (computing) science ((Eisenstadt & Moshaiov, 2018; Noguchi et al., 2014) where the results stress first and foremost the mathematical correctness of the game.

To the best of my knowledge no research has been done towards the multi-objective game that aims at understanding or describing the decision problem, such that it provides new insights to the field of management. Other research in the topic of complex decision making processes has been done. For example studies that incorporated political or social actions as part of the decision problem (Andersen, Soderlund & Vaagaasar, 2010; Anguelov & Stoyanov, 2013). The structure of complex decision making problems have also been under study (Bekius, 2019) by identifying different game concepts to describe decision processes. However, the multi-object game has not been the subject of study from a managerial standpoint before.

This thesis aims to fill this gap by identifying the possible contribution of the multi-objective game in the field of managerial decision analysis. The focus of this study is to develop the multi-objective game for managerial purposes and the integration of the multi-objective game in the decision making process. To this end this thesis will lead to several contributions. First of all, the game theoretical contribution of this thesis is the development of the multi-objective game such that it can be used describe and analyse a complex decision problem. Second, the multi-objective game is proposed as an additional phase in the entire multi-criteria decision analysis process, creating a link between game theory and MCDA. By conducting an extra analysis, the extended framework (presented in chapter 2) can help managers to better structure the decision making process and come to better decisions. The third contribution of this thesis is the empirical observation of the multi-objective game by means of an online experiment. The experiment is of an exploratory nature and implications are made for future research. The following research question is formulated in order

to make these contributions:

"To which extent can the multi-objective game be used to characterize decision making processes involving multiple objectives and multiple players?"

In order to answer this research question an exploratory sequential mixed methods design (Cameron, 2009) is adopted during the thesis. In this design a total of three research phases can be distinguished: a qualitative start of the study serves as input for (new) instrument design; quantitative data is gathered using this instrument in the form of an online experiment; at last a meta-approach is taken that interprets the qualitative and quantitative results, which will lead to the conclusion of this thesis. To this end, nine sub questions have been developed:

Sub Question 1: What are the current issues regarding complex decision making, especially those that involve multiple objectives and are related to peoples' preferences?

Sub Question 2: How can the multi-objective game be represented in managerial terms, such that it can be used for decision analysis?

These two sub questions are answered by conducting a literature review. The results are an overview of current methods in multi-criteria decision analysis and the role of peoples' preferences in the different methods. Next to that the multi-objective game is presented in terms that are in line with the field of management. Together these results form the input for the design of an experiment. The second research phase consists of the design, implementation and analysis of the experiment. Five sub questions have been developed with regard to the experiment:

Sub Question 3: What are the decisions that people make when they play the multi-objective game during an online experiment?

Sub Question 4: To which extent are the motivations of people in line with the decisions that they make when people play the multi-objective game during an online experiment?

Sub Question 5: What are the decisions that people make when they play the multi-objective game during an online experiment, if they are asked to state their preferences before the game is played?

Sub Question 6: To which extent are the motivations of people in line with the decisions that they make when people play the multi-objective game during an online experiment, if they are asked to state their preferences before the game is played?

Sub Question 7: Are there differences in the decisions that people make when they play the multi-objective game if they are asked about their preferences before they play the game?

Analyses of the results of the experiment provide an answer to sub questions three through seven. In the last phase a meta approach is taken to compare the empirical results with the previously presented theory. This meta analysis is guided by the last two sub questions:

Sub Question 8: How can the decisions and motivations of people when they play the multi-objective game be interpreted with regard to complex decision making?

Sub Question 9: How can the differences in decisions that people make when they play the multi-objective game if they are asked about their preferences before they play the game be interpreted with regard to complex decision making?

Conclusions are drawn from the meta analysis, which leads to implications about the multi-objective game within multi criteria decision analysis and, ultimately, an answer to the research question. A more thorough explanation of the methodology of this thesis is provided in chapter 3.

The remainder of this thesis is structured as follows. First an overview of current complex decision making methods is given and a further explanation of the multi-objective game will be provided in chapter 2. Chapter 3 will provide a detailed explanation about the methodological considerations and the methods used in this thesis. The three research phases are discussed separately, where the third phase is aimed at the integration of the first two phases. Chapter 4 will present the empirical results of the experiment. This involves an analysis of the behaviour of people when they play the multi-objective game during an experiment and the motivations behind their choices. A comparison is made between people that were asked about their preferences before they played the game and those that were not. Chapter 5 will compare the results of the literature review with the empirical results. Taking a meta-approach, conclusions are drawn and an answer to the research question is provided. Finally, in chapter 6, the conclusion will critically reflect on this study and its findings and recommendations for future research will be given.

2 Complex Decision Making Literature Review

This chapter will now focus on the two strategic decision making methods mentioned in the introduction: *Multi-Criteria Decision Analysis* and *Game Theory*. These two methods are the center of this thesis because of their possibility to complement each other. First the process to deal with a complex decision (from a multi-criteria perspective) problem is examined. Then multi-criteria decision analysis methods are explained and discussed on their capability to capture the entire process. Thirdly game theory is proposed as a method to enhance the decision making process that is currently captured by MCDA. At last the characteristics of the multi-objective game are explained and used to integrate both MCDA and game theory.

2.1 Methods for multi-criteria decision analysis

Multi-Criteria Decision Analysis (MCDA) focuses on decision problems that are too complex to be sufficiently described by one criterion (Banville et al., 1998). Problems that can be described by one criterion are not seen as a *decision* problem, but rather as a *measurement* problem (Zeleny, 2011). For example, consider your firm is looking for a new office. If price was the only criterion the problem would be solved by renting the office with the lowest monthly rent. However, there probably are multiple criteria that determine which office is the most suitable: location, surface, design, etc. Often these criteria are in conflict with each other: a better office location probably also increases the price. The result of this conflict is that the decision problem now also involves a trade-off: no solution to the problem is perfect (Zopounidis & Doumpos, 2002). In this thesis multi criteria decision analysis focuses on decision problems that are described by multiple *criteria* and involve *trade-offs* (Banville et al., 1998; Zeleny, 2011; Zopounidis & Doumpos, 2002).

Within the MCDA paradigm a decision problem is analysed adopting a certain structure (Bollinger & Pictet, 2003). This structure or process consists of several steps (Banville et al., 1998; Bollinger & Pictet, 2003; Goodwin & Wright, 2014; Henig & Buchanan, 1996; Zopounidis & Doumpos, 2002): (1) *problem formulation*, who are the decision makers and what goals do they pursue; (2) *alternative identification*, all the different courses of action are determined; (3) *criteria selection*, the criteria are the important aspects by which the alternatives are compared, for example cost and quality; (4) *identify attributes*, the identified criteria can be vague and therefore attributes are assigned in order to measure the criteria, for example cost can consist of the attributes purchase cost, maintenance cost and rent; (5) *evaluation of performances*, this step measures how well the alternatives score on each attribute, a value is assigned from the attributes to the alternatives; (6) *determining weights*, the weights are used to determine the relative importance of the attributes (how much do they contribute to the criterion?) as well as the criteria; (7) *aggregating performances*, using the weights and the performances on each attribute a score is calculated that

represents the overall performances of the alternatives; (8) *evaluation of alternatives*, at last the alternatives are compared (including sensitivity analysis), possibly leading to a conclusion about the best alternative.

Three comments must be made with regard to the eight steps presented above. First of all the steps should not be viewed as a linear process (Banville et al., 1998). Especially the first four phases might have an iterative nature. An additional alternative might be discovered while the criteria are identified. Of course this does not mean that the alternative should be excluded from the analysis. After the analysis it can also be concluded that not all the criteria are identified correctly or that measurement of the performances included mistakes. This should also lead to a repetition of the process until the decision makers are satisfied.

Second the MCDA process includes both objective and subjective aspects (Henig & Buchanan, 1996). Where the performances of the alternatives are measured as objectively as possible, the weights that are assigned to the criteria reflect the decision maker's preferences (Zopounidis & Doumpos, 2002) and are inherently subjective. The opinions of the decision maker might be subject to change after initial analysis, or they might simply disagree with his or her own stated preferences. The iterative nature of the decision process allows these subjective judgments to be revised.

The third comment is that the decision process described above is not intended to lead to a final decision (Goodwin & Wright, 2014). As the name suggests MCDA is used for analysis of a decision problem and the main goal of the process is a greater understanding of the problem. The iterative nature of the process always provides the decision maker with the opportunity to question the process in order to enhance his or her understanding. Of course the analysis should assist the decision maker towards his or her decision and to this end it is desirable that some of the alternatives can be selected as the most favourable (Goodwin & Wright, 2014). However, as Zeleny (2011) argues, since humans are responsible for the results of the decision they should be the ones making the decision and not the method that is involved in the process.

The steps defined in the process together with the comments make it possible to divide the decision making process in two phases, namely an *identification phase* and en *evaluation phase*. The multi criteria decision analysis process is presented by Figure 1 below. It consists of two phases and eight steps and takes into account the iterative nature of the process.

The remainder of this section investigates the use of MCDA in practice. Velasquez and Hester (2013) identified several methods within the MCDA field that scholars use in their research. Three of the most frequently used methods in the literature are: *Multi-Attribute Utility Theory*, the *Analytic Hierarchy Process* and *Fuzzy Theory*. Specific characteristics of the methods will be briefly explained, but the focus of each section is how the methods are used in order to assist in the understanding of the decision problem.

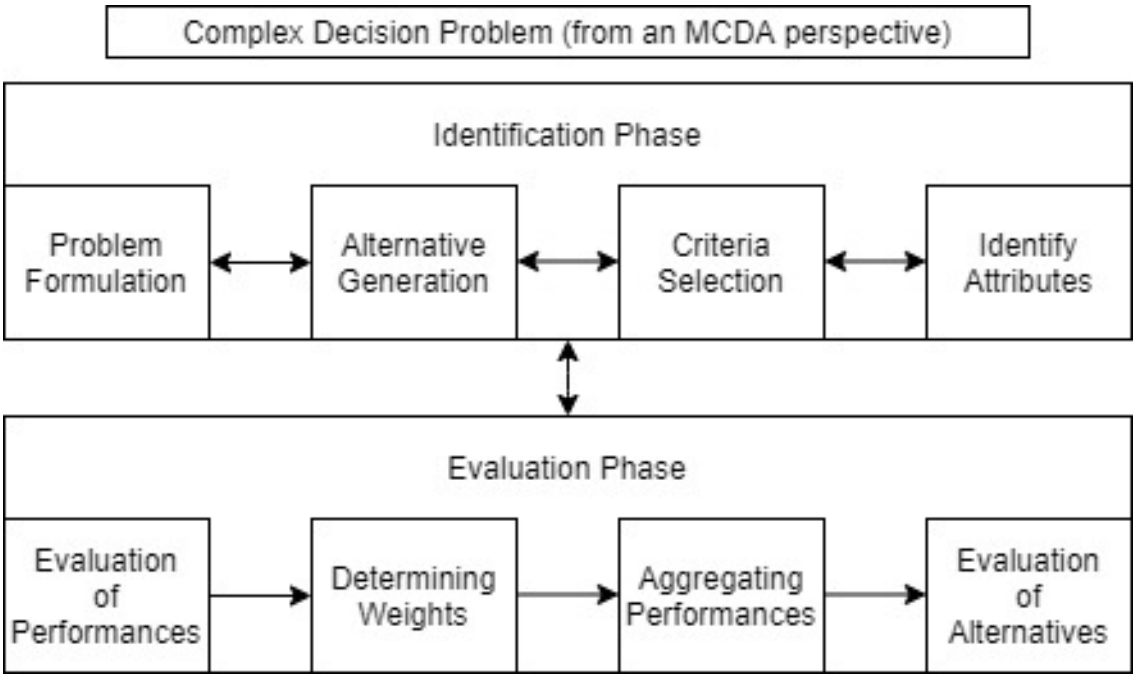

Figure 1: Multi Criteria Decision Analysis Process

2.1.1 Multi-Attribute Utility Theory

Multi-Attribute Utility Theory (MAUT) is an MCDA method that can be used to incorporate uncertainty into a decision problem (Canbolat, Chelst & Garg, 2005; Kailiponi, 2010). Next to the alternatives the most important criteria must be specified as well as the attributes that measure them. This can be done in a variety of ways, for example using a decision tree (Canbolat et al., 2005). MAUT makes use of utility functions for the valuation of the criteria. The relative importance of the criteria can be obtained with the use of *lotteries* (Kailiponi, 2010; Keeney (1977) or the *swing weight method* (Canbolat et al., 2005). For an explanation of these methods the reader is referred to Goodwin and Wright (2014). These utility functions assign a level of satisfaction (the utility) from the criteria to the alternatives. Monetary values are transformed into utilities too, allowing the decision maker to compare all criteria. Comparing the aggregate utilities of the alternatives will then reveal which alternative(s) are most preferred by the decision maker.

The MAUT process explicitly includes the identification of criteria and alternatives (Canbolat et al.,, 2005; Chen et al., 2010). As such the literature describes the objectives that constitute to the problem and the criteria that are used to measure them. However, this description does not explain how to analyse a problem situation, but rather the results of how the problem was defined in the study. Konidari and Mavrakis (2007) have studied extensive literature to identify climate mitigation criteria and mention their results, with little explanation. Kailiponi (2010) has interviewed up to eighty professional stakeholders to identify the most important criteria for evacuation problems. Yet

another study aimed to design a decision support system that could also be used by many different stakeholders (ranging from political institutions to households)(Loetsher & Keller (2002), yet these stakeholders were not included in the decision process when the alternatives were generated. From a practical perspective, it seems that the problem identification stage, along with criteria selection and alternative generation, is often performed by the researcher and then the problem is presented to the decision maker. The decision maker is then involved in order to obtain the utility functions that belong to the decision problem.

Velasquez and Hester (2013) argue that one of the main advantages of MAUT is its ability to incorporate preferences (through the ultility functions) of the decision maker in the decision. However, the authors note, these preferences need to be precisely formulated or the results will be biased. Personal preferences of the decision maker have a major role on the outcome of the decision problem (Keeney, 1977). If the preferences are described inadequately this will be reflected in the results, and therefore, in the decision. When it comes to measuring preferences, the literature uses formal procedures and explains its use and the outcomes in a transparent manner.

From a process perspective, a formal procedure (or procedures) seems to be missing in the early stages of the MAUT process. Especially, a procedure in which the actual decision maker is involved. Canbolat et al. (2010) formally identified the decision problem situation using a decision tree, however they do so in isolation of the decision maker. A point of attention that is not made in the MAUT literature is that the decision maker should agree with the criteria and alternatives that he or she is evaluating. If the decision maker is expected to express his or her preferences correctly, should he or she not also be expected to understand (and agree with) the decision problem that is presented to him or her?

2.1.2 The Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) as proposed by Saaty (1980) is often praised for its ability to deal with both quantitative and qualitative factors (Lee, Kim, Kim, & Oh, 2012; Okeola & Sule, 2011; Saaty, 2008). The AHP starts with structuring the problem with the development of a decision hierarchy (Leung, Muraoka, Nakamoto & Pooley, 1998). The hierarchy starts with the goal of the decision, followed by criteria and eventual sub criteria and ends with the alternatives (Okeola & Sule, 2011). Then pairwise comparisons are used in order to identify the weights of the criteria (Amiri, 2010; Konidari & Mavrakis, 2007; Wu, Chen, Chen & Zhuo, 2012). Performances of the alternatives are also determined by pairwise comparisons. As data is more qualitative, evaluations rely on the judgments of experts (Leung et al., 1998; Okeola & Sule, 2011). Because of the subjective nature of these judgments, pairwise comparisons are checked for consistency (the details of this procedure are beyond the scope of this thesis) (Konidari & Mavrakis, 2007; Lee et al., 2012; Leung et al., 1998). By aggregating the results of alternatives' performances and the criteria

weights the results of the decision analysis can be evaluated (Leung et al, 1998; Saaty, 2008).

Within the AHP the problem is structured with the use of a decision hierarchy, As such the process includes the identification of criteria and alternatives in a more structured manner then MAUT. This can be seen in the studies, as they represent the decision problem in more or less the same way (using a decision hierarchy). Lee et al. (2012), Leung et al. (1998) and Okeola and Sule (2011) used experts from various fields in order to construct a decision hierarchy. Amiri (2010) used the team of decision makers directly involved in the problem of selecting an oil field development project in order to structure the decision hierarchy. However, even though the experts are involved in the problem at an early stage, the researchers make only a limited attempt to explain how the information was obtained. For example, if a questionnaire was used for the identification of criteria, then the questions to extract these criteria are not presented. For a more formal approach of the decison making process this information could be useful for other researchers.

The AHP is (in theory) intended for the analysis of an entire problem: it starts with determining the goal of the project and ends with the evaluation of alternatives (Saaty, 2008). In practice the method is often used for partial analysis of the decision problem only. Amiri (2010), Konidari and Mavrakis (2007) and Wu et al. (2012) use the AHP for the identification phase and the determination of weights, but do not evaluate the alternatives through the pairwise comparisons of the AHP. Instead fuzzy methods (Amiri, 2010; Wu et al., 2012) are used or the decision making process is combined with the application of MAUT (Konidari & Mavrakis, 2007). A difference that is observed with the studies that do use the AHP to evaluate performances (see for example Leung et al. 1998) is the size of the decision hierarchy. As is explained by Konidari and Mavrakis (2007) the number of pairwise comparisons should be limited.

Finally, the studies that use the AHP for decision analysis often involve multiple stakeholder groups (Okeola et al., 2012; Wu et al., 2012; Leung et al., 1998). It is not the intention of this thesis to argue that this is due to the method. However, these studies use aggregated results of the pairwise comparisons for evaluation purposes. As a result, eventual differences between the stakeholder groups are foregone. This thesis argues that by putting a greater emphasis on the identification of stakeholder groups and determining the differences between them the decision making process can be enhanced (see section 2.2 for how to include different stakeholder groups).

2.1.3 Fuzzy Set Theory

Fuzzy set theory was first proposed by Zadeh (1965) and is a multi criteria decision analysis method that is intended to reduce the data intensiveness of the process (Machacha, & Bhattacharya, 2000; Velasquez & Hester, 2013). Fuzzy logic allows for imprecise information because it enables a computers emulate human reasoning, thereby also compensating for subjective judgement (Machacha, & Bhattacharya, 2000). This is done by translating ambiguous or inadequate responses

into a set that consists of multiple fuzzy values (Chou, Chang & Shen, 2007). This translation can be done in different ways and an adequate procedure must be chosen by the researcher. The input for the fuzzy values are the judgements given by experts. Unlike the AHP fuzzy set theory evaluates the alternatives independently, such that the result is not relative but rather absolute (Chou, Chang & Shen, 2007; Haled & Hamidi, 2011). After the linguistic scores are aggregated they are normalized and the results are presented to the decision maker.

Fuzzy systems are allowed to be further defined when more precise information becomes available. Once implemented fuzzy systems have proven to be of real value to decision making (Velasquez & Hester, 2013). However, the implementation can be a costly and time consuming process. When the method requires numerous simulations before implementation, presenting a clear structure of the process becomes infeasible (should we take six months, one year or two years before the system is designed well enough?). This is in contrast with the overall structure of the process, which explicitly involves the identification of alternatives and criteria, evaluating the alternatives and an aggregation procedure (Chou, Chang & Shen, 2007). The overall structure is much alike the structure that has been presented in the MAUT and AHP sections. Because the cost of a fuzzy system (in terms of time and resources) is hard to define the value of the method for decision problems that occur infrequently is not well defined.

Next to the unclear value of the process, the mathematical foundations behind fuzzy set theory are hard to comprehend and therefore are not explained in great detail. Chou, Chang and Shen (2007) show for example that the linguistic response 'very poor' should be translated to the fuzzy set $\{0, 0, 0, 3\}$. What the precise meaning of these numbers is, or why exactly these numbers were chosen is often not explained. From a decision maker's perspective it seems that once you have given your responses, the results will be automatically presented to you. The literature supports this idea by stating that fuzzy set theory might be difficult to comprehend by decision makers (Haled & Hamidi, 2011; Iç, 2011). As a result it is argued in this thesis that with regard to decision analysis (and understanding the decision problem) fuzzy set theory is less effective compared to MAUT and AHP.

2.1.4 Other MCDA methods

Velasquez and Hester (2013) Identified several other MCDA methods. Case Based Reasoning (CBCR) and Data Envelopment Analysis (DEA) are among the frequently used methods. However they are not discussed in great detail in this thesis. CBR aims to propose a solution to a decision problem by identifying similar cases (and the actions taken in those situations) (Daengdej, Lukose & Murison, 1999). Because every decision problem is in some way unique a lot of cases are required before CBR can be applied. This is why the method is most often used in the fields of for example insurance (Daengdej, Lukose & Murison, 1999) or for predicting financial results of

companies (Li & Sun, 2008). Next to amount of required data the method requires a lot of statistical analysis, what leads to the results being less intuitive compared to MAUT and the AHP.

DEA is a method that is used to compare relative efficiencies among projects, organizations or departments (Velasquez & Hester, 2013). The main advantage of the method is that efficiencies can be quantified and is therefore easy to analyze. The most efficient alternative has an efficiency of 1.0, while all other alternatives are rated between 0 and 1.0. One of the main disadvantages is that DEA requires precise inputs (Velasquez & Hester, 2013). Often, when a decision has to be made about the future these precise inputs may not be available. As a result, DEA is often used to evaluate passed performances, for example to compare the efficiencies of universities (Kuah & Wong, 2010) or those of R&D departments (Chen, Larbani & Chang, 2009). Another disadvantage is that DEA involves linear programming, which also makes the results of the analysis less intuitive.

2.1.5 MCDA, analysing the outcome more than the problem

This section has reviewed the multi-criteria decision analysis literature. First a complex decision problem was defined from a multi-criteria perspective as a problem that contains multiple criteria and involves trade-offs. In order to analyse such a problem a framework was proposed, indicating that an *identification phase* and an *evaluation phase* can be distinguished while analysing a complex decision problem. Next it was studied how this process came forward in studies using an MCDA method in order to answer the first sub question: *What are the current issues regarding complex decision making, especially those that involve multiple objectives and are related to peoples' preferences?*.

Multi-Attribute Utility Theory, the Analytic Hierarchy Process and Fuzzy Set Theory are among the most frequently used methods in the MCDA domain (Velasquez and Hester, 2013). Fuzzy set theory is the least intuitive method amongst these and understanding the outcome of the analysis is hard for a decision maker without a strong mathematical understanding of the method. Other methods, case based reasoning and data envelopment analysis, also use some form of mathematical analysis that is hard to understand for a decision maker. If the goal of decision analysis is to get a better understanding of the problem, MAUT and AHP are the most frequently used methods at hand.

Both MAUT and the AHP have performance evaluation procedures that are relatively easy to understand and also the aggregation procedures are both understandable and well explained. However, when it comes to the *identification phase* these methods use a wide variety of methods in order to describe the decision problem. The decision makers are often excluded in this stage and are only involved when their 'expert judgement' is required. A more formal approach to this phase of the process is currently missing. By involving the decision maker early in the decision process, the preferences (MAUT) or subjective judgement (AHP) can also be identified in an early

stage. This could in turn stimulate the iterative process, by critically reflecting on the influence of these preferences (or the absence of this influence). The remainder of this chapter aims to provide an answer to both of these remarks by proposing another decision making method for the identification phase: *game theory*.

2.2 Game Theory: Describing and analysing complex decision processes

Game theory as a field has its own terminology, and it is important to be specific about the characteristics of a game and their meanings. As such the most important concepts to describe a game are given first, before the mathematical definition of a game. Characterization of the game is done following the game theoretical definitions in Carmichael (2005).

"Game theory is a technique used to analyse situations where for two or more individuals (or institutions) the outcome of an action by one of them depends not only on the action taken by that individual but also on the actions taken by the other (or others)." (Carmichael, 2005, p. 3). This definition immediately shows the importance of mutual dependence that characterizes game theory. The situation under consideration is the *game* and those who are involved are called the *players*. The players both have a number of different actions to consider in the game: their *strategies*. When all the players in the game have decided to choose a certain strategy, the *outcome* of the game can be determined. The outcome of a game is any combination where all the players have chosen a strategy. Throughout this thesis it is said that the players 'play' a game when they determine their strategies.

The rewards that players receive as a result of a chosen strategy is referred to as the *pay-off* or *utility* for that player. The term pay-off can be used when this outcome is quantifiable, such as a monetary reward, whereas utility refers to the level of satisfaction of a player receives (quantitative and qualitative). Throughout this study pay-off will be the term that is more dominantly used. It is also assumed that players are *rational*. Rationality means that the players act in their best self-interest: they will pursue a maximal pay-off while they determine their strategies.

The order in which players choose their strategies in the game is also used to characterize a game. In *simultaneous-move* games the players choose their strategies at the same time, with the result that actions are hidden from other players. Games in which players choose in some predetermined order are called *sequential move* games. The multi-objective game is a simultaneous-move game: the strategies of the other players remain hidden during the game.

Games can also be classified as *cooperative* or *non-cooperative*. Games are cooperative if communication is allowed between the players before they choose their strategies. This means that they can agree to choose a mutually beneficial strategy. In a non-cooperative game such communication is not allowed. The multi-objective game is a non-cooperative game, which means that each player

chooses a (set of) strategy (strategies) in isolation.

Finally, games are described as games of *perfect* or *asymmetric information*. In a game of perfect information all players know their opponents and their pay-offs. In such a game the outcome(s) can easily be predicted. Asymmetric information means that different players (at least one) have different information: *private* information exists in the game. In the multi-objective game, players and their strategies are common knowledge, while the pay-offs and the objectives of the players are private. The multi-objective came is thus characterized as a game of asymmetric information.

2.3 Game Theory Mathematical Defenitions

2.3.1 Description of a game

Game theory is a mathematical tool that can be used to model and analyse situations that involve two or more decision makers or agents (Bacci et al., 2015; Coimbra & Correia, 2017). The models reveal interdependencies between the players. The most common way to represent games is the strategic form (Coimbra & Correia, 2017), especially when the game involves many (more than two) players and multiple strategies. Even though this thesis considers only games that include two players, the strategic form is still considered the most comfortable way to represent them. Following Bacci, Sanguinetti and Luise (2015) a game consists of three ingredients:

- A set of i players, they represent the main actors in the problem. Often their interests are conflicted. The set of players is denoted as $\mathcal{P}$ (Coimbra & Correia, 2017).

- The set of all the strategy profiles (outcomes) in the game. Each strategy profile contains exactly one chosen strategy for each player. The set of all strategy profiles is denoted as $\mathcal{S}$ (Coimbra & Correia, 2017). With $\mathcal{S}$ representing the set of all strategy profiles, $\mathcal{S}_i$ is the set containing all strategies available to player i, where $i \in \mathcal{P}$. The individual strategy profile s_i of player i is denoted as (s_i, s_{-i}), which represents one specific strategy of player i combined with any strategy of the other players $(-i)$. By definition, all strategy profiles of all players can be found in $\mathcal{S}$.

- A set of utility functions, one for each player. The result of the utility function (also referred to as pay-off) represents a player's individual outcome and takes as input all the other players' actions. The set of utility functions is represented by $\mathcal{U}$ (Coimbra & Correia, 2017).

As a result any game $\mathcal{G}$ can be represented as the triplet: $\mathcal{G} = \{\mathcal{P}, \mathcal{S}, \mathcal{U}\}$.

For those who are unfamiliar with the terms, they will be illustrated by a simple example. A well known game is the Prisoners' dilemma. In the Prisoners' dilemma, two people are facing jail time. They are being questioned about a crime (which they in fact committed) and can choose to

cooperate (i.e. confess) or defect (i.e. deny). The game is *non-cooperative*, and played *simultaneously*. Even though both players would benefit from cooperation, it is tempting for both players to defect (Carmichael, 2005; Coimbra & Correia, 2017). A visual representation of the game, numbers are taken from Carmichael (2005), is represented below:

		Prisoner 2	
		Cooperate	Defect
Prisoner 1	Cooperate	(-1,-1)	(-10,0)
	Defect	(0,-10)	(-5,-5)

- $\mathcal{P}$ consists of two players, P_1 and P_2:

$$\mathcal{P} = \{P_1, P_2\}.$$

- $\mathcal{S}$ consists of all the combinations that can be made when combining $S_1 = \{\text{cooperate, defect}\}$ and $S_2 = \{\text{cooperate, defect}\}$:

$$\mathcal{S} = \{\{\text{cooperate, cooperate}\}, \{\text{cooperate, defect}\}, \{\text{defect, cooperate}\}, \{\text{defect, defect}\}\}.$$

- The set of utility functions in this game is $\mathcal{U} = \{u_{P_1}, u_{P_2}\}$. Since both players have the same individual utility function, only one will be presented here:

$$\begin{aligned} u_{P_1}(\text{cooperate, cooperate}) &= -1. \\ u_{P_1}(\text{defect, cooperate}) &= 0. \\ u_{P_1}(\text{cooperate, defect}) &= -10. \\ u_{P_1}(\text{defect, defect}) &= -5. \end{aligned}$$

2.3.2 Domination

Dominant strategies are those strategies that always are a best response to the strategies of the other player (Carmichael, 2005). If a player has a dominant strategy in the game, this strategy is likely to be part of the outcome of the game. Following Coimbra and Correia (2017) a dominant strategy s_i exists if it yields a higher pay-off than every other strategy, $s_i^{'}$, irrespective of the strategies of the other player:

$$\text{Dominant Strategy } s_i: \quad u_i(s_i, s_{-i}) > u_i(s_i^{'}, s_{-i}). \tag{1}$$

In the case of the Prisoners' dilemma, *defect* is the dominant strategy for player 1. In this game this can be easily verified: if you compare $s_{P_1}(\text{defect, cooperate})$ with $s_{P_1}^{'}(\text{cooperate, cooperate})$ then it follows that:

$$u_{P_1}(s_{P_1}) = 0 > -1 = u_{P_1}(s'_{P_1}).$$

This means that *defect* is a best response to the *cooperate* strategy of player 2. And similarly, when you compare s_{P_1}(defect, defect) with s'_{P_1}(cooperate, defect) it follows that:

$$u_{P_1}(s_{P_1}) = -5 > -10 = u_{P_1}(s'_{P_1}).$$

Because both players have exactly the same pay-off function, it follows that *defect* also is the dominant strategy for player 2. This results in a dominant-strategy equilibrium: both players' dominant strategy together form a combination that are best responses to all the strategies of the other player (Carmichael, 2005).

This example, with two players that both have two strategies is easily analysed and finding the outcome of the game can be done by hand. However, the multi-objective game considers more alternative actions, which makes comparing all the different strategies with their pay-offs much less feasible. Next to that, not all games have a dominant-strategy equilibrium, or even one dominant strategy, but can still be 'solved' using game theory.

2.3.3 Nash Equilibria

Consider the game represented below. This game is presented for illustration purposes only and will be used to explain the concepts in the following two sections.

		Player2		
		A2	B2	C2
Player1	A1	(3,5)	(2,7)	(3,6)
	B1	(2,1)	(3,7)	(2,5)
	C1	(3,6)	(1,5)	(4,7)

This is an example of a game that has no dominant strategy, which means that there is no strategy that will always be played by one of the players. This game can still be solved by finding the Nash equilibrium (or equilibria) in the game. A Nash equilibrium exists in a game when a combination of strategies of the players consists of strategies that are best responses to each other (Carmichael, 2005). In the table above, all the players' best responses have been underlined. If Player2 chooses strategy A2, then Player1 should choose strategy A1 or C1, because 3 is a better pay-off for Player1 than 2. A Nash equilibrium then occurs if both numbers in a single cell are underlined. As can be seen above, this game has two Nash equilibria, namely (B1,B2) and (C1,C2). More formally, following Coimbra and Correia (2017) and Bacci et al. (2015), a Nash equilibrium s^{NE} exists if for all ($\forall$) players in the game, their individual strategy yields a higher (or equal) payoff than all of their ($\forall$) other strategies, given that the other players do not change their strategies:

$$\text{Nash Equilibrium } s^{NE}: \quad \forall i \in \mathcal{P}, \quad \forall s_i \in \mathcal{S}, \quad u_i(s_i^{NE}, s_{-i}^{NE}) \geq u_i(s_i, s_{-i}^{NE}). \tag{2}$$

Even though two Nash equilibria exist, only one of them is likely to be the outcome of this game.

2.3.4 Pareto Optimality

The most likely outcome of the game represented in section 2.2.3 is (C1,C2). This is because in the other Nash equilibria Player1 has an incentive to change its strategy. Player1 receives a higher pay-off when the Nash equilibrium (C1,C2) is played then the other the equilibrium (B1,B2). Only the equilibrium (C1,C2) is called Pareto efficient. An outcome of a game is called Pareto efficient if it is impossible to improve the pay-off of one player without lowering the pay-off of another player (Carmichael, 2005). If an outcome in a game is Pareto efficient, neither player has the incentive to deviate from the chosen strategy. As for the game discussed in section 2.2.3, the outcome (C1,C2) is said to Pareto dominate outcome (B1,B2), which is said to be Pareto inefficient (Carmichael, 2005). In formal notation, again following Coimbra and Correia (2017), a strategy profile $s \in \mathcal{S}$ is Pareto superior to another strategy $s' \in \mathcal{S}$ if all the players in the game get a higher or equal pay-off in s compared to s', where at least one pay-off of a player should be higher:

$$\text{Pareto Superior:} \quad \forall i \in \mathcal{P}, \quad u_i(s_i, s_{-i}) \geq u_i(s_i^{'}, s_{-i}^{'}). \tag{3}$$

From this it is concluded that an outcome s in a game is Pareto efficient if there is no other outcome $s^{'}$ in the game that is Pareto superior to s (Coimbra & Correia, 2017).

At this point there are two important points to mention regarding optimal outcomes in a game: first it is possible to have more than one (up to infinitely many) Pareto optimal solution in a game, which means that Pareto efficiency does not ensure a perfect solution. Second, Nash equilibira or equilibria in dominant strategies are not necessarily Pareto efficient. On the contrary: in the Prisoner's dilemma the dominant strategy equilibrium is the least preferred outcome of the game by both players! Achieving a Pareto efficient outcome might thus require cooperation between the players in the game (Coimbra & Correia, 2017; Madani, 2010).

2.4 The Multi-Objective Game

The previous section has focused on the mathematical description of game theory: description, domination, Nash equilibria and Pareto optimality. Explaining the first three aspects was necessary in order to make the concept of Pareto optimality understandable. Pareto optimality is an essential aspect of the multi-objective game, as the 'solution' of the game is the identification of all *Pareto efficient* strategies. This section will describe and define the multi-objective game and illustrate the theory by means of an example.

2.4.1 Description

The multi-objective game in this paper is modeled and analysed as a two player game, following research that has already been done (Lee, 2012; Eisenstadt & Moshaiov, 2018). Modeling the game requires a deep understanding of the decision problem as it requires you to formulate multiple objectives, together with your different courses of action. In modeling the problem as a game, getting the correct structure is essential in order to do a meaningful analysis (Madani, 2010). Next to that the other players' courses of action need to be identified as they affect your pay-offs. The objectives of the other player are hidden, which makes this a game of incomplete information. Speculation about the pay-offs is not part of the game. At last your individual outcomes for the conflicting objectives are determined, taking into account both your own and the other player's strategies.

Formally, the description of the multi-objective game changes slightly. The players ($\mathcal{P}$) and strategy profiles ($\mathcal{S}$) are presented in exactly the same way. The pay-offs should be represented differently. First of all, pay-offs of only one player are considered. Next to that, a pay-off is not represented by one number, but by a set of n numbers, one for each objective. These numbers are referred to as (o_1, o_2, ..., o_n). So, assuming that player $\mathcal{P}_1$ has x strategies, this means that:

$$\mathcal{U} = \{u_{P_1}\}$$

and subsequently,

$$\begin{aligned} u_{P_1}(s_1, s_{-i}) &= \{o_1, o_2, ..., o_n\}, \\ u_{P_1}(s_2, s_{-i}) &= \{o_1, o_2, ..., o_n\}, ..., \\ u_{P_1}(s_x, s_{-i}) &= \{o_1, o_2, ..., o_n\}. \end{aligned}$$

The game is 'solved' by finding a set of *Pareto efficient* strategies with regard to your own conflicting objectives. A strategy profile s is Pareto superior to another strategy profile $s^{'}$ if all the pay-offs in strategy profile s are higher than or equal to those in $s^{'}$, where at least one pay-off should be higher.

$$\text{Pareto Superior:} \quad \forall o_n \in u_{P_1}, \quad (o_n \in s) \geq (o_n \in s^{'})$$

Then it follows that a strategy s is Pareto efficient when no strategies $s^{'}$ exist that are Pareto superior to s. The game is 'solved' when all Pareto efficient strategies are successfully identified. These strategies may then serve as input for further decision analysis.

2.4.2 Illustrative Example

The multi-objective game in this study is a two player, *simultaneous move, non-cooperative* game with *asymmetric information*. This means that the game will take into account the pay-offs of only one player, because the other player's pay-offs are unknown. The strategies of the other player are common knowledge. Also, this game is played in isolation of the other player, but at the same time. One study that involved multi-objective game theory to analyse a decision problem is that of Lee (2012). It involved a decision problem regarding reservoir watershed management. However, the study aimed to optimize the decision that was made instead of analyze the problem, which would lead to multiple possible decision and the interaction between them. Basically this means that the mathematical methods that are used are too complex to comprehend. As such, the case is simplified here in order to model it as a game.

The reservoir watershed problem involves the destination of a water reservoir. This problem involves two opposing players, namely a player that wants to preserve as much of natural environment of the area as possible (EnvPlayer) and a player that wants to maximise its economic utility (EcPlayer). Both players can choose between three different strategies: Economic, Neutral and Environmental. The game now focuses on the situation for EcPlayer.

Even though EcPlayer is unaware of the exact pay-offs (or in this case: utilities) of EnvPlayer, it is common knowledge that an economic strategy of EcPlayer is less effective if EnvPlayer decides to choose the most environmental strategy. Besides the strategy chosen by EcPlayer, the player faces multiple objectives within each strategy. Economic gains can be derived from four different sources, namely: building a residential area, building a recreational area, fruit cultivation and tea cultivation. The reservoir area is too large to be exploited by one of the sources, such that EcPlayer has to make a trade-off between all the sources within each chosen strategy. For each of the different outcomes in the game, EcPlayer has identified its ideal combination of economic sources, and their pay-offs. In summary, their exist nine combinations of strategies and they all yield four pay-offs, relating to the four sources (residential area, recreational area, fruit cultivation and tea cultivation).

		EnvPlayer		
		Environmental	Neutral	Economic
EcPlayer	Economic	(7,4,3,2)	(8,5,4,3)	(10,5,3,2)
	Neutral	(5,4,6,5)	(6,6,5,4)	(5,4,4,3)
	Environmental	(2,6,5,6)	(3,4,5,4)	(3,5,5,6)

The tables indicate that the pay-off of EcPlayer is the set of pay-offs $\{7, 4, 3, 2\}$ when the strategy (Economic, Environment) is the outcome of the game [1]. Now the outcomes of the game can be de-

[1]The numbers in these cells are the same as in the experiment that is part of this thesis. Because there was no prior research found regarding the multi-objective game in a game theoretical setting these numbers are fictional. The numbers are used to explain the theoretical foundation of the multi-objective game.

termined. According to section 2.4.1 the outcomes are represented by the Pareto efficient strategies in the game. This means that we need to identify all strategies s for which the statement that there is no other strategy s' Pareto superior to s holds. The Pareto efficient strategies (and their pay-offs) in this example are:

(Economic, Neutral) : (8,5,4,3), (Economic, Economic) : (10,5,3,2),
(Neutral, Environment) : (5,4,6,5), (Neutral, Neutral) : (6,6,5,4),
(Environment, Environment) : (2,6,5,6), (Environment, Economic) : (3,5,5,6).

A step by step description of how Pareto efficient strategies are identified can be found in Appendix 1.

2.5 MCDA and Game Theory as complementary, rather than opposing, methods

Sections 2.3 through 2.4 examined the characteristics of game theory. First the language specific to game theory was explained, before the mathematical foundations behind the theory were examined. The mathematical definitions were required because the goal was to develop a new type of game and game theory is and remains a mathematical tool for analysis (Bacci et al., 2015; Coimbra & Correia, 2017). Only minor modifications had to be made in order to develop the multi-objective game: instead of a utility function that yielded one pay-off for each strategy now a strategy yielded a set of pay-offs. Applying the traditional concept of Pareto efficiency to these sets could then be used to determine the outcomes of a game.

In order to show that these mathematical concepts could also be applied a more managerial, intuitive, context an example has been taken from the literature that uses multi-objective optimization. The most important aspects of the decision problem had been described, namely the players involved in the problem, their possible strategies, and the most important options. By keeping the strategies limited to three and the options to four the problem could still be represented in strategic form, which makes the structure of the problem easily understood. The most important aspect of the options remained in tact: more economic benefits also led to more environmental pollution. Once the problem was presented in the *strategic form*, the Pareto efficient strategies could easily be determined. In summary, minor adjustments to existing game theory and an attempt to simplify what has previously been presented as extremely complex made it possible to consider multiple objectives within game theory in a more simple manner than was possible in standard game theory as presented in this thesis. Even though this might seem like only a small contribution, it has not previously been proposed and it makes it possible for many more decision problems to be analysed using game theory: those involving multiple criteria. From a game theoretical point of view the first

part of the second sub question of this thesis, *"How can the multi-objective game be represented in managerial terms, such that it can be used for decision analysis?"*, has been answered. The second part of this question, how to include the multi-objective game in the decision analysis (process) will be answered in the remainder of this section.

Many of the cases that had been studied in section 2.2, especially those focusing on MAUT or the AHP, often considered three or four alternatives (strategies), and up to a maximum of five major criteria. As such these problems could be represented in the *strategic form* that is known from game theory. This is possible because of the development of the multi-objective game in the previous section. It was concluded in section 2.1.5 that both MAUT and the AHP were the most suitable MCDA methods if the aim was to truly understand the decision at hand. The application of these methods did not involve a clear, transparent way of presenting the problem and often focused on the interpretation of the results of the analysis. This thesis proposes to enhance the entire complex decision making process as depicted in section 2.1 by including game theory in the *identification phase*. To this end modifications have been made to Figure 1, which resulted in the following Figure 2:

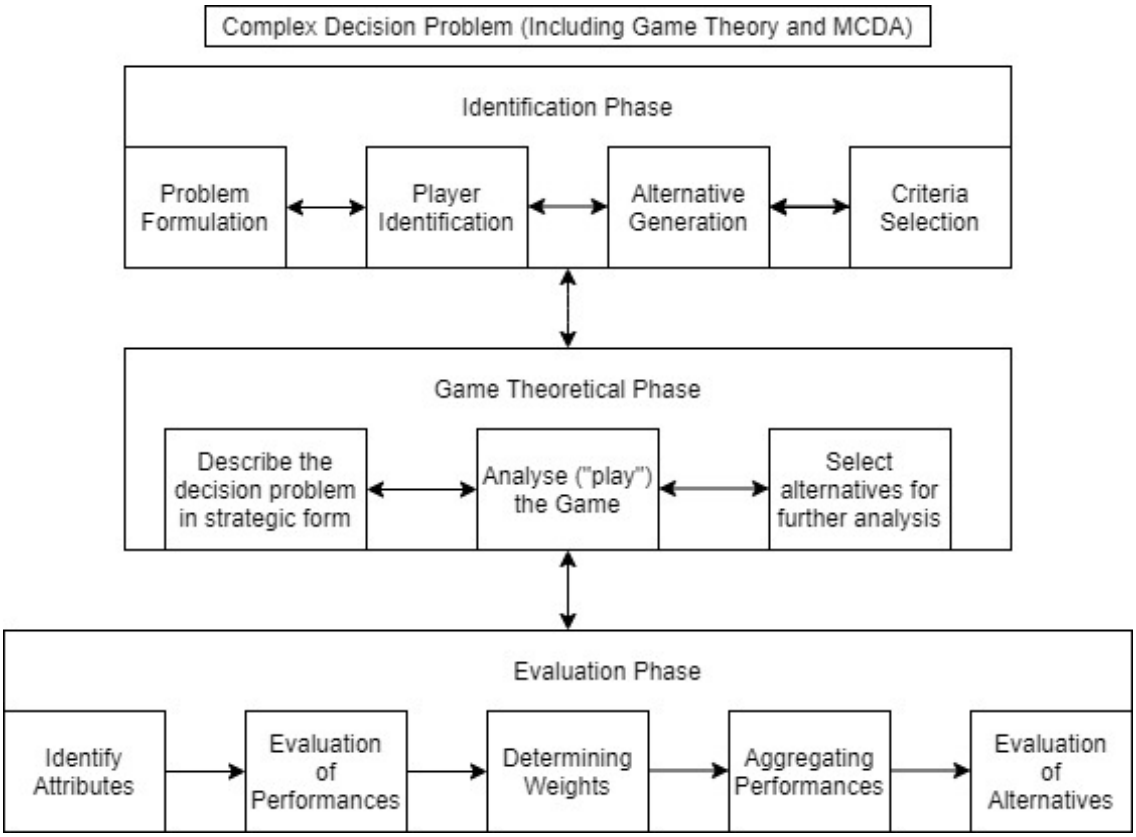

Figure 2: Complex Decision Problem including Game theory

The most remarkable change in this figure is the addition of a third phase between what were

previously considered as the only two phases in the process: the "Game Theoretical Phase." During this phase, the decision maker(s) are presented with an additional opportunity to analyse the decision problem. An important aspect to include in this phase is the involvement of the decision maker(s). It is not required from the decision maker(s) to describe the decision problem in game theoretical strategic form. However, before they analyse the decision problem, the decision maker(s) should accept the description of the problem. This is highlighted by the fact that the stages *Describe the decision problem in strategic form* and *Analyse ("play") the game* are iterative. If the decision maker does not agree with the problem that he or she is presented, the decision problem should be presented differently before any analysis is done. In order to achieve this 'approval' it would be wise for anyone who guides the decision process to include the decision maker(s) in the *identification phase*.

Two other changes also deserve additional attention when you compare Figure 1 (section 2.1) with Figure 2 in this section. First of all it is explicitly mentioned that the 'players' in the decision problem are identified. This is an essential part of game theory and also in MCDA many problems are situated in a context of multiple organizations or multiple departments in an organization, but this context is often neglected. So even if this addition is necessary for game theoretical purposes taking into account other players when you evaluate performances might also increase the analysis of traditional MCDA.

The second change is the shift of *identify attributes* from the *identification phase* to the *evaluation phase*. Even though this identification is of a more exploratory nature, it is not necessary to identify attributes that measure the criteria in great detail before the game theoretical analysis. The reason for this is that the identification of alternatives (strategies) and criteria (in the form of for example options) is sufficient to present the decision problem in *strategic form*. Also identifying attributes would focus on details of the decision problem that are not captured in the subsequent analysis. Next to that this thesis argues that after the *Game Theoretical Phase* the decision maker(s) will have a better understanding of the decision problem, especially the problem that is analysed and the context in which the decision problem takes place. This could lead to a better identification of the attributes in order to measure performances.

2.6 Concluding Remarks

This chapter has focused on several aspects. First a multi-criteria decision analysis process was structured in order to assess the capability of MCDA methods to capture the entire process. It was found that MAUT and the AHP were the two methods that contributed most to actually understanding the decision problem at hand. The methods were, however, better at making the outcomes of the process understandable than the process that led to these outcomes. Besides that

the methods are often criticised because the analysis is influenced by the personal preferences of the decision maker(s). Game theory was proposed as a more rational approach to complement the decision making process. In order to make managerial game theory applicable for multi-criteria decision analyses the field had to be expanded by developing a new type of game: the Multi-Objective game. This new type of game has been illustrated with an example from the literature, where the multi-objective game was used in order to solve an optimization problem. A proposition has been made as for how to include the multi-objective game into the complex decision analysis process.

Besides the theoretical contributions presented in this chapter, this thesis will also aim to provide empirical data about peoples behaviour when they play the multi-objective game. Chapter three will focus on the methodology of this thesis, among others the considerations with regard to the experiment and the design in an online format. Subsequently chapters 4 and 5 will present the results of the experiment, first in a more descriptive manner after which implications will be made with regard to the theory presented in this chapter.

3 Research Design & Methods

The design of this thesis can be characterised as an exploratory sequential mixed methods design (Cameron, 2009; Cresswell & Cresswell, 2005), consisting of three different stages. For a discussion about the use of a mixed methods study design the reader is referred to Cresswell and Cresswell (2005). This thesis has adopted a mixed methods design from a pragmatic point of view: some research questions could better be answered using qualitative methods, while others were better answered using quantitative methods (Cameron, 2009). As such, the first phase of this thesis has been completed by conducting a qualitative literature review, the second phase by conducting a quantitative online experiment and the in the third phase a meta-approach has been adopted in order to integrate the first two phases.

The first phase consisted of establishing a theoretical link between the multi-objective game and complex decision making, referred to as 'theoretical contribution', and this has been done in chapter 2. The output of this chapter served as input for the second phase of the thesis[2] and led to implications for the multi-objective game, when it is incorporated in the decision analyses process. After completion of this phase, the sub questions one and two had been answered. In the 'empirical observation' phase the multi-objective game has been empirically tested by means of an online experiment. This phase involved the design (using the results of the theoretical contribution), conduction and analysis of the experiment. After this phase was completed, sub questions three through six had been answered. The 'practical implications' phase integrated the results of the first two phases. Taking a meta-approach the research question of this thesis, *"To which extent can the multi-objective game be used to characterize decision making processes involving multiple objectives and multiple players?,"* had been answered.

This chapter of the thesis considers each of these stages individually and outlines the methodological considerations behind the design, the specific methods that have been used within the different phases to gather the data as well as the validation process of each phase. The chapter concludes with a section that discusses ethical considerations that involve this thesis.

3.1 Theoretical Contribution

3.1.1 Methodology

The use of existing knowledge to relate your own academic work in the broader field of academic research is the building block of all academic research (Snyder, 2019). This thesis aimed to integrate literature from the different fields of game theory, complex decision making and the

[2]Completing the theoretical contribution is part of the final design of the thesis. As a result, what is presented in chapter 2 as part of the research proposal is an overview of the concepts involved, though not as exhaustive as can be expected in the final thesis.

specific knowledge that was available regarding the multi-objective game. Because these three areas all take a different academic perspective (management, economics and science, resp.) this review can be classified as a narrative or integrative literature review (Baumeister & Leary, 1997; Snyder, 2019). This type of research does not have as aim to lead to new conclusions, but bring together what is known about a certain topic. Because of little theoretical contributions these types of studies are published only with reluctance (Baumeister & Leary, 1997). However, this thesis merely started with a review of current literature and does not aim to contribute to theory solely through the use of a literature review. Integrative literature reviews are also said to be useful while addressing new topics and are more common in business related literature (Snyder, 2019). As such, the literature review in this study aimed to provide 'new ways of thinking' (Torraco, 2005) about the multi-objective game. At the same time, a comprehensive overview about MCDA and game theory has been presented.

3.1.2 Methods

The literature review of this study started by examining literature in which the 'multi-objective game' was specifically mentioned in the title or subject terms, combined with 'game theory' in the text. As these search terms yielded more than 20.000 results in RuQuest relevant articles had to be selected (Snyder, 2019). First the year of publication had been set between 2010 and 2020 to ensure articles were not outdated. This still yielded more than 15.000 results, which strengthened the belief that this was a recent topic. In order to seriously narrow down results, the same search terms were entered into Business Source Complete and yielded 15 results. As this was a manageable amount, the next step was to start reading abstracts and the introductions of the articles. This led to the conclusion that the concept of game theory was barely explained in those articles. Snowballing was used to gain a deeper insight into the way these articles used game theory and led to a comprehensive overview of the game theoretical basic concepts.

In order to keep the more (mathematically oriented) economic field of game theory aligned with the field of management *A Guide to Game Theory* written by Carmichael (2005) has been used to explain concepts. This book is chosen for several reasons: it discussed all the game theory concepts that are mentioned in the theory section; it is used as teaching material for Strategic Management students at the Radboud University such that it represents how these game theoretical concepts are understood by the world's future managers; the book had the highest degree of accessibility for the researcher. By presenting the concepts in the order as has been done in chapter 2 of this thesis the multi-objective game has been presented as an extension of current game theoretical literature that allows for multiple objectives to be analysed in a single game. The multi-objective game provided the basis for the development of the experiment that was central to the second phase.

Finally, the literature review aimed at establishing a conceptual link between the multi-objective

game and complex decision making. To this end, literature has been reviewed regarding traditional multi criteria decision analysis. A clear overview presented by Velasquez and Hester (2013) has been found, and again with the use of snowballing additional literature was found that focused on strengths and limitations of the different methods. Especially, the role of preferences in the decision process has been brought forward. The role of preferences served as the second type of input for the development of the experiment that was central to the second phase.

3.1.3 Data Validation

The validation of a literature review depends mainly on the way in which data has been gathered. *"Steps taken to verify the validity or authenticity of key ideas and themes that emerged from the analysis should be described..."* (Torraco, 2005, p. 361). The importance of transparency is emphasized by Snyder (2019). By describing the search terms and article selection the researcher aimed to enhance the possibility to replicate the process. This is also the place to notice one last time that the topic *game theory* has been reviewed from a mathematical, economical and managerial point of view, the aim of which was to present a thorough, though understandable, overview of the topic.

3.2 Empirical Observation

3.2.1 Methodology

This thesis aimed to argue that the multi-objective game could have additional value while making complex decisions. In order to substantiate (or reject) this argument empirical data has also been gathered. Even though widely criticised in the early years of game theory, it has currently been acknowledged that experiments can provide empirical information for game theory, as it compares theory with the actual behaviour of people (Camerer, 2010; Crawford, 2002; Gächter, 2004; Samuelson, 2005). As such, empirical data in this thesis has been gathered by the use of an experiment. The development of this *new experiment* focusing on the multi-objective game was the result of the qualitative data gathered in the first research phase of this thesis (Cresswell & Cresswell, 2005). Croson (2002) identified three issues that have to be considered by the researcher before the experiment is designed.

First, the design of an experiment can become so complicated that it is unclear whether the theory is actually tested. This severely reduces the *internal validity* of the experiment (Croson, 2002). The multi-objective game in this thesis had three important distinguishing elements: it considers two players that have *conflicting* strategies (one) and there is no single best solution to the problem, but instead a number of viable options (two). The third characteristic of the game is the fact that choices have to be made simultaneously while the pay-offs of the other player are 'hidden.'

As such the experiment viewed the decision problem from the perspective of one player only. Next to that the focus of the experiment has been centered around the characteristics mentioned and as little circumstantial information as possible. For example, backgrounds about the companies in the experiment were not provided.

Second, the number of *treatments* has to be considered by the researcher. Every treatment in the study should control for one variable only, as with changing more than one variable it will be unclear which one caused the change (Croson, 2002). This thesis aimed at collecting empirical evidence regarding the multi-objective game during an experiment. At the same time the thesis aimed to identify a difference in the decisions that are made when people are asked about their preferences before they play the game. As a result the experiment included one treatment variable. This means that the experiment consisted of two subject pools, the control group and the group that underwent the treatment (i.e. subjects were asked about their preferences before they played the multi-objective game).

The third design issue that has to be considered is that of a *within- or between-subject design*. A within-subject design allows allows a subject to undergo more than one treatment during the experiment resulting in more information, whereas in a between-subject design each subject undergoes only one treatment (Croson, 2002). As mentioned above the experiment in this thesis consisted of two subject groups, one of which underwent the treatment. Naturally, this leaded to a between-subject design.

3.2.2 Methods

Next to the design of the experiment, the implementation deserves individual attention. In order to receive complete results and obtain the objective of internal validity, a number of aspects must be considered. Croson (2002) identified three critical aspects, namely *randomness, deception* and *privacy*. The online experiment in this thesis will be developed using Qualtrics, an online survey platform used by the Radboud University. Because the multi-objective game is a one-player game, i.e. no communication with others is needed to play the game, the structure of a survey was sufficient to present the multi-objective game to the respondents. Specific issues that arise when conducting an online experiment are also addressed in this section. Especially the issue of *dropouts* is discussed seperately.

The treatments in an experiment must be assigned to the subjects at random. This prevents the results from systematic bias related to groups for example a morning group and a group in the afternoon (Croson, 2002). Because this experiment will be conducted online, assigning treatments to the subjects at can be given to the platform as a command. The researcher has tested and monitored this randomness in order to make sure it was implemented correctly.

The validity of experimental results is questioned when the subjects in participants are deceived.

In experimental economics this deception often involves promising the participants pay-offs that they will not actually receive (Croson, 2002). Next to that the participants should be informed truthfully about the purpose of the experiment. As such, all participants will be informed that this study aims to contribute to the field of complex decision making and that their responses are not treated as either right or wrong. Next to that, it is beyond the capacity of the researcher to award people according their achievements during the experiment. Therefore the participants will not be informed about any monetary reward as a result of their participation.

At any point during the experiment the privacy of the participant must be respected. The identity of all participants should remain secret during and after the experiment (Croson, 2002), meaning that results of individuals have not been shared with other participants during the experiment. Of course all results have been made anonymous after the results had been collected, explicitly before any analysis was run. Because all data was collected online confidentiality during the experiment could be ensured: all participants could, if they pleased, take part in the experiment in isolation.

Dropouts (also referred to as attrition) should receive a little extra attention here. In an online experiment, attrition can take place at any moment and the researcher has virtually no control about when people decide to quit (Arechar, Gächter & Molleman, 2018). Experiments that are only partially completed will affect the validity of the results. Therefore this thesis aimed to only accept those experiments that have been fully completed as data for further analysis. In order to minimize attrition the experiment has been thoroughly tested for inconveniences by the researcher, and all test subjects were explicitly asked not to participate in the final experiment.

3.2.3 Experiment Design

Different aspects about experiments have been highlighted above. This section will explicitly elaborate on the design of the experiment. The set up of the experiment and data analysis procedures are discussed below.

The experiment has been conducted online. The main reason for this choice were the uncertain circumstances during which the experiment has been conducted[3], preventing the researcher from the possibility to gather a group of people in a room. The experiment consisted of two subject pools, one of which is the treatment group. According to Hair, Black, Babin and Anderson (2014) sample sizes should be at least 30 per subject pool in order to draw meaningful statistical conclusions. Consequently this meant that this experiment needed at least 60 respondents. A total of 63 fully completed responses have been recorded and used for analysis. It was made sure that both groups consisted of enough respondents. The control group consisted of 32 respondents, whereas 31 in the treatment group completed the experiment.

[3] At the time of writing, the COVID19 pandemic led to measures in the Netherlands that urged people to stay inside.

The experiment consists of one case that involves the multi-objective game. Because of time and concentration constraints of the subjects, they are not asked to play the multi-objective game in more than one case. As such, one case was designed to conduct the experiment. The case involves a description of the decision problem and representation of the problem (game) in *strategic form*. The subjects in the control group are asked to select the strategie(s) that they would prefer as the outcome of the game. After the subjects played the game, they are presented with a few questions about the motivations behind their decisions. The experiment for the treatment group will be the same, except that they are asked a few questions about the different options in the game before they are presented with the case.

Before the experiment was put online it was tested several times. Testing was extremely important for this experiment because it was conducted online. This meant that the respondents did not have the opportunity to ask questions if anything was unclear to them. This could lead to unintended answers by the respondents or even to dropouts if any confusion prohibited the progress of the respondents. As such, during the testing phase, the most valuable aspect of the experiment to the researcher was clarity. Did the respondents understand what was expected of them? Did they understand the way the experiment was presented to them? These questions were asked to the respondents and any inconveniences experienced by the testing respondents were taken seriously. Subsequently the researcher has tried to eliminate them from the experiment. This has led to several modifications, some of which may have impacted the original theory behind the experiment. So have several extra phases been included in the experiment in order to make the decisions that the respondents had to make easier to understand. Whereas some of the testing respondents were involved in multiple testing rounds, each round also included some respondents who did not participate in the other rounds. After three rounds of testing, the fourth round did not result in any confusion by the respondents. This means that after four testing rounds the experiment had been put online. Naturally, the testing respondents were asked not to participate in the final experiment.

The results of the experiment have led to several insights. First of all the results can be used to analyse how 'well' the multi-objective game was played. The game has several good answers. Every good answer is the choice for a strategy (outcome) of the game that is Pareto efficient. Identifying all of them would be the perfect result. At the same time, every chosen strategy that is not Pareto efficient is regarded as 'wrong' (this is not to be confused with a wrong answer, all subjects were perfectly free to choose Pareto inefficient strategies). Using descriptive statistics, the amount of 'good' and 'wrong' chosen strategies have been identified. The different scenarios have been investigated separately, but aggregate results of the entire experiment had also been presented. At first, because the analysis was of an exploratory nature, the entire response set of 63 completed experiments had been analysed. This was done because this greater sample size would be less affected by outliers and because no assumptions have been made about the possible influence of

the preferences for the treatment group. Later in the analysis, if there was a reason to suspect that the treatment group gave different answers compared to the group scores, both groups had been analysed *seperately* in order to present the differences correctly. Besides the decisions of the respondents their motivations contained valuable information. The motivations were labeled into different categories and then the motivations were compared to the decisions in an aim to identify a pattern between the motivations and the decisions. Here again, this was done first for entire response set after which the treatment group was analysed on its own.

3.2.4 Data Validation

Various measures have been mentioned above that are aimed at safeguarding internal validity. These included how complicated the experiment is designed, assigning treatments randomly, being truthful towards the participants as a researcher and the aim of accepting only completed experiments. Next to that the external validity has to be discussed, since this will determine to what extend the results of this study can be generalized to a wider context. Three issues regarding external validity are discussed that have been found to be of particular interest for economic experiments (Banerjee, Chassang & Snowberg 2017): scalability, the effect on different populations and the effects if the experiment was run again on the same subjects.

Scalability refers to what might happen to the the results if the experiment was conducted in a larger setting (Banerjee, Chassang & Snowberg 2017). The participants in this study were gathered through three different channels: people were contacted directly by the researcher through Whatsapp, keeping these respondents close to the researcher; fellow students were contacted through email, these respondents were not necessarily in the network of the researcher but were all students; through Pollpool, an online platform were students or researcher complete each others' surveys, these people were definitely outside the network of the researcher, but were still probably students. Given the fact that all respondents were aged under 30 it can be concluded that most respondents were either students or had recently finished studying. This might lead to different results if this research is to be conducted with respondents that have varying ages or are all above thirty years old. Since there were no specific access requirements to reach this group of participants (e.g. no specific institution were involved) repeating this study with a similar subject pool should be feasible for other researchers.

A different population might lead to different results when this experiment is conducted again. Since this experiment was conducted for the purposes of exploration this comes as no surprise to the researcher. On the contrary, because this study had limited time and resources, more empirical evidence regarding this experiment is encouraged. This experiment should, however, not be conducted with the same subjects. If a subject from the treatment group were presented with this particular experiment again, that person is likely to show different behaviour from a person that has

not participated in this experiment before.

3.3 Practical Implications

3.3.1 Methodology

In the last phase of this thesis the first two phases have been integrated. Concretely this means that no new data is collected in this phase (Tashakkori & Teddlie, 2003). In mixed methods research this phase of integration is about the inferences that have been made earlier in the research process. The term inference refers to different outcomes that are the result of a study: *"The outcome may consist of a conclusion about, an understanding of, or an explanation for a(n) event, behaviour, relationship, or a case (e.g. in qualitative research)"* (Tashakkori & Teddlie, 2003, p. 71-72). At this point of the thesis, two inferences have been made. The first inference was obtained after the first research phase was completed and it includes the answers to the first two sub questions. These answers can be found in chapter two of this thesis. The second inference was obtained after the more quantitative analysis of the experiment and is presented in the thesis as a compound answer to sub questions 3, 4, 5 and 6. These answers are presented in chapter 4 of this thesis. This means that the final meta-inference (Cameron, 2009) was a comparison between qualitative and quantitative data. The meta-inference is the center of chapter five of this thesis.

3.3.2 Comparing Qualitative and Quantitative Data

The data used for the meta-inference (Cameron, 2009) were obtained from a qualitative literature review and a quantitative online experiment. The first led to an overview of multi-criteria decision methods and implications with regard to the integration of multi-objective game in the complex decision making process. The second gathered empirical data regarding the multi-objective game. Especially, the results of the comparison between research question 3 & 4 and 5 & 6 where subject to further analysis in this phase. Hence the meta-inference was obtained from interpreting the results of empirical tests with implications that were grounded in theory. Following Teddlie & Tashakkori (2006) this analysis was twofold: first it was assessed if the conclusions from both phases pointed towards similar results; second, following this first conclusion, a conclusion was drawn which aimed at gaining a deeper understanding about the multi-objective game in complex decision making processes. This led to an answer to the research question of this thesis:

To which extent can the multi-objective game be used to characterize decision making processes involving multiple objectives and multiple players?

3.4 Ethical Considerations

The last section of this chapter discusses some ethical issues regarding the process of this thesis. First of all the researcher was aware of the integrity guidelines of the Research Integrity Guidelines of the Radboud Universiteit Nijmegen and acted accordingly during the completion of this thesis. To this end, the researcher handed in a signed research integrity form to the secretary of Business Administration. Participants were free to end their participation in this thesis at any stage while the thesis was written. Also, the topic of the thesis has been communicated towards all participants before they engage in the experiment, leaving them with the option to withdraw if necessary. Because the participation took place online, engagement could take place in a situation as confidential as the participant pleased. All information that could reveal the identity of participants was destroyed (or at least separated from all results) before data analysis started in order to ensure anonymity. As gratitude for their participation in this thesis, all participants had been given access to the results of the thesis if they liked. To this end, the participants were provided with the opportunity to leave their contact information such that access information (only access information!) could be disclosed by the researcher. The results of this thesis have been made public by submitting the thesis to the Radboud thesis Repository.

4 Empirical observations

The previous chapter reflected on the methodology of this thesis, the structure of the research. After chapter two explained the theoretical contribution of this thesis this chapter will now focus on the empirical contribution. First it is discussed how the multi-objective game was developed from a theoretical concept into an empirically measurable instrument (by means of an online experiment). How the game theoretical terms *strategy, outcome, rationality* and *Pareto efficiency* were presented in the experiment and hence how the choices of the respondents were analysed and interpreted is discussed. The second section of this chapter will focus on the results of the experiment. The responses are analysed according to the definitions given in the first section and interpretations will be made. The implications of the results will be discussed separately in chapter five, where the experiment and theory will be used to enhance each other.

4.1 The Multi-Objective Game: From theory to experiment

In order to develop the multi-objective game into a measurable concept the multi-objective game was included in an online experiment. The example from Lee (2012), as discussed in chapter 2, was taken as a starting point. The example included two *players* that had opposing *strategies* regarding the management of a reservoir watershed: one organization wanted to maximize its economic reward of the project while the second player wanted to minimize the (negative) environmental impact of the area. In the study, their were multiple *options* that could be pursued by the economically oriented player, all with different performances on economic value and environmental pollution. This complex decision problem has been translated into an experiment in order to empirically observe the decisions made by humans as well as their motivations when they are presented with a complex decision problem in multi-objective game theoretical form.

Since the experiment was to be conducted online, the case in the study had to be simplified in order to make it intuitive for the participants. First and foremost the options that were identified in the study: *residential area, recreational area, fruit cultivation and tea cultivation*. The most important characteristic of these options is as follows: in general an option that yields more economic benefits also has a higher negative impact on the environment (Lee, 2012). However, when confronted with tea cultivation or fruit cultivation, most participants will not be able to associate them with their economic benefits or environmental pollution. As such, the following options were used in the experiment: *develop infrastructure, develop a residential area, develop a recreational area, additional forest development*. These options were easily understood during the testing phase, taking into account the most important characteristic: the more economically oriented options are also more harmful to the environment. These options are in conflict with each other because a *trade-off* had to be made as to which extend certain options were pursued at the cost of the other options.

The options in the study together with the different players involved made it an appropriate case for multi-criteria analyses in the form of a multi-objective game. The name of the *players* in the game had to be considered too because no names were included in the original study, but were needed to create a more interactive experiment. For the experiment it was chosen to present the players as two organizations, Build and Develop Inc., who adopted the role of a construction company, and a not for profit organization by the name of NoWasteDevelopment (NWD).

Next to the options and the names of the organizations, the presentation of the game had to be considered. Remember from the examples in chapter two that normally the *players* in a *game* consider their *strategies* while simultaneously considering the strategies of the other players. The example of the multi-objective game in chapter 2, extracted from the Lee (2012) study, presented three such strategies for both players: *ecnonomic, neutral* and *environmental*. During the first testing round it became apparent that presenting the decision problem to the participants all in once was infeasible. It would take a great deal of explanation to make the participants understand how to interpret the pay-offs and even then it was found to be really hard to compare the nine scenarios at the same time in an online format. As such the decision was presented to the participants in three parts. The strategies of the players were labeled as *scenarios*. Each of the scenarios of NoWasteDevelopment was presented separately. This meant that the respondents had to consider one strategy (scenario) of NoWasteDevelopment and compare it with the three strategies (scenarios) of Build and Construct Inc. During the testing phase this was found to feasible. The introduction of the organizations, as well as the information presented in the different scenarios can be found in Appendix 2.

Finally, it had to be determined how the choices that the participants could make would be designed. These numbers were briefly mentioned in chapter two and are repeated in Table 1, followed by an explanation. The entire game in the experiment consisted of three strategies for both players: one focused on economic value, one focused on environmental concerns and one strategy in which a neutral standpoint is taken. For NWD these strategies were separated in three *scenarios* and presented to the respondents as three different decision situations. For Build and Develop Inc. these strategies were presented as 'Economic Opportunist,' 'Neutral Development,' and 'Environment comes first.' The introduction to the case as well as the different scenarios, as presented to the respondents, can be found in Appendix 2.

		NoWasteDevelopment		
		Economic	Neutral	Environmental
Build and Develop Inc.	Economic Opportunist	(10,5,3,2)	(8,5,4,3)	(7,4,3,2)
	Neutral Development	(5,4,4,3)	(6,6,5,4)	(5,4,6,5)
	Environment comes first	(3,5,5,6)	(3,4,5,4)	(2,6,5,6)

Table 1: The multi-objective game included in the experiment, presented in strategic form.

The first scenario that was presented was the one in which NoWasteDevelopment choose the *economic* strategy. This meant that the respondents had to make a decision between the following pay-offs (the values from left to right represent the pay-offs of the options infrastructure, residential area, recreational area and forest development):

$$\text{Economic Opportunist}\{€1.000.000, €500.000, €300.000, €300.000\},$$
$$\text{Neutral Development}\{€500.000, €400.000, €400.000, €300.000\},$$
$$\text{Environment comes first}\{€300.000, €500.000, €500.000, €600.000\}.$$

In chapter 2 it was explained that the best outcome of a game is one that is Pareto efficient. A strategy is Pareto superior to another strategy when all the four options yield a higher or equal outcome than those in the other strategy. A strategy is Pareto efficient when there is no other strategy that is Pareto superior to that particular strategy. Strictly speaking none of these three strategies is Pareto inefficient to another strategy. However the strategy *Neutral Development* does not yield the highest pay-off on any of the four options and has the lowest total value (€1.600.00 compared to €2.100.000 and €1.900.000). In order to keep the experiment realistic this choice was made. It would have made no sense to list only three strategies if two of them would outperform the third strategy on all options (i.e. then the third option could only be chosen by someone who did not pay attention). Recall that in the table including all strategies of both players (the one that was presented at the end of chapter two), the outcome (Neutral, Economic) is in fact Pareto inefficient (it is dominated by (Neutral, Neutral)). As such, in this scenario, *Neutral Development* was seen as the Pareto inefficient strategy, whereas *Economic Opportunist* and *Environment comes first* were seen as the Pareto efficient strategies. From a Pareto efficiency point of view choosing for any of these two decisions would be a rational decision, where the best decision would be to choose both the Pareto efficient strategies. In the situation where the respondent would decide to choose one of these options, the concept of rationality would require the respondent to choose the strategy with highest total value. Therefore *Economic Opportunist* is seen as the purely rational strategy, based on the fact that it yielded the highest total monetary outcome (€2.100.000).

The second scenario that was presented was the one in which NoWasteDevelopment choose the *neutral* strategy. This meant that the respondents had to make a decision between the following pay-offs:

$$\text{Economic Opportunist}\{€800.000, €500.000, €400.000, €300.000\},$$
$$\text{Neutral Development}\{€600.000, €600.000, €500.000, €400.000\},$$
$$\text{Environment comes first}\{€300.000, €400.000, €500.000, €400.000\}.$$

In this scenario the strategy *Environment comes first* is in fact Pareto dominated by *Neutral Development*. This is because *Neutral Development* shows a higher pay-off than *Environment comes*

first on both the options infrastructure and residential area, while the pay-offs on the options recreational area and forest development are equal. The strategies *Economic Opportunist* and *Neutral Development* both are not Pareto superior with respect to each other and hence were the Pareto efficient strategies in this scenario, where *Neutral Developement* is seen as the most rational strategy because of the total monetary outcome of €2.100.000.

The third scenario that was presented was the one in which NoWasteDevelopment choose the *environmental* strategy. This meant that the respondent had to make a decision between the following pay-offs:

$$\text{Economic Opportunist}\{€700.000, €400.000, €300.000, €200.000\},$$
$$\text{Neutral Development}\{€500.000, €400.000, €600.000, €500.000\},$$
$$\text{Environment comes first}\{€200.000, €600.000, €500.000, €600.000\}.$$

Strictly speaking, this scenario does not have a Pareto inefficient strategy. Again this was done in order to present a more realistic scenario to the participants. As can be seen, *Economic Opportunist* performs worse than the other two strategies on three of the four options. Only the option infrastructure will still yield the highest pay-off if the strategy *Economic Opportunist* is chosen. However, like in the first scenario, this strategy still has the lowest total value (€1.600.000 compared to €2.000.000 and €1.900.000) and the strategy is dominated by the outcome (Economic, Economic) when you consider all the strategies simultaneously as was done in chapter 2. Therefore, in the third scenario, *Economic Opportunist* was seen as the Pareto inefficient strategy, whereas *Neutral Development* and *Environment comes first* are the Pareto efficient strategies. Based on the highest total value €2.000.000, *Neutral Development* was seen as the most rational strategy.

This section has focused on explaining how the characteristics of the multi-objective game were translated into an online experiment. Some modifications had to be made with respect to the content and design. It was chosen to present the outcomes in three different *scenarios*, separating the strategies of NWD. With respect to the design of the *outcomes*, the definition of Pareto efficiency was somewhat relaxed in order to maintain more realistic options, but in all three scenarios one strategy was identified as Pareto inefficient. The most important aspect of the multi-objective game, the fact the outcome was represented by a set of pay-offs, remained in tact. It was explained which choices were presented to the respondents and how they could be interpreted from a game theoretical perspective. The next section will focus on the results of the experiment. The will do so by answering the sub questions three through six. Next to the presentation of results, it is briefly tried to explain them as well. Some larger implications will be left for chapter 5.

4.2 Results

The previous section explained how theory was translated into an experiment and how the possible decisions of the respondents were to be evaluated from a game theoretical perspective. This section will focus on the results of the experiment. This will be done by answering sub questions three through six separately. But first the characteristics of the respondent group is presented in order to enhance the understanding of the reader with regard to the further analysis.

4.2.1 Respondent Group

In total 63 complete responses of the experiment have been collected. An accumulated 95% of these respondents was aged under thirty. This combined with the fact that 92% of the respondents were currently in college or had completed an academic study resulted in the fact that the response group largely consisted of young (former) students. This makes the respondent group less generalizable to the entire population. However the results of this thesis will be most valuable to managers (see section 6.2 Discussion), and they will probably also have some form of higher education, which means that the results might be closer (more generalizable) to the population of managers. Of the respondents 40 were male, 22 were female, and one respondent chose to answer the gender question with 'other.' The differences between man and women will be compared in section 4.2.2 in order to identify whether there might be gender differences that could have managerial value. Of the 63 respondents, 32 respondents had to indicate their preferences before they made their decisions. Section 4.2.2 and 4.2.3 will first focus on the entire response group in order to get a general understanding of the behaviour of the respondents. This choice was made in light of the exploratory nature of the analysis. The treatment group will be analysed separately in sections 4.2.4 and 4.2.5 in order to find out whether their is reason to suspect that there are differences between the treatment group and the control group. If there is reason to suspect a difference a further analysis of the difference and its implications will be left for chapter 5.

4.2.2 (SQ 3) *What are the decisions that people make when they play the multi-objective game during an online experiment?*

Figure 3 below represents the decisions made by the respondents in the first scenario. In this scenario the Pareto efficient strategies were *Economic Opportunist* and *Environment comes first*. The numbers indicate that 56% of the respondents have chosen either one of these Pareto efficient strategies. However what is most important here is that the strategy labeled as Pareto inefficient, *Neutral Development*, was chosen most frequently. This might indicate that there are other factors influencing the decisions the respondents made than purely economic factors.

The respondents' decisions in the second scenario are presented in Figure 4. In this scenario,

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Economic Opportunist	15	23,8	23,8	23,8
	Neutral Development	22	34,9	34,9	58,7
	Environment comes first	21	33,3	33,3	92,1
	Economic Opportunist & Neutral Development	2	3,2	3,2	95,2
	Economic Opportunist & Environment comes first	1	1,6	1,6	96,8
	Neutral Development & Environment comes first	2	3,2	3,2	100,0
	Total	63	100,0	100,0	

Figure 3: Decisions in Scenario 1

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Economic Opportunist	11	17,5	17,5	17,5
	Neutral Development	38	60,3	60,3	77,8
	Environment comes first	8	12,7	12,7	90,5
	Economic Opportunist & Neutral Development	4	6,3	6,3	96,8
	Economic Opportunist & Environment comes first	1	1,6	1,6	98,4
	Economic & Neutral & Environment	1	1,6	1,6	100,0
	Total	63	100,0	100,0	

Figure 4: Decisions in Scenario 2

the most rational strategy *Neutral Development* was chosen by 60% of the respondents. This is in contrast with the first scenario, where the most rational strategy, *Economic Opportunist*, was chosen by only 25% of the respondents (which made it the least preferred strategy). After evaluating two of the three scenarios it seems that there are other factors than purely economic results that influence the decisions of the respondents.

Figure 5 shows the decisions made by the respondents in the third scenario. In this scenario. *Neutral Development* and *Environment comes first* were the Pareto efficient strategies. Together these two strategies were chosen by 85% of the respondents, with only 5% choosing for the Pareto inefficient strategy *Economic Opportunist*. This scenario could indicate that people act rational when they make their decisions. However, when you compare the third scenario with the first and second scenario it seems that people tend to act more rational when they have the opportunity

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Economic Opportunist	3	4,8	4,8	4,8
	Neutral Development	30	47,6	47,6	52,4
	Environment comes first	24	38,1	38,1	90,5
	Neutral Development & Environment comes first	5	7,9	7,9	98,4
	Economic & Neutral & Environment	1	1,6	1,6	100,0
	Total	63	100,0	100,0	

Figure 5: Decisions in Scenario 3

to combine economic benefits with a strategy that is less harmful for the environment. Overall, *Economic Opportunist* was chosen in the first and second scenario (where it was a Pareto efficient strategy) only 20% of the time. In contrast *Environment comes first* was a Pareto efficient strategy in scenario 1 and 3 (but never the most rational strategy) and was chosen in a combined 35% by the respondents. *Neutral Development*, the strategy which was labeled as neither harmful nor stimulating, was the most rational strategy in scenario two and three and was chosen in a combined 54% by the respondents. It seems that other motivations than purely rational thinking led to the decisions of the respondents. These motivations are further discussed in the next section and what this implicates is the subject of chapter 5.

The decisions specific for men and women have also been compared. This was done in order to find out whether there was reason to suspect that any differences existed between the two groups. If any differences are found this might have managerial value. If men and women make different decisions, you might want to consider these groups separately in order to keep the results as close to the truth as possible. What you do not want as a manager is to put time and effort into a decision analysis only to find that both groups (men and women) are dissatisfied with the results because they are in the middle of both groups' decisions. The decisions of male and female respondents separately can be found in Appendix 3. For the second and third scenario there were virtually no differences observed and hence those responses do also not deviate (much) from the decisions made by the entire group. In the first scenario, however, 30% of the male respondents chose the most rational strategy Economic opportunist, while 14% of the female respondents chose this strategy. This might be because men care more about economic benefits than women, or maybe the female respondents were a little more confused when they had to make their first decision. However, since only one of the three scenarios showed a difference in decisions, and finding a difference was not part of the original aim of this thesis, the results for men and women will not further be discussed separately.

4.2.3 (SQ 4) *To which extent are the motivations of people in line with the decisions that they make when people play the multi-objective game during an experiment?*

During the experiment the respondents were asked to describe the motivations behind their decisions. Since this was an open question to the respondents, different types of answers could be expected. Of the 63 respondents a total of 47 explained their thoughts in a clear manner. Their motivations have been divided in six categories, labeled as: 'Economic value', the respondents indicated that profit was the most important motivation; 'Environmental concerns', these respondents indicated a better environment should come before economic profits; 'Balance the Economy and Environment', this was seen as a combination between the first two motivations; 'NWD (other player)', these respondents let possible future actions of NWD influence their decisions; 'NWD and profit', these respondents indicated that profits and actions of the NWD should be taken into account; 'One option most important', these respondents said that one of the options was most important in their decisions. Four of these labels could be translated to rational choices, as long as the respondents make choices that maximise what is most important to them. The options 'NWD (other player)' and 'NWD and profit' are harder to combine with rational choices. Except for when your own interests and those of NWD are exactly aligned choosing for the interests of another player will come at the cost of your own profits.

As Figure 6 below indicates, 43% (20 out of 47) of the respondents has chosen to take possible future actions of NWD into account when making their decision, i.e. they have indicated in their motivations that they were willing to comply with NWD. Of these twenty respondents a combined nine have chosen the Pareto inferior strategy *Neutral Development*. None of these respondents have chosen the strategy *Economic Opportunist*, which was told to upset NWD. This does however not make it a rational choice, since *Economic Opportunist* would still be in the best self-interest of the respondents. In fact these respondents have chosen the Pareto inefficient strategy *Neutral Development* more than any other strategy. Another point that must be mentioned is the fact that all four respondents who have chosen for more than one scenario also indicated the interest of NWD to be their main motivation. This might have to do with an increased level of uncertainty, because the specific interest of NWD was not precisely described. However, the amount of respondents is too low to draw statistical conclusions and there remains a higher amount of people who chose one strategy than two strategies.

Figure 7 and Figure 8 show the results for the scenarios two and three, respectively. In these scenarios *Neutral Development* was the most rational strategy. Since this was already the most frequently chosen strategy in the first scenario (by those respondents who took into account NWD) it is no surprise that this is also the most chosen strategy when the choice is rewarded with economic benefits (and not upsetting NWD). It is the first scenario that indicates that these people seem to focus more on the context in which the decision is made than the precise outcome of their decisions.

		Economic Opportunist	Neutral Development	Environment comes first	Economic Opportunist & Neutral Development	Economic Opportunist & Environment comes first	Neutral Development & Environment comes first	Total
Motivation_Label	Economic Value	8	0	2	0	0	0	10
	Environmental Concerns	0	3	5	0	0	0	8
	Balancing the Economy and Environment	1	1	3	0	0	0	5
	NWD (other player)	0	4	2	1	1	2	10
	NWD and Profit	0	5	5	0	0	0	10
	Option most important	1	3	0	0	0	0	4
Total		10	16	17	1	1	2	47

Figure 6: Motivations and decisions in Scenario 1

		Economic Opportunist	Neutral Development	Environment comes first	Economic Opportunist & Neutral Development	Economic & Neutral & Environment	Total
Motivation_Label	Economic Value	0	10	0	0	0	10
	Environmental Concerns	0	3	5	0	0	8
	Balancing the Economy and Environment	1	4	0	0	0	5
	NWD (other player)	4	3	0	2	1	10
	NWD and Profit	2	8	0	0	0	10
	Option most important	1	3	0	0	0	4
Total		8	31	5	2	1	47

Figure 7: Motivations and decisions in Scenario 2

		Economic Opportunist	Neutral Development	Environment comes first	Neutral Development & Environment comes first	Total
Motivation_Label	Economic Value	0	7	3	0	10
	Environmental Concerns	1	2	5	0	8
	Balancing the Economy and Environment	0	2	2	1	5
	NWD (other player)	0	4	3	3	10
	NWD and Profit	0	8	2	0	10
	Option most important	1	3	0	0	4
Total		2	26	15	4	47

Figure 8: Motivations and decisions in Scenario 3

With regard to the other motivations, people tend to follow their own responses. All respondents who deemed economic value to be most important have chosen one of the Pareto efficient strategies in all three scenarios, with a majority choosing the most rational strategy (*Economic Opportunist*, *Neutral Development* and *Neutral Development*). The respondents with stronger environmental concerns chose the strategy *Environment comes first* most in all three scenarios (five out of eight respondents in each scenario). In the second scenario this strategy was Pareto inefficient. Even though choosing the environmental strategy was in line with their motivations, it seems that some of the respondents who were environmentally oriented put more emphasis on the meaning of their

decisions (i.e. favour the environment), than the actual result for their company.

4.2.4 (SQ 5) *What are the decisions that people make when they play the multi-objective game during an online experiment, if they are asked to state their preferences before the game is played?*

The decisions made by the 31 respondents who were asked to express their preferences are presented in Figures 9, 10 and 11. In the first scenario only 15% percent of the respondents had chosen for the most rational strategy *Economic Opportunist*, making it the least chosen strategy. The Pareto inefficient strategy Neutral development was the most chosen strategy, being selected by 42% of the respondents This (again) shows that there might be other reasons for the respondents to make a decision apart from purely economic benefits. In the second scenario 61% had chosen the most rational strategy Neutral development, and the respondents were more or less divided between choosing the Pareto efficient strategy Economic opportunist and the Pareto inefficient strategy Environment comes first as both were selected by between 15 and 20 percent of the respondents. In the third scenario the two Pareto efficient strategies Neutral development and Environment comes first were chosen by 90% of the respondents, where Neutral development was chosen slightly more (15 times compared to 13).

In order to assess whether the respondents act in line with their preferences their most preferred options have been compared with their decisions. For each respondent one option was selected as the most preferred. At first you would expect people who preferred infrastructure (more economically oriented) to choose a strategy which yields better results, whereas people who prefer forest development (more environmentally oriented) are expected to make a decision that suits the environment. That is if their preferences would be translated into their decisions. The preferences of the respondents compared with their choices have are presented in figures 12, 13 and 14.

The first thing that stands out is the amount of people that deemed the option Forest development to be the most important option, namely 55% of the respondents (17 of 31). As can be seen in the figures, these respondents almost never choose for the option economic opportunist regardless of the scenario (once, twice and once in the three scenarios). Because Economic opportunist was one of the Pareto efficient strategies in the first two scenarios, this resulted in less rational choices. It is however not the case that these respondents will always choose the strategy Environment comes first, since in all three scenarios their decisions are more or less divided between both strategies.

With regard to the respondents' preferences, it seems that those who prefer infrastructure tend to make more rational decisions. Combined over three scenario these respondents have chosen a Pareto inefficient strategy just once, whereas they chose the most rational strategy eight times (they made a combined twelve decisions). However, since there were only four respondents who preferred this option, conclusions should be drawn with great care. Of the respondents who preferred

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Economic Opportunist	5	16,1	16,1	16,1
	Neutral Development	13	41,9	41,9	58,1
	Environment comes first	12	38,7	38,7	96,8
	Neutral Development & Environment comes first	1	3,2	3,2	100,0
	Total	31	100,0	100,0	

Figure 9: Decisions of people with preferences in scenario 1

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Economic Opportunist	5	16,1	16,1	16,1
	Neutral Development	19	61,3	61,3	77,4
	Environment comes first	6	19,4	19,4	96,8
	Economic Opportunist & Neutral Development	1	3,2	3,2	100,0
	Total	31	100,0	100,0	

Figure 10: Decisions of people with preferences in scenario 2

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Economic Opportunist	2	6,5	6,5	6,5
	Neutral Development	15	48,4	48,4	54,8
	Environment comes first	13	41,9	41,9	96,8
	Economic & Neutral & Environment	1	3,2	3,2	100,0
	Total	31	100,0	100,0	

Figure 11: Decisions of people with preferences in scenario 3

residential area more than 50% has chosen the strategy Neutral development in all three scenarios. Remember that this was the Pareto inefficient strategy in scenario 1, but that does not seem to affect the decision. When you purely look at the preferences of people it seems (too) that merely their preference for one of the options was not the only factor that led them to make their decisions.

		Economic Opportunist	Neutral Development	Environment comes first	Neutral Development & Environment comes first	Total
Preference	Infrastructure	2	1	1	0	4
	Residential Area	1	5	2	0	8
	Recreational Area	1	0	1	0	2
	Forest Development	1	7	8	1	17
Total		5	13	12	1	31

Figure 12: Preferences and decisions in Scenario 1

		Economic Opportunist	Neutral Development	Environment comes first	Economic Opportunist & Neutral Development	Total
Preference	Infrastructure	0	4	0	0	4
	Residential Area	3	5	0	0	8
	Recreational Area	0	1	1	0	2
	Forest Development	2	9	5	1	17
Total		5	19	6	1	31

Figure 13: Preferences and decisions in Scenario 2

		Economic Opportunist	Neutral Development	Environment comes first	Economic & Neutral & Environment	Total
Preference	Infrastructure	0	2	2	0	4
	Residential Area	1	6	1	0	8
	Recreational Area	0	2	0	0	2
	Forest Development	1	5	10	1	17
Total		2	15	13	1	31

Figure 14: Preferences and decisions in Scenario 3

4.2.5 (SQ 6) *To which extent are the motivations of people in line with the decisions that they make when people play the multi-objective game during an online experiment, if they are asked to state their preferences before the game is played?*

Of the 31 respondents who were asked about their preferences 27 have substantiated their decisions with a clear motivation. Their motivations are depicted in Figure 15. 33% Has indicated that they made their decisions with possible actions of NWD in mind while 56% indicated that they paid most attention to economic value, the environment or an combination of the two. If we briefly compare this with the total group numbers it can be seen that there 43% had indicated to take NWD into account while 49% paid most attention to economic value, the environment or a combination of the two. This might indicate that asking people about their preferences led them to focus more on the options and less on NWD. This possible difference will be further explored in chapter 5.

		Economic Value	Environmental Concerns	Balancing the Economy and Environment	NWD (other player)	NWD and Profit	Option most important	Total
Preference	Infrastructure	2	0	0	0	2	0	4
	Residential Area	2	0	1	1	1	3	8
	Recreational Area	1	0	0	0	0	0	1
	Forest Development	1	7	1	3	2	0	14
Total		6	7	2	4	5	3	27

Figure 15: The motivations of respondents who expressed their preferences

Figures 16 through 18 show the motivations of the 27 respondents together with their decisions. In the first scenario none of the 9 respondents who said to take NWD into account has chosen the most rational strategy Economic opportunist. The same can be said for the people who based their decisions on environmental concerns. It seems that the most important aspect for these respondents was to decide against the economic strategy. That eight of these fourteen respondents chose the Pareto inefficient strategy Neutral development shows that other factors than purely economic value influenced their decisions. The second and third scenario show similar results. Again, the respondents who indicated that their decisions were motivated by economic concerns have chosen the most rational strategy more than any other strategy and never chose the Pareto inefficient strategy. The respondents that were motivated by environmental concerns were divided between the strategies Neutral development and Environment comes first. However, in the second scenario Environment comes first was the Pareto inefficient strategy, again indicating that these people were driven by more than just the results of their decisions. The respondents who indicated that the took possible future actions of NWD into account have all chosen for one of the Pareto efficient strategies, indicating that they tend to choose for more economical values if this does not upset the other player. These results show great similarities with the motivations of the entire respondent group.

4.2.6 (SQ 7) *Are there differences in the decisions that people make when they play the multi-objective game if they are asked about their preferences before the game is played?*

The answer to this is sub question is essentially short: the fact that people are asked to make their preferences explicit before they are asked to make decisions *does not* influence their decisions. The total group decisions in the second and third scenario show virtually no differences. Taking a closer look at the first scenario, 16.1% (5 out of 31) of the respondents who indicated their preferences chose the strategy *Economic Opportunist*, whereas this is 31.2% (10 out of 32) for the respondents who did not indicate their preferences before they made their decision. Because this is not reflected in the amount of times that the strategies *Neutral Development* and *Environment comes first* were chosen (they are chosen with similar frequencies by both respondent groups, making them indecisive between the strategies) it cannot be concluded based on this one difference that the two respondent groups showed different behaviour.

		Economic Opportunist	Neutral Development	Environment comes first	Neutral Development & Environment comes first	Total
Motivation_Label	Economic Value	4	0	2	0	6
	Environmental Concerns	0	3	4	0	7
	Balancing the Economy and Environment	1	0	1	0	2
	NWD (other player)	0	2	1	1	4
	NWD and Profit	0	3	2	0	5
	Option most important	0	3	0	0	3
Total		5	11	10	1	27

Figure 16: Motivations and decisions of people with preferences in scenario 1

		Economic Opportunist	Neutral Development	Environment comes first	Total
Motivation_Label	Economic Value	0	6	0	6
	Environmental Concerns	0	3	4	7
	Balancing the Economy and Environment	1	1	0	2
	NWD (other player)	3	1	0	4
	NWD and Profit	1	4	0	5
	Option most important	0	3	0	3
Total		5	18	4	27

Figure 17: Motivations and decisions of people with preferences in scenario 2

		Economic Opportunist	Neutral Development	Environment comes first	Total
Motivation_Label	Economic Value	0	4	2	6
	Environmental Concerns	1	2	4	7
	Balancing the Economy and Environment	0	1	1	2
	NWD (other player)	0	2	2	4
	NWD and Profit	0	3	2	5
	Option most important	1	2	0	3
Total		2	14	11	27

Figure 18: Motivations and decisions of people with preferences in scenario 3

That the expression of preferences did not influence the decisions that the respondents made does not mean that there were absolutely no differences observed when the groups were compared. The *motivations* of the respondents who expressed their preferences did seem to differ from those who didn't. Of the respondents who expressed their preferences 56% indicated that they paid most attention to economic value, the environment or a combination of the two and 33% indicated that their decisions were influenced by possible future actions of NWD. This means that of the 20 respondents who did not express their preferences, but did explain their motivations 40% (8 respon-

dents) indicated that they paid most attention to economic value, the environment or a combination of the two and 55% (11 respondents) indicated that their decisions were influenced by possible future actions of NWD. What this difference might mean is discussed in chapter 5.

4.3 Concluding Remarks

This chapter has focused on the empirical results of this thesis. First it was explained how the multi-objective game had been translated from a theoretical construct into a measurable construct in the form of an online experiment. The game theoretical elements in the experiment have been thoroughly explained, as well as how they were to be interpreted in order to enhance the understanding of the reader. Next to that the results if the experiment have presented. First of all this was done from a game theoretical perspective and the analyses mainly revealed the rational and Pareto (in)efficient choices made by the respondents. Next to that the motivations behind the decisions of the respondents were labeled and compared to the decisions. This revealed that rationality, or even the options between which the respondents had to choose, were not the only factors that influenced the decisions. The involvement of a second player, NWD, also had an influence on the decision of many respondents. The next chapter will focus on the additional meaning of the results, in extend it will be focused on the implications.

5 Implications

The previous chapter has described the empirical results of the experiment of this thesis. The analysis was of an exploratory nature and was predominantly descriptive. What these descriptive results might mean, i.e. their implications, are the subject of this chapter. The implications of the results are examined and the connection is made with the theory on and analysis of complex decision-making processes as presented in chapter 2. Next to that the specific influences of preferences on the decisions are discussed, as well as what they might implicate with regard to the complex decision making process.

5.1 The Multi-Objective Game and MCDA: empirical results

This section aims to provide an answer to sub question 8 of this thesis: *How can the decisions and motivations of people when they play the multi-objective game be interpreted with regard to complex decision making?*

First of all it is concluded from chapter 4 that people do not necessarily tend to act rational, which means that they are not purely economically driven. This is, however, not a new finding as this was already identified by Tversky and Kahneman (1989). Because of the development of a new type of game in this thesis the concept of rationality was adopted with regard to the multi-objective game, but it is not surprising to see that this was only partially true when empirical data was analysed. Only the respondents who said to be driven by economic value tended to be rational, this is probably because the game in this experiment determined which decisions were rational on the basis of their monetary rewards.

It is interesting take a closer look at what caused the respondents not to show rational behaviour. It was concluded in chapter two that in multi-criteria decision analysis methods, especially multi-attribute utility theory (MAUT) and the Analytic Hierarchy Process (AHP), are often criticised because the personal preferences or subjective judgement influence the weighting of criteria or the performance evaluation of alternatives. This in extent would influence the outcome of the analysis. In this light it could have been expected that peoples' preferences for the environment would cause them to make less rational decisions. But when the respondents in this thesis were asked about what led them to their decisions (their motivations) 43% of the respondents indicated that their decisions were influenced by possible future actions of NWD, a second player included in the decision problem. Traditional MCDA often looks at only one player where multiple players are often involved in complex decision problems (Wernz & Deshmukh, 2010). The results of this thesis show that multiple players, if they are considered in the decision analysis process, do actually involve the decisions that people will make. Therefore the inclusion of the Multi-Objective Game in the decision making process could provide managers (and many other decision makers)

with additional value, since it takes into account aspects that are not (well enough) addressed by MCDA.

One thing that stands out is the amount of respondents that opted to choose more than one strategy. In all three scenarios, the amount of respondents that chose more than one strategy remained below 10%. This is in contrast with the fact that each scenario contained two strategies that were labeled as Pareto efficient. From a game theoretical perspective two strategies were rational and could be determined as the outcome of the game. Since the respondents were explicitly asked to make a *preliminary decision*, it was expected that more than 10% would have chosen multiple strategies [4]. In an attempt to reveal why so few of the respondents have chosen multiple strategies, some of the respondents have been contacted after the experiment. They were asked again about their decisions and especially why they opted to choose for one strategy in all the scenarios. Part of the respondents indicated that they chose the one option which best suited their motivations or opinions. For them it was a logical choice to choose for only one strategy. This could indicate 'tunnel vision' where the respondents put too little attention to options that they consider to be of less value. However, part of the respondents also indicated that they were not really aware that they could choose for multiple strategies. This could be a limitations of this thesis and will be further discussed in the discussion section. Whichever of these two possibilities is true, this thesis has not provided the empirical evidence to draw any meaningful conclusion.

An MCDA perspective would also expect that several alternatives which are not immediately deemed as better than the others are considered for further evaluation. The fact that people tend to choose only one option (which is in their opinion the best option) is not necessarily good or bad. The general aim of decision analysis, as was explained in chapter 2, is to improve the *understanding of the decision problem*. By enhancing the complex decision making process with an extra analysis moment in the form of the multi-objective game the decision makers could be pointed towards their possible 'tunnel vision' which could allow them to adopt a more open perspective to multiple alternatives in the remainder of the process.

5.2 Preferences or no preferences: the differences?

This section will now aim to provide an answer to the ninth and final sub question of this thesis: *How can the differences in decisions that people make when they play the multi-objective game if they are asked about their preferences before they play the game be interpreted with regard to complex decision making?*

[4] Even though no expectations have been expressed throughout this thesis (on purpose), 10% feels like an extremely low amount. If for example 30% had decided to select multiple strategies it would still feel like a low amount, but it could more easily have been attributed to the fact that the experiment was conducted online (i.e. no contact between the respondents and the researcher was possible).

In chapter 4 it was found that the motivations of the respondents who expressed their preferences were more oriented towards the options of the decision problem than to the context (NWD), compared to the respondents who did not express their preferences. This might indicate that a stronger focus on the options, which main characteristic was a focus on economic benefits and environmental pollution, might have shifted the focus of the respondents more towards these options instead of the context of the decision problem, or put more simply, the other players in the game. Under different circumstances in another decision problem this shift in motivations could lead to different decisions. Unless it is the intention to strengthen the focus of the decision maker on the options or criteria of a decision problem (and away from the context), anyone who guides the decision making process should be careful not to cause this shift accidentally. This comment is made with caution because of two reasons: (1) the sample sizes of both groups are relatively small (below 30) and (2) investigating what caused the respondents' motivations was not part of the goal of this thesis.

Regardless of what caused the different motivations of the respondents, the results of this thesis have identified that different motivations do in fact exist when people make their decisions. These can vary from a focus on one or more of the options (criteria) to one or more of the actors (players) involved in the decision problem. By means of the multi-objective game these different motivations have been identified. Knowledge about these motivations could be helpful for further decision analysis. First it tells both the decision maker and the organization for which he or she works what is important to this person and maybe even what is as a result important to the company. Second it can identify these motivations before the decision maker is required to evaluate the alternatives in a more detailed manner, either by expressing his or her preferences for the different performances (MAUT) or using expert judgement (AHP). A better understanding at this point may reduce the bias of the decision maker.

5.3 The Multi-Objective game: an additional step in the decision making process.

In chapter two the multi-objective game was proposed as a second phase in a new three phase multi-criteria decision making process. The goal of this second step was to include an additional moment of analysis in the decision process. Because the multi-objective game finds its origin in game theory it takes a more rational approach towards a decision problem. The empirical results of this thesis showed that people do not necessarily act rational, but this does not mean that the analysis is pointless. Involving the multi-objective game in the decision making process might reveal additional motivations of people that drive their decisions. This could be the input for further discussion. What are the motivations of the decision makers that determine their decisions? How

come they do not comply with rational behaviour? Was the problem presented in an inadequate manner? Are there other criteria we should include to identify accurate pay-offs? All these questions might occur as a result of what is called *irrational* behaviour. Answering these questions, and changing the problem description accordingly, will increase discussion (not arguments) and eventually the understanding of the decision problem. This thesis argues that it is better to confront these questions early in the decision making process, where adjustments can still be made. Making adjustments will take less effort when the problem has been identified on a more superficial level (including players, options and criteria) compared to when a complete and thorough analysis (including measurement) has already taken place.

The multi-objective game is not intended to merely stimulate discussion. If the decision problem is presented well (possibly after several iterative discussion rounds) the analysis in the form of a game can identify options or strategies that are Pareto efficient and Pareto inefficient. If the decision makers agree with the problem description, they should also agree with the identification of the Pareto (in)efficient options. These Pareto inefficient options (strategies) can be excluded in the remainder of the analysis because there simply exist better options. The experiment empirically tested in this thesis showed how these Pareto inefficient options should be determined (this does not mean that the problem was perfectly presented to all the respondents that took part in the experiment). So the multi-objective game has as a second advantage that it can reduce the size of the decision problem, by turning the focus to the options that will all be regarded as a good decision. This way the remainder of the decision making analysis process can put more effort in analysing the most important options.

5.4 Concluding Remarks

This chapter has focused on the implications of the results of the experiment conducted in this thesis. The most important results of chapter 4 were briefly repeated and their meaning has been further examined. At the same time, these results were integrated into the entire complex decision making process which was presented in chapter 2. The three most important points to remember from this chapter before the conclusion of the thesis is presented are: (1) the context in which a complex decision is made, involving multiple actors, is important to consider when dealing with a complex decision problem and the multi-objective game can serve as a tool to consider this context; (2) an extra moment of analysis in the form of the multi-objective game might reveal and adjust 'tunnel vision' of the decision maker(s); (3) people do not necessarily make different decisions if they express their preferences beforehand, but this expression might cause the motivations behind their decisions to change and in effect change the decisions in another decision problem; (4) the multi-objective game should be used in a complex decision making analysis process in order to

stimulate discussion and reduce the size of the decision problem.

6 Conclusion & Discussion

The last chapter of this thesis will start with an answer to the research question: "*To which extent can the multi-objective game be used to characterize decision making processes involving multiple objectives and multiple players?*" In order to formulate an answer to the research question a mixed methods approach was taken. First theory that focused on multi-criteria decision analysis was studied in order to construct a multi-criteria decision analysis process. Then the game theoretical literature as it is commonly used in the field of management was expanded with a new type of game: the multi-objective game. The multi-objective game was proposed as an addition to the current theory on multi-criteria decision analysis. In order to provide empirical data the multi-objective game was tested in an online experiment. The results of the experiment have been discussed and implications have been formulated, both with regard to the earlier proposed theory and some practical implications that discussed the contribution of the multi-objective game in the complex decision making process.

After providing an answer to the research question this thesis will conclude with a discussion about its contributions, limitations and recommendations for future research.

6.1 Conclusion

The multi-objective game can be used to describe complex decision processes. The game can be used to describe a problem because of its capability to capture multiple players and multiple objectives that are involved in a decision problem simultaneously. This thesis has revealed that the involvement of multiple players is important to consider. This means that when multiple players are involved, people will take their possible future actions into account while they make their decisions. The multi-objective game can reveal different preferences or motivations of different decision makers and as a result may contribute to foster discussion about the problem itself. Because of the iterative nature of the complex decision making process this in turn may lead to a better description of the problem.

The multi-objective game should, however, not be considered to support the entire decision making process. In the first phases of the process, the multi-objective game can result in a reduction of the size of the problem because some options or strategies can be disregarded for further analysis. The latter phases of the process do require a more thorough analysis, though. Detailed measurement of criteria and attributes is necessary in these phases, but cannot be represented as such in the form of a game. Therefore the multi-objective game could be combined with multi-attribute utility theory or the Analytic Hierarchy Process in order to structure the entire decision making process.

6.2 Discussion

This thesis has led to several contributions. The game theoretical field, as it is used in the field of management, has been expanded with the introduction of the multi-objective game. This game makes it possible for many more decision problems to be included in game theory: those with multiple criteria. Even though other games might also capture decision problems that involve multiple criteria, they can only be analysed with the help of one aggregated measure. The multi-objective game makes it possible to include possibly conflicting criteria while still presenting the problem in a relatively simple manner. Because the multi-objective game is a game of asymmetric information, it can be argued that this increases uncertainty. Complex decisions often involve uncertainty about the consequences of the actions taken (Venkatraman & Huettel, 2012). The multi-objective game acknowledges that other players exist, and tries to incorporate this by taking into account different strategies of all players in the game. Assigning probabilities to the strategies is, however, not likely to increase the strength of the analysis.

This thesis has contributed to the managerial field of complex decision making because it presented clear and ample guidelines to structure the decision making process. Even though much literature discusses aspects of decision analysis, a clear visual representation of the decision analysis process has not been found. The empirical contribution of this thesis provided data about peoples behaviour while they play the multi-objective game. Even though people were not found to be completely rational (which also has never been suspected) the game did reveal that multiple factors can influence the decisions of a decision maker. These were not all expected by the researcher, and neither will they be in the future when a decision analysis starts. Through the iterative nature of the decision analysis process, the multi-objective game can be used to stimulate discussion and improve understanding of the decision problem.

The results of this research could be helpful for managers throughout the decision analysis process, with the multi-objective game being particularly helpful in the first and second stages of the process (as proposed in this thesis). In this stage, objectives have to be articulated and alternative courses of action identified (Goodwin & Wirght, 2014). By describing the problem as a game, the managers are forced to describe the problem as simple as possible. Because the multi-objective game requires, as the name suggests, multiple conflicting objectives the results are more useful for managers higher up the hierarchy, where decision problems might involve multiple departments. At last it is stressed one more time that the multi-objective game does not solve the decision problem at hand, but that the game should be used to support a better understanding of the decision process.

This thesis has also been subject to several limitations. First of all the researcher was a student and this study was completed with limited time and resources. Experiments in the (economic) game theoretical field are often conducted with an extra incentive in the form of monetary rewards. This incentive should lead to participants taking an extra effort to make good decisions. Even

though the respondents were not informed about any monetary reward (upholding the integrity of the researcher), studying the responses of some of the participants indicated that they might have put more emphasis on completing the experiment than trying their best to make considerate decisions. This is however a general pitfall of an online experiment and was beyond the control of the researcher.

Also the COVID19 pandemic during which this thesis was completed had its influences on the results. Because it was impossible to gather a group of respondents in a (class)room the experiment had to be conducted online. This meant that any inconveniences experienced by the respondents would lead to a misunderstanding of the experiment at best and dropouts at the worst. In order to prevent both these issues the experiment had been thoroughly tested on clarity. This meant that some modifications in the design of the multi-objective game as presented in the theory had to be made. The most important change was to present the case to the respondents in three separate scenarios. Even though this increased the ease of interpretation, completely 'true' results could only have been obtained when the respondents made their decisions if they were presented with one complete problem. In order to achieve this, physical presence of the researcher and the respondents at the same place could have made this possible as any misunderstandings could have been clarified by the researcher.

The fact that the experiment has been conducted online might have led to an additional limitation with regard to the responses. As was indicated in chapter 5 a large part of the respondents has chosen for only one strategy in all three scenarios. This could be because of the fact that the respondents were unaware of the possibility to choose multiple strategies. In that case the online experiment was not suited to expect multiple responses from the respondents and maybe this experiment should be repeated in an offline setting. Another reason could be the fact that, as a result of the modifications to the design of the experiment, the respondents could choose between only three strategies in each scenario. Maybe that the respondents are more tempted to select multiple strategies if they are presented with a larger set of options, such that it becomes harder to 'order' them for the respondents. These issues are both important and interesting to consider if this experiment is repeated in future research.

The respondents that participated in the experiment were mostly students. This means that the respondents were not the decision makers that could benefit from the results of this thesis. These are higher level managers, for example CEO's or executives that lead a department of their company. These people have more experience when it comes to making complex decisions. The results of the experiment might be different if these people where the participants. Especially, because they have more experience, they are probably aware that multiple alternatives should be considered during the analysis. Future research could repeat this experiment with this target group in mind in an aim to identify whether this group makes 'better' decisions, in extend they select multiple alternative

strategies more frequently.

This thesis served as a starting point to develop a new topic to study: the multi-objective game. As such, the contributions of this thesis have been mainly theoretical. In order to further develop the theory and identify its best use in practice empirical evidence in the form of case studies is required. Testing the complex decision making process as it has been structured in this thesis, including the multi-objective game, is the best way to identify its actual value in the managerial field and improve the theory further. This could be done in an experimental setting, where one group analysing a case adopts the decision making process that includes the use of the multi-objective game, while another group focuses on the same case, but adopts the decision making process as presented in this thesis without the multi-objective game. Other research might aim to enhance the theory even further, for example by developing cases that involve multiple (more than two) players or by examining the scope of decision problems (in terms of options or strategies) that would be suited to analyse using the multi-objective game.

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8 Appendices

8.1 Appendix 1: Identifying Pareto Efficient Strategies

Remember from section 2.4.1 that "a strategy profile s is Pareto superior to another strategy profile $s^{'}$ if all the pay-offs in strategy profile s are higher than or equal to those in $s^{'}$, where at least one pay-off should be higher." This was also called Pareto domination. From this it followed that a Pareto efficient strategy is a strategy that is not Pareto dominated by another strategy. Now suppose that there are s_x strategies that each exist of o_n objectives. Then Pareto efficient strategies can be identified in the following way:

- Take the first strategy s_1 (referred to as the *reference* strategy) and start comparing the pay-offs of the objectives $s_1(o_1)$ through $s_1(o_n)$ with those of strategy s_2[5].
  - If one of the pay-offs $s_1(o_x)$ is higher than the corresponding pay-off of the other strategy $s_2(o_x)$, then you conclude that strategy s_1 is not Pareto inefficient compared to strategy s_2. You move on to compare strategy s_1 with strategy s_3.
  - If all of the pay-offs of strategy s_2 are higher than or equal to the corresponding pay-offs of strategy s_1 (with at least one inequality), you conclude that strategy s_1 is Pareto inefficient. You start again with the process, but now you take strategy s_2 as the *reference* strategy.
  - If all pay-offs are equal, both strategies are neither Pareto superior to the other strategy, neither Pareto dominated by the other strategy. You start comparing strategy s_1 with strategy s_3.
- Repeat this process until strategy s_1 is compared to all other strategies.
- If strategy s_1 has not been identified as Pareto inefficient in the previous steps, you conclude that strategy s_1 is Pareto efficient. You start the process again, but now you take strategy s_2 as the *reference* strategy.
- Repeat this process until all strategies have served as the *reference* strategy.

After you have completed the entire process (all strategies have served as the *reference* strategy), you have identified all Pareto efficient strategies.

[5]When any other strategy than s_1 is the *reference* strategy, you start comparing pay-offs of the *reference* strategy with the pay-offs of strategy s_1.

8.2 Appendix 2: Description Experiment

8.2.1 Introduction

During this experiment you will adopt the role of a decision maker in a construction company: Build & Develop Inc. The local government has identified an underdeveloped area between the cities Nemijgen and Ernham and asked Build & Develop Inc. to submit a development proposal. Before any proposals were developed, it has come to your attention that another organization, NoWasteDevelopment (NWD), has also been involved in the development of the area by the local government. Even though NWD is a not for profit organization and is not viewed as a competitor by your company, you do realise that the approval of NWD influences the success of the project. As a result the proposal is developed taking into account the goals of NWD.

Please read the following text carefully before proceding to the questions.
For the area under development, your company has identified the following four options for consideration:
1: Additional infrastructure: the traffic between Nemijgen and Ernham increases due to closer connections between the cities. By using the area for the development of a new highway, the A101, the increasing traffic delays will be reduced.
2: A residential area: because of the closer connections between Nemijgen and Ernham both cities attract additional residents, but find themselves short of housing options. Additional residence place also reduces traffic delays, but the estimations state that this does not exceed 40% of the improvements that the highway realises.
3: Recreational area: use of the area could also be used for the creation of additional leisure activities (focused on sporting facilities). This helps the surrounding villages, since individual sportsclubs are struggling to make ends meet due to reduced membership numbers. This option would also benefit from increased residence numbers.
4: Forest development: to attract more tourism to the area the land can be used for nature development (e.g. 'wandelparken'). This is an opportunity for the catering industry to increase revenue. Any plans for nature development are severely hindered if the highway is built straight accross the area.
All the options can be developed to a bigger or lesser extent because of the size of the area and the maximum land use of the different options. Also, as is described above, the development of one option influences the development of another (or multiple) other option(s).
The questions that follow address the situation that is described above. Please continue if everything is clear to you or read the case one more time if something was unclear the first time.

8.2.2 Scenarios

Next to the different options your company has identified three courses of action, which are called scenarios:
Economic opportunist: in this scenario the company focuses most on the options that generate the highest economic results, infrastructure (1) and residential area (2). The options recreational activities (3) and Forest development (4) are still pursued, but for completion of the area only.
Neutral development: this scenario has a strong focus on the division of the land in the area. The division is balanced, which increases the attractiveness of the area after completion of the project. For example, the preferred grounds for forest development (4) are considered at the same time as the development of infrastructure (1) instead of afterwards.
Environment comes first: in this scenario the area is developed with an emphasis on minimizing the environmental impact. Obviously in this scenario forest development (4) will be more important than infrastructure (1). Besides choosing an environmentally friendly combination of options, the options are also developed in

an environmental manner. For example, the residential area (2) includes the use of solar pannels when the houses are built.
Next to your own scenarios NWD also has the opportunity to consider three different scenarios. The scenarios of NWD can be categorized as economic, neutral and environmental.
The questions that follow address each of the scenarios of NWD seperately. In each scenario you are asked to identify which scenario(s) you would like to pursue on behalve of your company: Economic opportunist, Neutral development and/or Environment comes first.
Please continue if eveything is clear to you or read the case one more time if something was unclear the first time.

8.2.3 Scenario 1

In the economic scenario NWD wants to support the development that is proposed by your company. However, then the proposal must include a clear destination plan for forest development (4). This limits the space for infrastructure, but the support of NWD will increase the success of the other options. At the same time, if your company decides to pursue the most economic opportunity (where the option infrastructure (1) will be pursued most), NWD protests against your plans, leading to negative publicity and and worse performances of the other options.

8.2.4 Scenario 2

In the neutral scenario NWD is not really involved in the project of your company. NWD is aware of the plans, but as long as your plans aren't harmful for the environment your company doesn't gain negative attention during this project. A strong focus on extra forest development (4) also will not yield more positive attention to increase performances of the other options.

8.2.5 Scenario 3

In the environmental scenario NWD makes it its personal mission to ensure that the area is developed in an environmentally friendly manner. This means that pollution must be kept to a minimum and in addition the proposal must include environmentally friendly solutions. For example, infrastructure (1) that is not necessary will lead to a negative reputation of the area. Likewise, NWD demands the use of solar pannels only to prevent negative publicity. All these environmental activities increase costs, while they don't lead to extra positive publicity.

8.2.6 Decisions as presented to the Respondents

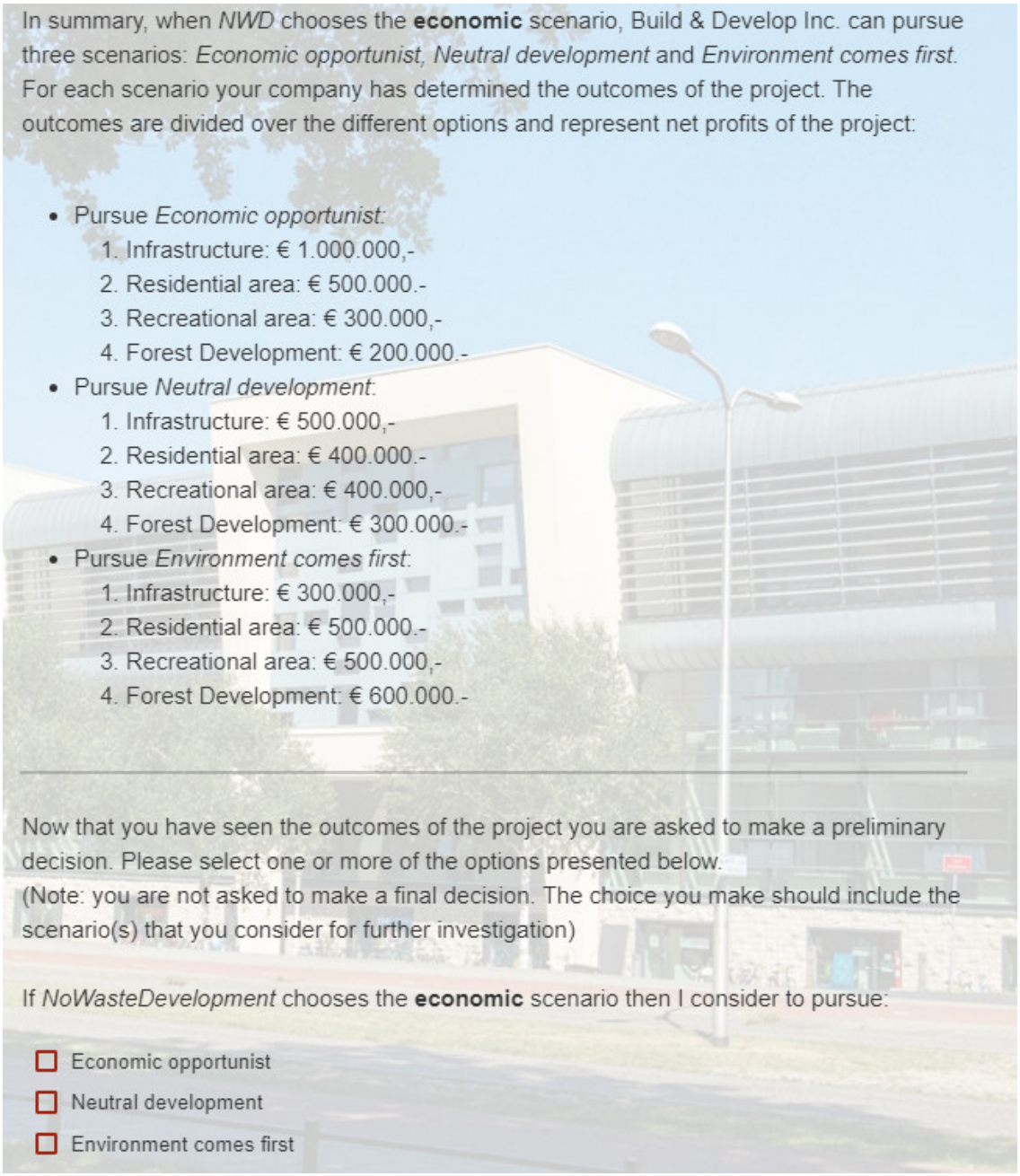

Figure 19: Decision in scenario 1 as presented to the respondents

Figure 20: Decision in scenario 2 as presented to the respondents

Figure 21: Decision in scenario 3 as presented to the respondents

8.3 Appendix 3: Male vs Female responses

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Economic Opportunist	12	30,0	30,0	30,0
	Neutral Development	12	30,0	30,0	60,0
	Environment comes first	14	35,0	35,0	95,0
	Economic Opportunist & Neutral Development	1	2,5	2,5	97,5
	Economic Opportunist & Environment comes first	1	2,5	2,5	100,0
	Total	40	100,0	100,0	

Figure 22: Decisions of men in scenario 1

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Economic Opportunist	3	13,6	13,6	13,6
	Neutral Development	10	45,5	45,5	59,1
	Environment comes first	6	27,3	27,3	86,4
	Economic Opportunist & Neutral Development	1	4,5	4,5	90,9
	Neutral Development & Environment comes first	2	9,1	9,1	100,0
	Total	22	100,0	100,0	

Figure 23: Decisions of women in scenario 1

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Economic Opportunist	8	20,0	20,0	20,0
	Neutral Development	24	60,0	60,0	80,0
	Environment comes first	5	12,5	12,5	92,5
	Economic Opportunist & Neutral Development	2	5,0	5,0	97,5
	Economic Opportunist & Environment comes first	1	2,5	2,5	100,0
	Total	40	100,0	100,0	

Figure 24: Decisions of men in scenario 2

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Economic Opportunist	3	13,6	13,6	13,6
	Neutral Development	13	59,1	59,1	72,7
	Environment comes first	3	13,6	13,6	86,4
	Economic Opportunist & Neutral Development	2	9,1	9,1	95,5
	Economic & Neutral & Environment	1	4,5	4,5	100,0
	Total	22	100,0	100,0	

Figure 25: Decisions of women in scenario 2

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Economic Opportunist	2	5,0	5,0	5,0
	Neutral Development	23	57,5	57,5	62,5
	Environment comes first	12	30,0	30,0	92,5
	Neutral Development & Environment comes first	2	5,0	5,0	97,5
	Economic & Neutral & Environment	1	2,5	2,5	100,0
	Total	40	100,0	100,0	

Figure 26: Decisions of men in scenario 3

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Economic Opportunist	1	4,5	4,5	4,5
	Neutral Development	7	31,8	31,8	36,4
	Environment comes first	12	54,5	54,5	90,9
	Neutral Development & Environment comes first	2	9,1	9,1	100,0
	Total	22	100,0	100,0	

Figure 27: Decisions of women in scenario 3