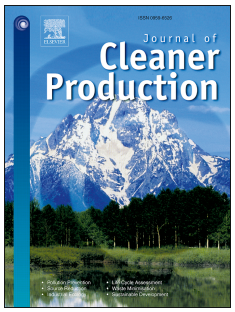
Accepted Manuscript



Teaching sustainability to a broad audience through an entertainment game – The effect of Catan: Oil Springs

Emile J.L. Chappin, Ph.D., Xanna Bijvoet, Alexander Oei

PII: S0959-6526(17)30787-4

DOI: 10.1016/j.jclepro.2017.04.069

Reference: JCLP 9424

To appear in: *Journal of Cleaner Production*

Received Date: 29 August 2016

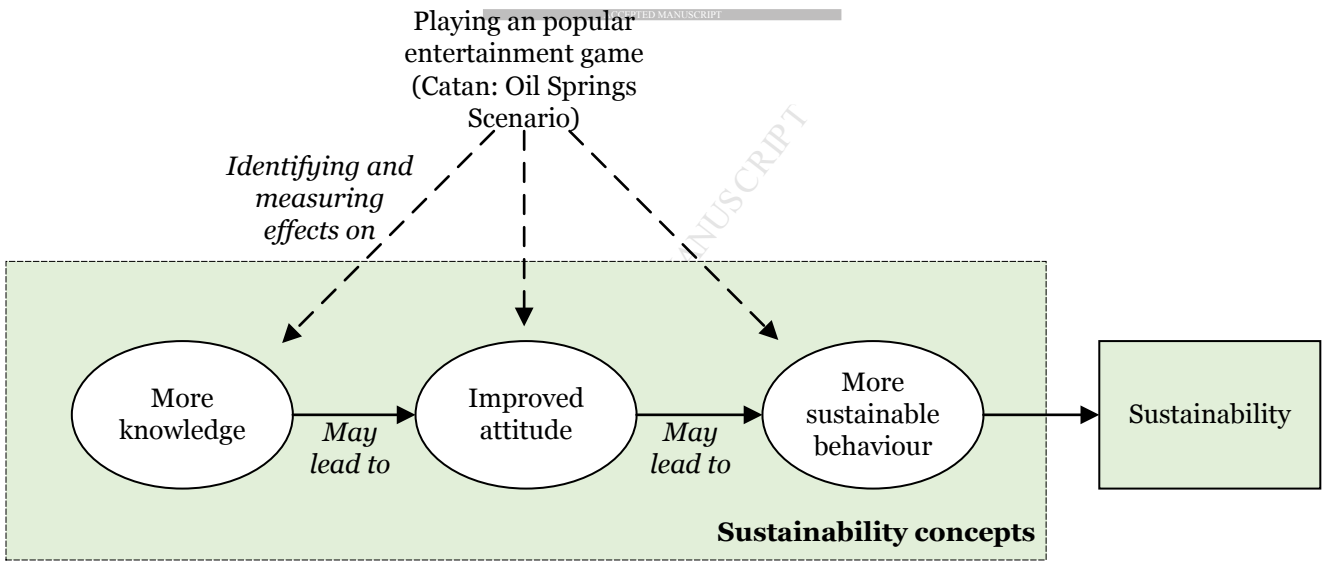
Revised Date: 1 April 2017

Accepted Date: 11 April 2017

Please cite this article as: Chappin EJL, Bijvoet X, Oei A, Teaching sustainability to a broad audience through an entertainment game – The effect of Catan: Oil Springs, *Journal of Cleaner Production* (2017), doi: 10.1016/j.jclepro.2017.04.069.

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

ACCEPTED MANUSCRIPT



ACCEPTED MANUSCRIPT

Teaching sustainability to a broad audience through an entertainment game – The effect of Catan: Oil Springs

Abstract

In order to attain a truly sustainable society it is necessary for people to make 'the sustainable choice' in daily life, business and governance. Instrumental in increasing the awareness and understanding about sustainability issues and improving people's behaviour regarding sustainability issues is sustainability education. However, sustainability education is not yet widespread and is found to not always be effective in tackling people's behavioural aspects regarding sustainability issues. This paper addresses a novel form of sustainability education that has potentially both a wide reach and tackles behavioural aspects of sustainability issues directly: serious gaming. It is shown how an entertainment game, a scenario expansion for the popular board-game Settlers of Catan, can be used to educate a broad audience on sustainability issues. Through a causal analysis of the educational mechanisms embedded in the game scenario the strategies that players might use were found. Subsequently, workshops were held to observe how players are affected by playing the game. The results suggest that playing the game affects people's attitude towards sustainability and, predominantly, the sustainability of the behaviour. Although only the second finding could be supported by statistical tests, the anecdotal observations and quantitative findings do point in the same direction. It was found that the sustainability concepts embedded in the game together with the gameplay dynamics drove the educational effects of the game. These game dynamics enable players to experience real sustainability issues: players are forced to reconsider their strategies, not necessarily to save the Island of Catan, but for their own victory in the game – which is a strong lesson related to sustainability in general and climate change specifically. Future research should focus on conducting larger-scale surveys supporting the execution of statistical tests. In addition, this research points at the untapped potential of teaching sustainability concepts through entertainment games and suggests that game developers incorporate sustainability concepts through educational mechanisms in their games.

Keywords: Climate change awareness; Behavioural change; Serious gaming; Entertainment game; Sustainability; Education

Word count: 8147

1. Introduction

Ever since the Club of Rome published their 'Limits to Growth' in 1972 it has become increasingly clear that there is a need for sustainable development (Meadows et al., 1972). Later, in 1987, the Brundtland Commission devised the now commonly accepted definition of what *sustainable development* is: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland et al., 1987). Within this context, sustainability essentially remains an ill-defined concept (Gatto, 1995) on moral choices between a person's own welfare, the welfare of other people and the health of our environment (Blakely et al., 2009; Ostrom, 1998). It is unlikely that a form of social organization, formalized in for instance laws and regulations will fully capture the true meaning of sustainable development. Instead, it is the *choices* people make that are central to the attainment of sustainable development – by making them sustainability-conscious.

Sustainability education aims to instil the knowledge and understanding needed for people to grasp sustainability concepts and sustainable development. The importance of teaching sustainability concepts is already acknowledged by many educational institutions as is

underlined by the fact that many curricula include courses about sustainable development or tools that support sustainable development. Despite the fact that the prevalence of sustainability education is widespread in higher education programs, this is less so in lower education programs (Dieleman and Huisingh, 2006). The lack of the dissemination of sustainability concepts to a wider public hampers the involvement of sustainability in their decision-making. However, teaching sustainability concepts to the general public using traditional educational methods (i.e. lectures, assignments and projects) may prove to be challenging because (1) the subject matter is complex (Fabricatore and López, 2012) and (2) the traditional means of sustainability education are not always found to be engaging by students (Prensky, 2006).

Studies using frameworks based on knowledge, attitude and behaviour – the basis of the conceptual framework in Figure 1 – show that knowledge alone is not enough to successfully change behaviour (Schrader and Lawless, 2004). A study into the effects of environmental education finds that increased knowledge positively affects attitude (Bradley et al., 1999). Related, Ramsey and Rickson (1976) shows that the environmental attitude is a prominent factor influencing behaviour. The Theory of Planned Behaviour (TPB) shows that one reason is a lack of behavioural control (Ajzen, 1985). A meta-study of 128 studies underlines the relationship between the sources for a lack of behavioural control (situational factors, action skills, locus of control and personal responsibility) and knowledge, attitude and behaviour (Hines et al., 1987).

<< FIG 1 >>
Figure 1: The conceptual framework uses serious gaming as a tool to instil people to make 'the sustainable choice' more often which in turn will lead to a higher level of sustainability.

The goal of this paper is to explore the effectiveness of serious games (Bevilacqua et al., 2015) for sustainability education to a potential large outreach by using an existing extension to a popular board game, Settlers of Catan. The extension used is the Oil Springs Scenario, because it covers the core sustainability concepts in its gameplay. However, currently it is unclear how effective the serious game might be in teaching sustainability concepts to the general public, let alone improve their attitude and cause the players to act more sustainable in the real world after playing the game. The paper addresses the extent to which this game is able to change the general public's awareness and understanding of sustainability concepts and whether playing the game leads to more sustainable behaviour. The research question of this study is formulated as: *"How effective is the Catan: Oil Springs Scenario as a tool to increase the awareness of the general public regarding sustainability issues and affect the sustainability of their behaviour?"*

The effectiveness is defined as the extent to which the scenario reaches the general public (in this case, the potential is outlined above), increases their awareness and understanding of sustainability concepts, and influences their behaviour towards more sustainable practices.

This paper first discusses existing research that used serious games for sustainability education (section 2) and the research method this paper applies (section 3). Subsequently, the Oil Springs Scenario is explored in terms of how the game works and what mechanisms underlie how people play the game and how it might change their views on sustainability (section 4). Then, the actual impact of the scenario on people's knowledge, attitude and behaviour is estimated (section 5). Finally, the conclusions are presented (section 6).

2. Serious games for sustainability education

Serious games, Susi et al. (2007) argue, "are concerned with the use of games and gaming technology for purposes other than mere entertainment or fun" and have the power to motivate and instruct (Meadows, 1999). Some consider gaming to be the most important tool for education because it grounds the educational effort in experience (Harteveld, 2011) and

creates a high involvement (Jahangirian et al., 2010). Moreover, games allow for communication of a complex topic (Duke, 1980; Kelly et al., 2007) and can be developed for a variety of purposes including the application of games in entertainment, education, experiments, research or operational questions (Stahl, 1988). Furthermore, games have proven to be successful in various domains, such as health (Blakely et al., 2009), military (Smith, 2009), law (Rosato, 1995), management (Wolfe & Guth, 1975), and sustainability (Meadows, 2001).

Using games as a teaching approach can be an efficient method for environmental education and for the transmission of sustainability concepts to a large public (Bevilacqua et al., 2015). Serious gaming as a tool has proved to be effective in teaching sustainability concepts (Katsaliaki and Mustafee, 2013), though it is not yet widespread (Michael and Chen, 2005). According to Bevilacqua et al. (Bevilacqua et al., 2015) playing games is an appropriate activity in the context of learning for sustainable development. So far, previous research with serious gaming related to sustainability has focused on the awareness of sustainability issues. Knol and de Vries (2011) sought to use serious gaming as a tool to stimulate the awareness and attitude regarding sustainability and energy saving. Results show clear effects on the awareness and attitude of participants. The University Virginia Bay Game was used to test if the game is an effective platform to learn and raise awareness on sustainability issues among different constituencies (Learmonth et al., 2011). Initial test results showed that game participants abandoned their initial game behaviour and adopted low-impact practices due to insights gained in the direct relationship between human activities and the health of the Chesapeake Bay through playing the game.

Existing research shows that serious gaming can also be used to influence player's behaviour. The focus on behavioural change is often applied in areas as military, corporate and healthcare. One project used games in order to accomplish safer traffic behaviour and it was shown that game based simulations can be used to enhance aspects of learning in driving education and that the learning aspects are about learning the specific traffic safety behaviour (Backlund et al., 2007). The 'Heart Sense Game', aimed to teach players about how to deal with heart attacks in order to reduce delay in seeking care if one ever encounters a heart attack in the real world (Silverman et al., 2001). This particular game affected a change in knowledge about the topic.

Although more successes have been found in the application of serious games in influencing player's behaviour, there are few hard robust findings on how serious games may cause behavioural change. The reason for that lies in the diversity and complexity of games and the range of different perspectives taken by researchers which makes it hard to generalize results (Kirriemuir and McFarlane, 2004). More specifically, there is still a lack in literature of well-founded research describing the influence of serious gaming on behavioural change regarding sustainability concepts. Therefore, in this research the effects of serious gaming on behavioural change regarding sustainability concepts is further explored.

Research on the effects of serious gaming are often performed in higher education. However, sustainability concepts concern every individual, independent from educational level, gender, religion, income etc. Therefore using serious gaming to teach sustainability concepts should not be limited to a certain group of people, but reach a wider public. Using serious gaming aspects in an entertainment game could offer a means to reach a wider public.

3. Method

In this section, the method of this paper is described. The relevance of the game is established in section 3.1, the conceptual analysis of the educational mechanisms is described in section 3.2 and the empirical analysis on the basis of workshops is described in section 3.3. More details on the workshops are described with the results (in section 5).

3.1 The Catan: Oil Springs Scenario

An entertainment game with sustainability concepts embedded is The Catan: Oil Springs Scenario. We show that the features of the game fit with the research purpose of this paper, because key sustainability concepts are covered and the popularity of the game shows a potentially large outreach.

The scenario is an addition to the popular board game Settlers of Catan released in October 2011 and was developed in cooperation with the original developers of Settlers of Catan. The scenario is used to complement the regular Settlers of Catan game by bringing oil as an additional resource into the world of Catan. Oil gives benefits to the user, but also poses risks in terms of pollution and adverse-effects due to climate change. The scenario is therewith an effort to draw attention to today's sustainability challenges. Ultimately the hope is that increased attention will lead to a transformation in thinking, *awareness*, and as a result of that a change in behaviour. Oil, in this scenario, is a proxy for all fossil fuels and mineral resources. Sustainability concepts that are explicit in the game are:

- Externalities (Coase, 1960): certain activities lead to (negative) effects that are not priced in the product of the activity, such as pollution & climate change),
- Resource dependence (Meadows et al., 1972): the dependence on scarce and finite resources (energy, materials) for our economic activities.
- The tragedy of the commons (Hardin, 1968): the rational that a common good is overused, because its attractiveness for each user to use it, despite the fact that this may lead to a collapse of the common good.

The potential outreach of The Oil Springs Scenario may be estimated by looking at the magnitude of the base-game The Settlers of Catan and the dissemination of the scenario itself. "The Settlers of Catan is available in over 30 languages and has sold over 18 million units worldwide since 1995" (Catan GmbH, 2015). With an active player base of approximately 20 million people worldwide the potential audience is substantial, which makes the scenarios development interesting in terms of potential reach. The scenario was released in 2011 in English and German and later in seven other languages and can be downloaded for free. Based on server data from the developers, the scenario was downloaded approximately 15,000 times in English and 10,500 times in German until March 2015. This would mean that the realized dissemination of the scenario is currently less than 1% of all Settlers of Catan players (~25k/20M)[1]. However, informal comments from users indicate that 80% is positive about the scenario and recommends it (Boardgamegeek, 2015), which points at the untapped potential outreach of the game. Moreover, Catan GmbH could decide to tap into this potential by promotion activities, which were limited so far.

3.2 Understanding the educational mechanisms of the scenario

The context of the scenario serves as a basis for determining the potential impacts of playing the Oil Springs Scenario. The potential impacts of playing the scenario are illustrated using a conceptual tool called a causal diagram. In such a diagram causal relations between factors such as people's awareness about sustainability issues and scenario elements such as the number of disasters triggered are related to each other visually. The causal diagram serves as the basis for what is to be tested: does playing the scenario result in a change of perspective on sustainability issues? The relations that are specified in the causal diagram are the result of a mental model based on which hypotheses can be made about the real world. The game rules provided input for this analysis. Subsequently, the educational mechanisms driving learning in the scenario are deduced from the causal diagram. It is conjectured that the educational mechanisms of the scenario form driving forces of the strategies of the players, and that they affect players in their choice between cooperative and competitive strategies.

[1] The percentage is a lower range estimate, as a considerable proportion of the 18 million games sold could be out of use at the moment.

3.3 Measuring the impact of playing the scenario

To gather data on the impact of playing the scenario workshops were conducted in the Netherlands which enabled testing various hypotheses that were identified during the first step. In order to be able to measure a change in people's *knowledge, attitude and behaviour* first the baseline perspective on sustainability issues of workshop participants is determined. Subsequently, after playing the scenario in the workshop a potential change in workshop participants' perspectives was measured. A sample of the Dutch population was invited to play the scenario under the controlled circumstances of a workshop.

Six workshops were held in the Netherlands with between 4 and 9 participants each, accounting for a total of 35 participants, at various gaming events organized for different societal subgroups at gaming events in March-May 2015 and regular attendants of these gaming events were asked to participate in the workshops. The first survey was held directly before playing the game; before handing out this survey, participants were asked whether they agreed to participate in the study. The survey questionnaires are all in Appendix A.

The sample is surveyed before playing the game in order to establish a baseline about their perceptions on sustainability issues. Immediately after playing the game the workshop participants are asked to fill out a survey on sustainability issues again so that a potential change in their perceptions can be measured. Details on the setup of the workshops, the surveys and the results are presented in the remainder of section 5.

People's perspective on sustainability issues is measured *indirectly* by estimating their level of knowledge, attitude towards and behaviour regarding sustainability issues through indicators for these three factors. The reason for indirect measurement opposed to direct measurement is to prevent biases in the result due to potentially socially desirable responses from workshop participants when surveyed more directly. A more direct way of estimating people's perspective on sustainability issues could have been along the lines of: are you familiar with the concept of 'tragedy of the commons'? ; do you find the 'energy transition' towards more sustainable means of satisfying our energy demand important? ; to what extent do you incorporate sustainability concepts in your daily life decisions? An alternative course of action could have been to set out either indirect or direct surveys on Settlers of Catan user group websites to reach a higher number of respondents. The preference for this study was not to do this in order to survey the study participants under the controlled circumstances of a workshop and prevent biases caused by for instance varying game lay-out or interpretations of the game rules.

4. Exploring the Oil Spring's Scenario

In this section, first, the rules of the game are discussed (section 4.1). Consequently, the research rules of the educational mechanisms present in the scenario are elucidated by means of a causal analysis. In addition, the causal analysis informs on potential player strategies and the resulting game dynamics (section 4.2). Finally, the observed mechanisms and individual and collective strategies of players during the game are illustrated (section 3.3).

4.1 The Catan: Oil Springs Scenario – the rules of the game

The Oil Springs Scenario is an extension of the board game the Settlers of Catan, in which players have to build up their towns and cities, while competing for locations that provide access to the resources, brick, lumber, ore, grain and wool[2]. The scenario introduces oil as a valuable new resource which can be converted into other resources and enables upgrades of cities into metropolises. Figure 2 illustrates the adaptation to the game, which shows that oil

[2] Games rules for Settlers of Catan can be downloaded from the original website for the world of Catan: http://www.catan.com/service/game-rules

spring tiles need to be placed on the desert hex, the 9 forest hex and the northeast 10 pasture hex. An oil spring overrides the underlying resource and only oil can be produced.

<< FIG 2 >>
Figure 2: The game board with the Oil Springs Scenario.

The supply of oil is finite and using oil is not without a cost. The use of oil causes pollution and climate change and, in time the effects can lead to the threat of coastal flooding even flooding the island of Catan. Players decide during the game whether or not will they make use of the discovered oil, how much oil they use.

Players with oil units in stock can, at the start of the turn, choose to consume the oil unit or to sequester it. Oil units can be converted into two units of one of the other resources. Oil units can also upgrade a city to a metropolis with additional advantages. Finally, players can sequester a maximum of one unit of oil per turn, which permanently removes it from the game. As this contributes to sustainability, they can gain a victory point and the first player who sequesters three oil units earns the Champion of the environment token, which is worth a victory point.

There is a limited supply of oil and each player can hold a maximum of 4 units of oil. Multiple oil units can be used during a turn, but at a cost: the consumption of oil results in pollution and climate change, so a disaster is triggered after every five oil units used. To determine what kind of disaster strikes, the two dice need to be rolled. In most cases, industrial pollution strikes, on one of the hexes with the number with the outcome of the dice role. If this hex is an oil spring, three oil of the general supply will be removed. If the hex has another resource, it is spoiled and fails to produce from then onwards. The exception to this is the dice show a seven: this triggers a climate change induced natural disaster, flooding the coasts. Settlements bordering a sea hex are destroyed and removed from the board; cities are reduced to settlements.

The game typically ends when one of the player reaches twelve or more victory points, but an additional end is possible: when five hexes are struck by disaster, the whole island floods. In the latter case, there is no game winner. The person who holds the 'Champion of the Environment'-token achieves a so-called 'Pyrrhic Victory'. That player is recognized by the international community for his efforts to mitigate climate change.

4.2 Understanding the educational mechanisms of Oil Springs Scenario

The causal diagram in Figure 3 illustrates the Catan: Oil Springs Scenario from a player's perspective. It illustrates key causal factors influencing his or her decisions regarding oil and the economic, environmental and social consequences. Since in playing Settlers of Catan one's success in acquiring victory points largely depends on the amount of resources that can be secured, a player with a competitive attitude would try to use oil to gain an economic advantage. The possible side-effects of using oil – increased likelihood of disasters and induced floods and landscape infertility – may cost players resources in the long run (and even a complete failure). Prior beliefs and strategies of players affect the evolution of the game: player's environmental concerns make them more prone to consider the negative consequences of possible disasters.

<<FIG 3>>
Figure 3: The Causal diagram of the Oil Springs Scenario's working shows factors as ovals, arrows indicate causalities, with a plus sign implying a direct positive causal relation, and a negative sign a direct negative relationship. Some arrows are dashed for clarity. The circular arrows represent feedback loops, in other words reinforcing relations.

4.2.1 Educational mechanisms

Players have to decide over and over again whether to use oil, or, whether to form alliances to refrain from using oil and sequester the resource instead. The influence of these key decisions are defined as the so called educational mechanisms, which also stem from negative feedback loops that tend to stabilize or positive feedback loops that tend to be uncontrolled (noted as such in Figure 3).

- *Finite resources* – Oil resources are finite and any use of oil lowers the amount of resources available. Although scarcity eventually lowers the use of oil, before the end of oil it incentivizes players to acquire as much of the oil as they can in order to avoid a competitive disadvantage (the latter is visualized in the causal diagram).
- *Learning from disasters* – In order to reduce these disastrous consequences players can decrease their oil use and thus lower the chance of future disasters. This learning effect is very important for the awareness of the player's behaviour in oil consumption and their consequences on the Island.
- *Learning by shock* – There is the one-time possibility to learn by 'shock', in which the game fails completely, leaving no one as a winner. This occurs after too many disasters. By ending the game prematurely, the players are pointed strongly on the possible severity of climate change effects in the long run.
- *Managing and free-riding the commons* – As mentioned the resource oil forms a commons and a complex set of mechanisms play a role in to what extent the commons can be managed or allows for free-riders. Mechanisms as avoidance to put themselves into a disadvantage positions towards others and concerns about the effects of their oil consumption play a role in the players deciding on the amount of oil is consumed.
- *Competition* – The objective of winning the game drives players to focus on their individual gains, more than on the common goals of all players. Players are forced to make decisions and therefore are faced with forming a strategy regarding how to react to other players that want to manage the commons or try to free-ride. Competitive pressure will reinforce the lessons learned regarding the consequences of the player's oil consumption.

4.2.2 Player's strategies

Players start the game with their initial individual strategies based on their intrinsic values. From the causal diagram, two distinct dimensions can be derived on which the players can vary:

- The extent to which players are driven by *environmental concerns* or just *individual gains* (environment versus economics). This is not necessarily the same balance as a player has in the real world, but rather his intuition, ideas or experience regarding the relative importance of environmental and economic factors in the game.
- To what extent the player is *willing to form agreements* with other players (alone versus together). This relates to the abilities to negotiate, but also to see the desire or see opportunities to collaborate to gain more economic power in the game.

These two dimensions span the strategy space visualized in Figure 4 and allow for five distinct strategies. The four corner strategies as the extremes are described to illustrate the strategy space.

- A '*green hard-liner*' is only convinced of his moral values, which implies that he is purely driven by environmental concerns and he will not consume oil. The player may realize that by not building settlements on oil springs he puts himself in a disadvantaged position. Nevertheless, the player is of the opinion that everyone should find out for themselves.
- Whereas a '*fundamentally green*' player knows the potentially disastrous consequences of using oil, so he will not consume oil during the game, either by not building settlements on oil springs or by producing and sequestering oil. The latter strategy helps this player in the long-run by avoiding the competitive advantage of other players consuming oil and by building trust towards collaboration.
- An '*opportunistically green*' player focuses on his individual gains; he assumes that the advantage of consuming oil outweighs the shared burden of the potential

disasters. Still, this player behaves opportunistically, as he is able to form green agreements when he expects to benefit most.
- Though a '*purely self-interested*' player focuses on his individual gain and makes use of the opportunities of oil for as long as he can. The player runs a serious risk of flooding Catan, which would prematurely end the game.
- Lastly a '*calculative player*' aims to strive for a balance between the disastrous consequences of oil consumption and the advantages oil consumption brings. Experience with the game and this scenario will push players towards a calculative balance in their strategy.

<<FIG 4>>
Figure 4: Strategy space spanning the willingness of forming agreements and the environmental and economic drivers

4.2.3 Game dynamics
All players influence the result: the system result emerges from the repeated actions and interactions of the players. The described educational mechanisms and other events during the game make players adapt their individual strategies which, as a result, can lead to a variety of game patterns. On this basis, the following game dynamics are expected:

- *Intrinsically green* – Players completely avoid the use of oil at the cost of economic growth; the agreement to collaborate holds against the possibilities to free-ride.
- *Conjointly greening* – When several disasters are triggered after a while, all players will realize that no disasters should occur anymore otherwise more resource fields are lost and Catan will flood eventually and they will decide that nobody can consume oil anymore.
- *Collective learning* – The awareness of the side effect of oil consumption slowly influences the individual strategy of the player into a more environmentally concerned driven strategy since all players agree with each other that oil consumption is prohibited.
- *Punishment for free-riders* – If a player continues consuming oil until other players are annoyed, they will cooperate in order to force the free rider to stop consuming oil.
- *Tragedy of the commons* – Players are all aware of the fact that no disasters should occur anymore otherwise Catan will flood within a few turns, but the focus on their individual gains is predominate. They cannot agree to collaborate with each other and this eventually leads to collapse.

4.3 Observed mechanism and individual and collective strategies
During the workshops (of which the details are discussed in section 5), the strategies that players used and how they changed were monitored. The observations are summarized in Figure 5.

<< FIG 5 >>
Figure 5. Observations from workshops indicate the forces that affect players' strategies.

4.3.1 Educational mechanisms
The effect of finite resources was not often visible, true scarcity was rare. Disasters had a large influence on strategies of players whose competitiveness was directly affected. Competition is the key driver of the game: it was observed that it made people to free-ride, continuing to use oil after disasters. Learning by shock was not observed, as in none of the workshops the Island of Catan flooded (despite the fact that the developers experienced that on average 15% of the game sessions they observed ended in fatal disaster for the island of Catan). Attempts to free-ride and manage the commons were observed: players did try to nudge the others to agree on stopping to use oil.

4.3.2 Individual strategies

Not all individual strategies were observed. The extremely green strategies (green hard-liners and fundamentally green) were not used. All players were persuaded to try to use oil, in only out of curiosity. The other strategies (purely self-interested, opportunistically green and calculative consumer) have all been observed.

Observations indicate that the educational mechanisms (as described above) in the game do affect the individual strategies used. Many players were able to adapt their strategies. The most notable effects move was from purely self-interested towards opportunistically green or calculative consumer. Figure 5 illustrates how the mechanisms affected the players' strategies. Competition drives people to focus on individual gain. Free-riders force make others avert agreements, disasters make people more concerned and the understanding of the commons make them more willing of forming agreements. The other two mechanisms – finite resources and learning by shock were not observed and therefore did not affect the strategies.

4.3.3 Game dynamics
Not all identified collective strategies have been observed: neither intrinsically green nor conjointly greening appeared as such in the workshops: there were always players not willing to cooperate to a successful collective greening strategy. Nevertheless, players did agree on lowering oil use but did not completely abandon it. Collective learning and the tragedy of the commons emerged as expected. Finally, free-riders were not directly punished. When punished, for instance by the robber or by excluding from trade, it was to prevent a player from winning and therefore targeted well-performing players in general, not particular those using oil.

The experience from the workshops confirms that the game forces players consistently to face the question of using oil and it makes people experience important sustainability concepts – how strong the tragedy of the commons is and how hard it is to safeguard against free-riders.

5. Measuring the impact of the scenario

This section measures the effectiveness of the Catan Oil Springs Scenario as a tool to teach sustainability through the educational mechanisms and strategies identified earlier. Firstly, it gives an overview of the workshops that were held (section 4.1). Then the measured effects of playing the game are illustrated (section 4.2).

5.1 Workshops

During the workshops the participants play Settlers of Catan with the Oil Springs Scenario with 3-4 players per game.

5.1.1 Survey setup
The workshop participants are subjected to two surveys: a so-called 'pre-test' and a 'post-test', which are described in Appendix A. The pre-test is issued before playing the scenario in the workshop to establish a baseline of participants' perspectives on sustainability issues. Immediately after playing the game in the workshop the post-test is issued to measure a potential change in participants' perspectives on sustainability issues. All surveys contain eight questions about knowledge, eight questions about attitude and eight questions about behaviour: the structure of the pre-test and post-test is the same, but the questions are different. The questions are inspired by the causal analysis of section 3, regarding knowledge of, attitude towards and behaviour regarding the sustainability concepts covered in the game and the related educational mechanisms. Additionally, the pre-tests contain general questions regarding demographics.

To prevent that respondents share their answers with each other, three different versions of the survey are used (versions A, B and C), with different questions about knowledge, attitude and behaviour (see Appendix A for the composition of these versions). The fact that also the

version before and after playing the game are different, introduces a considerable risk of measurement errors: the questions will not necessarily be fully comparable. Nevertheless, it was decided to use different versions and adapt these outcomes (according to the approach described below 4.2.3); this weakens the findings but avoids priming as far as possible.

5.1.2 Sample and representativeness
The necessary sample size for a survey is dependent on the heterogeneity of the population about which statements are made, the desired accuracy and the desired confidence interval. Despite the fact that the Oil Springs Scenario targets a wide audience and this requires a reasonable sample size, practical reasons limit the sample drawn in this research study. The sample will merely provide for an indication of the effects and generalizability of the results of the sample size will remain an issue.

On the basis of the analysis of the general questions and a statistical comparison with official Dutch statistics (CBS, 2015), it is concluded that the sample is acceptable in terms of gender (60% men, difference to the Dutch average not significant at 95% confidence level, a result caused by the small size of the sample), but that there is a strong focus on young people (72% of the participants is <30 years, average age and age groups different to the Dutch statistics significant at 95% confidence level), with, most likely as a consequence, an income level lower than the Dutch average (difference statistically significant at 95% confidence level). Finally, the sample is too highly educated (groups different to the Dutch educational levels significant at 95% confidence level). These issues with representativeness indicate that the sample is too small and skewed and the results are mostly applicable for young people and educational level above average. All quantitative findings need to be interpreted with care. Tests and details can be found in Appendix B.

5.1.3 Determining the overall scores on knowledge, attitude and behaviour
The questions on knowledge, attitude and behaviour are used to determine the overall awareness of the respondents. All these questions are measured on a similar 5-step Likert scale, as can be seen in Appendix A. In order to make the questions from the three different survey versions comparable an additional group of 32 cases is used that do not participate in the workshops. This reference group answers all questions that occur in the different survey versions. These answers determine an average score per question. Not the absolute scores of workshop participants, but the relative scores of the workshop participants compared to the averages of the reference group are used to determine the knowledge, attitude and behaviour levels of the workshop participants. The knowledge, attitude and behaviour levels are measured before and after playing the game. For example, when the average score on a particular question on knowledge in the reference group is 1.2 and an individual scored 2 in the test, his denoted score is 2 – 1.2 = 0.8. This can be interpreted as that his knowledge is 0.8 higher than average. As all participants get the same number of questions, the sum computes his or her overall score on the knowledge level, the attitude level and the behaviour level, both before and after playing the game. The result is the basis for the analysis. Also for this group, representativeness is tested. Similar issues are found with representativeness as those described for the sample above. This reconfirms that all statistical results need to be interpreted with care. Tests and details can be found in Appendix B.

5.2 Measured effects of playing the game
Various tests and analyses are used to measure the impact of the game. The results are summarized in Figure 6. The results in general are weakened by the small size of the sample and lack of representativeness and, as a consequence, merely provide indicative findings.

<< FIG 6 >>
Figure 6. Overview of findings that indicate the impact of the playing the game. Regular arrows indicate significant correlations (at 0.05 level). Dashed arrows indicate significant

coefficients from various regression analyses (at 0.05 level). Regression models predict knowledge and attitude before playing the game and the behaviour after playing the game.

The measured correlations support the theoretical model of knowledge leading to attitude and, in turn, leading to behaviour. A regression analysis finds that sustainable behaviour of participants after playing the game is affected by the attitude after playing the game and the sustainable behaviour that participants had before playing the game. The fact that the attitude after playing the game is the explanatory factor, and not the attitude before playing the game, suggests that there is an impact of the game and that it operates through the change in attitude towards sustainability that participants experience during the game. Other regression analyses suggest that the level of education of participants affects their knowledge level with respect to sustainability, which is an intuitive result and that gender affects the attitude towards sustainability, where females have a more sustainable attitude. In the remainder of this section, these results are discussed in detail. Appendix C includes other tests which with inconclusive findings that are not presented here for clarity.

5.2.1 Correlations between knowledge, attitude and behaviour

Correlations between the pre-test and post-test on knowledge is 0.694, on attitude 0.581 and on behaviour is 0.551 and these correlations are significant (at 0.05 level). This implies that the variation in knowledge, attitude and behaviour after playing the game is for 30-48% determined by the players' knowledge, attitude and behaviour respectively before playing the game. The remaining variance in the post-test's scores has to be the result of playing the game or that of measurement errors, such as the errors in making the questions comparable. In the first case, this is a strong finding that the game has a real effect on the participants view on sustainability, and the game is, by means of experience, able to get across some of the important sustainability concepts.

Table 1 shows the relationships between knowledge, attitude and behaviour, which turn out to be significant. The largest correlations are found between attitude and behaviour. The correlation between knowledge and attitude is lower and the correlation between knowledge and behaviour even lowest. These findings appear to fit the conceptual framework model in Figure 1, where knowledge on sustainability issues affect the attitude regarding sustainability and that, in turn, the attitude affects sustainable behaviour.

Table 1. Correlations between knowledge, attitude and behaviour. All correlations are significant at 0.05 level.

	Pre-test			**Post-test**		
Variable	Knowledge	Attitude	Behaviour	Knowledge	Attitude	Behaviour
Knowledge	-	0.352	0.517	-	0.370	0.179
Attitude	0.352	-	0.539	0.370	-	0.566
Behaviour	0.517	0.539	-	0.179	0.566	-

5.2.2 Regression analysis

A linear regression analysis with the behaviour regarding sustainability issues after playing, estimates that behaviour as follows:

*Behaviour after playing = 0.245 + 0.629 * attitude after playing + 0.354 * behaviour before playing*.

The terms are significant and the model explains 44% of the variance. Standardized coefficients indicate that both terms are similar in their explanatory value. It is important to note that the attitude *after* playing the game is the first independent variable in this model, which is a significant effect of playing the game: the attitude during the game is affected and

that influences the behaviour, together with all factors that already influenced behaviour before playing the game. Demographic variables were included in the analysis, and were found not to be significant as independent variables.

The independent variables in the model support the inconclusive findings from paired T-tests (as described in Appendix C) and indicate that the game is not influencing knowledge, but it does have an effect on attitude which has a significant effect on behaviour. This indicates that the knowledge gained by playing the game is rather abstract, but that the effect of playing the game seems to mean that players are forced again and again to make conscious decisions regarding their oil-related behaviour. This is a mechanism that ties well into the theory of planned behaviour: one is forced out of the habitual behaviour of filling up the tank of the car at the gas station, which is generally difficult to achieve with other means (Jensen et al., 2015).

Additional regression models were executed for the knowledge, attitude and behaviour before playing the game. Only education was found to have an influence on the knowledge before playing the game, a higher educational level affecting a higher knowledge level, explaining 25% of the variance in knowledge. Gender was found to have an influence on the attitude towards sustainability, i.e. women having a greener attitude than men, explaining 25% of the variance in attitude. The latter was confirmed by anecdotal observations that women did play the game differently: they appeared on average more willing to cooperate than men (for instance their strategy in trading). These regression models and their terms were found significant. None of the demographics had a significant effect on behaviour. The findings suggest that there is a significant effect of gender, but this finding could relate to the effectiveness of the game.

5.3 Comparison to similar work

When looking at similar games for education of sustainability-related issues, it is found that a study on a 'Heart sense game' applies a similar knowledge-attitude-behaviour model. That study mainly shows effects on attitude (they use the term intention) (Silverman et al., 2001). This differs to the findings in the study of this paper, which suggests a direct effect on behaviour. The game is played with a small advisory group of doctors and general practitioners and a small user group (but they are unspecified) and do not seem to target the a more general audience. Interesting is that they used different versions of their game to test the effect of different configurations. The health sector is a prominent domain for the use of serious gaming for training purposes, and the 'Heart sense game' fits well in that literature stream.

Different to study of this paper, Silverman et al. (2001) deliberately use the same questionnaire before and after playing the game because their core purpose is training (and repetition is a key element of learning). For the study in this paper, this would not work, because we are primarily interested in the effect that the game itself has, not the learning by the questionnaire itself (and possibly discussion of the questions amongst participants. The other difference is that the questions they use are very close to the content of the training. Because the game used in this paper is a strong abstraction – it is an entertainment game – this paper aims to study the effect on sustainability issues in general and the survey questions are phrased accordingly.

The findings of this study do corroborate results from the 'UVa Bay Game' (Learmonth et al., 2011), which essentially also is a game with a tragedy of the commons, but applied to a very different domain. Through playing the game participants gained a better understanding of the consequences of their decisions on the health of 'the bay'. This includes the fundamental dynamics of a tragedy of the commons and possible responses (despite the fact the authors use other terms). As in these results, Learmonth et al. (2011) suggest a direct effect of playing

this game on the expected behaviour of participants regarding various sustainability concepts.

6. Conclusions

This paper explores the potential of using serious gaming in teaching sustainability concepts directed at improving people's awareness and understanding of and behaviour regarding sustainability issues. In current literature examples of the application of serious gaming in teaching sustainability concepts exist, but these efforts were always directed at higher educated people. Novel in this research is that it is directed at a broad public by using an entertainment game, which may potentially have a substantial reach. The research question is: *"How effective is the Catan: Oil Springs Scenario as a tool to increase the awareness of the general public regarding sustainability issues and affect the sustainability of their behaviour?"*

In order to gage the effectiveness of the Catan: Oil Springs Scenario, first, a qualitative analysis was conducted in order to identify the educational mechanisms that drive player's strategies in the game, the overall game dynamics and therewith learning. Subsequently, the impact of playing the scenario on people's perspective on sustainability issues was measured through indicators for people's perspective on sustainability issues being people's knowledge of, attitude towards and behaviour regarding sustainability issues.

6.1 Qualitative findings

Through a causal analysis of the mechanics of playing the game six educational mechanisms were identified which are believed to drive learning in the game. Four of these six educational mechanisms stood-out and are identified as the drivers behind players' strategies and the overall game dynamics being: competition, managing the commons, learning from disasters and free-riding the commons. Anecdotal observations of players' behaviour while playing the game during six workshops confirmed the findings from the causal analysis: the players adapted their individual strategies in the game based on what they learned while playing the game. Most importantly, learning seemed to be induced by the educational mechanisms described. Furthermore, the overall game dynamics that emerged while playing the game were in line with expectations: awareness of and efforts to prevent the 'tragedy of the commons' from moving forward was clearly visible. The findings in the qualitative analysis therewith suggest that playing the game will result in a change in people's awareness and understanding of sustainability issues. Additionally, it would change their behaviour regarding sustainability issues since the players' learned from adapting their strategies.

6.2 Quantitative findings

In order to substantiate the hypothesis that playing the game will result in a change in people's perspective, the impact of playing the game was also measured. Workshop participants were surveyed before directly after playing the game to measure potential change in their knowledge of, attitude towards, and behaviour regarding sustainability concepts. Results show that the correlations between the pre-test and post-test on knowledge, attitude and behaviour are significant, which is in line with the hypothesis. The strongest correlation is between attitude and behaviour, corresponding with the conceptual framework (presented in Figure 1) where knowledge on sustainability issues affects the attitude regarding sustainability and that, subsequently, the attitude affects sustainable behaviour. The results from the regression analysis show that the scenario does not influence knowledge, but it does affect attitude, which has a significant effect on behaviour. Additional regression models for knowledge, attitude and behaviour before playing the game show that participants' level of education has an effect on 'knowledge' and participants' gender on 'attitude'. No significant results are found on the influence of the demographics on behaviour. However, due to the small sample size and deviating demographics, the sample is not representative for the Dutch population, which makes it impossible to generalize these results.

The decision to measure the impact of the game *indirectly* through indicators for knowledge, attitude and behaviour regarding sustainability issues enabled us to prevent bias in the measurement due to for instance socially desirable responses from participants. In addition, using multiple variants for the surveys prevented discussion among participants. As a result, it avoids a bias in the survey results as much as possible. However, it is likely that these decisions also caused the measured impacts on participants' perspective on sustainability issues to be smaller than the impact of playing the game actually was.

6.3 Next steps for sustainability education

In conclusion, the statistical results are in line with the expectations posited in the qualitative analysis. Although not all results were statistically significant, they are at least not conflicting. The statistical results are, therefore, interesting and as such an encouragement to build on the developed research framework by executing larger-scale workshops in order to acquire a large sample size. Executing larger-scale workshops will also make it possible to acquire a more representative sample for the general public.

This research has shown that serious gaming elements incorporated in an entertainment game can be used as a tool to influence people's awareness about sustainability issues and affect people's behaviour regarding sustainability issues. The results point at the potential of adding serious gaming elements to existing entertainment games. Game designers could therefore step away from developing for-purpose games, and opt to use more of what exists and is popular. By elucidating the drivers in the game and the educational mechanisms that could be expected educators and designers would be able to determine the appropriateness of existing entertainment games. They could be expanded, as in this paper, but one could also imagine designing appropriate workshops with original entertainment games. These options should be seriously considered for education, in particular as they have the potential to have a farther outreach. And that may prove worthy for the overall impact that serious gaming may gain.

ACCEPTED MANUSCRIPT

References

Ajzen, I., 1985. From Intentions to Actions: A Theory of Planned Behavior, in: Kuhl, J., Beckmann, J. (Eds.), Action Control - From Cognition to Behavior, SSSP Springer Series in Social Psychology. Springer, pp. 11–39.

Backlund, P., Engström, H., Johannesson, M., Lebram, M., 2007. Games and traffic safety-an experimental study in a game-based simulation environment, in: Information Visualization, 2007. IV'07. 11th International Conference. IEEE, pp. 908–916.

Bevilacqua, M., Ciarapica, F.E., Mazzuto, G., Paciarotti, C., 2015. "Cook &Teach": learning by playing. J. Clean. Prod. 106, 259–271. doi:10.1016/j.jclepro.2014.11.085

Blakely, G., Skirton, H., Cooper, S., Allum, P., Neimes, P., 2009. Educational gaming in the health sciences: systematic review. J. Adv. Nurs. 65, 259–269. doi:10.1111/j.1365-2648.2008.04843.x

Boardgamegeek, 2015. Catan Scenarios: Oil Springs.

Bradley, J.C., Waliczek, T.M., Zajicek, J.M., 1999. Relationship between environmental knowledge and environmental attitude of high school students. J. Environ. Educ. 30, 17–21.

Brundtland, G., Khalid, M., Agnelli, S., Al-Athel, S., Chidzero, B., Fadika, L., Hauff, V., Lang, I., Shijun, M., de Botero, M.M., 1987. Our Common Future ('Brundtland report').

Catan GmbH, 2015. About Catan GmbH.

CBS, 2015. CBS Statline.

Coase, R.H., 1960. The Problem of Social Cost. J. Law Econ. 1960, 1–23.

Dieleman, H., Huisingh, D., 2006. Games by which to learn and teach about sustainable development: exploring the relevance of games and experiential learning for sustainability. J. Clean. Prod. 14, 837–847. doi:10.1016/j.jclepro.2005.11.031

Duke, R.D., 1980. A Paradigm for Game Design. Simul. Games 11, 364–377.

Fabricatore, C., López, X., 2012. Sustainability Learning through Gaming: An Exploratory Study. Electron. J. E-Learn. 10, 209–222.

Gatto, M., 1995. Sustainability: Is it a Well Defined Concept? Ecol. Appl. 5, 1181–1183.

Hardin, G., 1968. The Tragedy of the Commons. Science 1968, 1243–1248.

Harteveld, C., 2011. Triadic Game Design -- Balancing Reality, Meaning and Play. Springer-Verlag, London, UK.

Hines, J.M., Hungerford, H.R., Tomera, A.N., 1987. Analysis and synthesis of research on responsible environmental behavior: A meta-analysis. J. Environ. Educ. 18, 1–8.

Jahangirian, M., Eldabi, T., Naseer, A., Stergioulas, L.K., Yong, T., 2010. Simulation in manufacturing and business: A review. Eur. J. Oper. Res. 203, 1–13.

Jensen, T., Holtz, G., Chappin, E.J.L., 2015. Agent-based assessment framework for behavior-changing feedback devices: combined spreading of devices and energy conservation in domestic heating. Technol. Forecast. Soc. Change 98, 105–119. doi:10.1016/j.techfore.2015.06.006

Katsaliaki, K., Mustafee, N., 2013. Serious games for sustainable development.

Kelly, H., Howell, D., Glinert, E., Holding, L., Swain, C., Burrowbridge, A., Roper, M., 2007. How to Build Serious Games. Commun. ACM 50, 45–49.

Kirriemuir, J., McFarlane, A., 2004. Literature review in games and learning.

Knol, E., De Vries, P.W., 2011. EnerCities-A serious game to stimulate sustainability and energy conservation: Preliminary results. ELearning Pap.

Learmonth, G., Smith, D.E., Sherman, W.H., White, M.A., Plank, J., 2011. A practical approach to the complex problem of environmental sustainability: The UVa Bay Game. Innov. J. Public Sect. Innov. J. 16, 2011.

Meadows, D.H., Meadows, D.L., Randers, J., Behrens, W.W., 1972. The limits to growth. N. Y. 102.

Meadows, D.L., 2001. Tools for Understanding the Limits to Growth: Comparing a Simulation and a Game. Simul. Gaming 32, 522–536. doi:10.1177/104687810103200408

Meadows, D.L., 1999. Learning to Be Simple: My Odyssey with Games. Simul. Gaming 30, 342–351. doi:10.1177/104687819903000310

Michael, D.R., Chen, S.L., 2005. Serious games: Games that educate, train, and inform. Muska & Lipman/Premier-Trade.

Ostrom, E., 1998. A behavioral approach to the rational choice theory of collective action. Am. Polit. Sci. Rev. 92, 1–22.

Prensky, M., 2006. Don't bother me, Mom, I'm learning!: How computer and video games are preparing your kids for 21st century success and how you can help! Paragon house St. Paul, MN.

Ramsey, C.E., Rickson, R.E., 1976. Environmental knowledge and attitudes. J. Environ. Educ. 8, 10–18.

Rosato, J.L.., 1995. All I Ever Needed to Know About Teaching Law School I Learned Teaching Kindergarten: Introducing Gaming Techniques into the Law School Classroom. J. Leg. Educ. 45, 568–581.

Schrader, P.G., Lawless, K.A., 2004. The knowledge, attitudes, & behaviors approach how to evaluate performance and learning in complex environments. Perform. Improv. 43, 8–15. doi:10.1002/pfi.4140430905

Silverman, B.G., Holmes, J., Kimmel, S., Branas, C., Ivins, D., Weaver, R., Chen, Y., 2001. Modeling emotion and behavior in animated personas to facilitate human behavior change: the case of the HEART-SENSE game. Health Care Manag. Sci. 4, 213–228.

Smith, R., 2009. The Long History of Gaming in Military Training. Simul. Gaming 41, 898–920.

Stahl, I., 1988. Using operational gaming, in: Handbook of Systems Analysis. Elsevier Science Publishing, pp. 121–171.

Susi, T., Johannesson, M., Backlund, P., 2007. Serious games: An overview.

Wolfe, J., Guth, G.R., 1975. The Case Approach Versus Gaming in the Teaching of Business Policy: An Experimental Evaluation. J. Bus. 48, 349–364.

ACCEPTED MANUSCRIPT

Appendix A Survey questions

Data was gathered before and after the workshop. All tests include questions on workshop participants' knowledge of, attitude towards and behaviour regarding sustainability issues. To prevent a potential bias from participants discussing the survey questions with each other different there are three versions. The composition of the survey versions is shown in Table A1.

Table A1. Composition of survey versions. The numbers relate to the related knowledge, attitude and behaviour questions in Appendices A.3, A.4 and A.5 respectively.

Survey	Version A	Version B	Version C
Pre-knowledge, attitude and behaviour	1-8	1-4, 9-12	5-8, 13-16
Post-knowledge, attitude and behaviour	9-16	5-8, 13-16	1-4, 9-12

The pre-test also includes a general set of questions, listed in Appendix A.2. The specific questions are listed in Appendices A.3-A.5.

A.1 General questions in each pre-test

1. What is your gender?
   - o Male
   - o Female

2. What is your year of birth?

   _____

3. What is your highest level of education?
   - o Primary school
   - o VMBO/LBO/VBO/MAVO
   - o MBO/HAVO/VWO
   - o HO/WO Bachelor
   - o WO Master/Doctoral

4. In which income group do you belong?
   - o To €20.000,- a year
   - o Between €20.000,- and €30.000,- a year
   - o Between €30.000,- and €40.000,- a year
   - o Between €40.000,- and €60.000,- a year
   - o More than €60.000,- a year

5. What is your religion?
   - o No religious denomination or religious group
   - o Roman Catholic
   - o Dutch Reformed
   - o Reformed Churches
   - o Protestant Church in the Netherlands
   - o Islam
   - o Jewish
   - o Hindu
   - o Buddhist
   - o Other church or religious group, namely _____

6. In which country were you born?
7. In which country were your father born?

8. In which country were your mother born?

6-8 with the following answers:
- Netherlands
- Suriname
- Netherlands Antilles
- Turkey
- Morocco
- Other country, namely _____

A.2 Knowledge questions

Please indicate to what extent you are familiar with the following facts:

Possible answers: not known, more unknown than known, neutral, more known than unknown, and fully known

1. The average water consumption in the Netherlands is approximately 125 litres per day per person
2. Extraction of oil is often accompanied by local pollution of the environment by for example leaking oil during transportation
3. The threat of overfishing, where more fish is extracted from the sea than fish shoals can recover, leads to losses of fish species.
4. Combustion of fossil fuels, including oil, is accompanied by emissions of greenhouse gases such as carbon dioxide
5. Human activities have a measurable effect on the global carbon dioxide concentrations
6. The increase in global carbon dioxide concentrations has an enhancement of the green houses effect as result
7. An enhanced greenhouse effect ensures a change in the Earth's climate
8. The combustion of diesel or gasoline in a car is accompanied by the emissions of carbon dioxide
9. Collecting and recycling waste contributes to a sustainable society
10. When more water is returned to the ground water tank than is withdrawn from the ground water tank one speaks of durable groundwater extraction
11. Development is seen as sustainable development when the needs of the present fit without compromising the ability of future generations to endanger their own needs
12. Fossil fuels can run out
13. Global population growth puts the limited resources of Mother Earth under increasing pressure
14. The Netherlands will generate at least 14% of its energy using renewable energy sources in 2020
15. The Netherlands will generate all of its energy using renewable energy sources in 2050
16. It requires much more land, energy and water to produce 1 kg of meat, than producing 1 kg of vegetable, fruit or cereal

A.3 Attitude questions

Please indicate to what extent you find yourself in the following statements:

Possible answers: strongly disagree, disagree, neutral, agree, and strongly agree

1. I think that intervention by the government in the fisheries sector is needed in order to prevent overfishing
2. I feel guilty if I do not turn of the heating before leaving the house because I thereby waste energy
3. I feel guilty if I do not turn off the television before leaving the house because of environmental considerations
4. I hate to waste raw materials or energy
5. I think it is annoying when people around me waste raw materials or energy

6. I think it harms the environment if I do not take a bag with me to the supermarket and I therefore have to buy a plastic bag
7. I find it important that the Netherlands invests in renewable energy
8. I believe the Netherlands should invest more in renewable energy
9. It is important that the Dutch economy is less dependent on fossil fuels
10. I think it is a good idea to invest in electric vehicles as this can promote a transition to a more sustainable energy supply
11. I am willing to deploy time, money and knowledge for a more sustainable future
12. I think that sustainability in terms of raw material and energy deserves greater priority in Dutch politics
13. I think it is a good idea that eventually plastic bags in Dutch shops may no longer be provided free of charge in order to reduce the production of plastic waste
14. I believe that waste should be reused whenever possible
15. I believe that waste should be reused as much as possible, even if that means that the waste is more expensive
16. I believe that the Netherlands must reduce its carbon dioxide emissions only if other countries commit to do the same

A.4 Behaviour questions

Please indicate whether the following statements match your own choices in life:

Possible answers: rarely or never, sometimes, neutral, often, almost always, and always

1. I consciously choose to use public transport or non-motorized vehicle travel rather than personal motorized vehicles because of environmental concerns
2. If I have not turned the heating off before leaving the house, I try to go back home to turn it off after all
3. If I have not turned off the television off before leaving the house, I try to go back home to turn it off after all
4. I consciously try to waste as minimal resources and energy as possible for environmental reasons
5. I consciously buy LED or energy-saving lamps instead of halogen or incandescent bulbs because they use less energy
6. I like to convince people around me about the importance of sustainability
7. I confront people around me if they are wasting recourses and energy
8. I take a reusable bag to the grocery store because I do not want to waste plastic into a plastic bag
9. I consciously lower my energy use for heating my house for environmental reasons
10. I have a contract for green energy or consider switching to a green electricity supplier based on sustainability considerations
11. I separate waste to make it easier to recycle waste
12. When I am doing grocery shopping I consciously choose for products with a label that is focused on nature and environment
13. I consciously choose to dry my clean laundry on a clothesline instead of drying in a dryer because of environmental reasons
14. I donate or consider donating to green organizations such as WWF or Greenpeace
15. I consciously eat less meat because of the environmental impact which meat production entails
16. I plan my vacation consciously close to my home because of the environmental impact associated with traveling

ACCEPTED MANUSCRIPT

Appendix B Tests for representativeness

In Table B1, the key variables for representativeness are compared to most recent the Dutch data, gathered from CBS Stateline (http://statline.cbs.nl/). The statistics cover averages, and percentages.

Table B1. Demographic properties and tests for representativeness.

Variable	**Dutch statistics**	**Statistics**		**Tests**	
		Sample	**Reference group**	**Sample**	**Reference group**
Gender	Men: 49.6% Women: 51.4%	Men: 60% Women: 40%	Men: 59% Women: 41%	*One sample t-test:* T-value 1.250 Significance 0.220	*One sample t-test:* T-value 1.119 Significance 0.272
Age	Avg.: 41.0 yrs. <20: 37.3% 20-40: 29.4% 40-65: 25.6% 65-80: 6.7% >80: 1.0%	Avg.: 28.9 yrs. <20: 3,0% 20-40: 81.8% 40-65: 15.1% 65-80: 0% >80: 0%	Avg.: 36.5 yrs. <20: 0,0% 20-40: 68.8% 40-65: 21.9% 65-80: 9.4%% >80: 0%	*One sample t-test:* T-value -7.350 Significance 0.000 *Chi-square test:* Chi value: 30.109 Significance: 0.000	*One sample t-test:* T-value -1.565 Significance 0.128 *Chi-square test:* Chi value: 6.146 Significance: 0.046
Gross income	Avg.: 43.8 k€	Avg.: 21.0 k€	Avg. 31.3 k€	*One sample t-test:* T value -7.679 Significance 0.000	*One sample t-test:* T value -2.853 Significance 0.008
Education	Primary school: 11% High school L: 22% High school H: 40% Univ. BSc: 17% Univ. MSc: 9.6%	Primary: 3.9% High (L): 7.7% High (H): 40% Univ. BSc: 17% Univ. MSc: 9.6%	Primary: 0.0% High (L): 0.0% High (H): 3.1% Univ. BSc: 53.1% Univ. MSc: 43.8%	*Chi-square test:* Chi value: 14.409 Significance: 0.000	*Chi-square test:* Chi value: 45.429 Significance: 0.000

ACCEPTED MANUSCRIPT

Appendix C Scatter plots and paired T-tests

This appendix provides additional scatter plots and paired T-tests that did not lead to conclusive results. Effects of playing the game can be illustrated by means of scatterplots for knowledge, attitude and behaviour (Figure C1). The horizontal axis scores the pre-tests and the vertical axis scores the post-tests. All outcomes are summed for the eight related questions and represented as differences to the averages of the reference group. A reference line is added for interpretation: cases above the reference line imply an increase in knowledge, attitude or behaviour by playing the game; cases below the reference line imply a decrease.

<<FIG C1>>
Figure C1. Workshop survey results on knowledge, attitude, and behaviour. The horizontal axis score the pre-tests. The vertical axes the post-tests. All results are summed for 8 questions on a 5-Likert scale, and relative to the average of the external group.

The scatterplots do not indicate a strong and consistent effect nor does it indicate that nonlinearity or heteroscedasticity will influence the tests. Apart from a few outliers, the outcomes of knowledge and attitude vary less widely than those of behaviour.
Paired T-tests are used to determine whether the mean from the pre-test differs significantly from the mean of the post-test. Table C1 shows the mean values of the deviation of the pre-knowledge and post-knowledge, pre-attitude and post-attitude, and pre-behaviour and post-behaviour as well as the result from the statistical test whether knowledge, attitude and/or behaviour increase by playing the game. The statistics are determined for the full data set and the data set after removing the outliers (defined here as more than 2 times the standard deviation away from the average on the score on pre-knowledge).

Table C1. Results from paired T-tests, measuring the effects of playing the game on knowledge, attitude and behaviour.

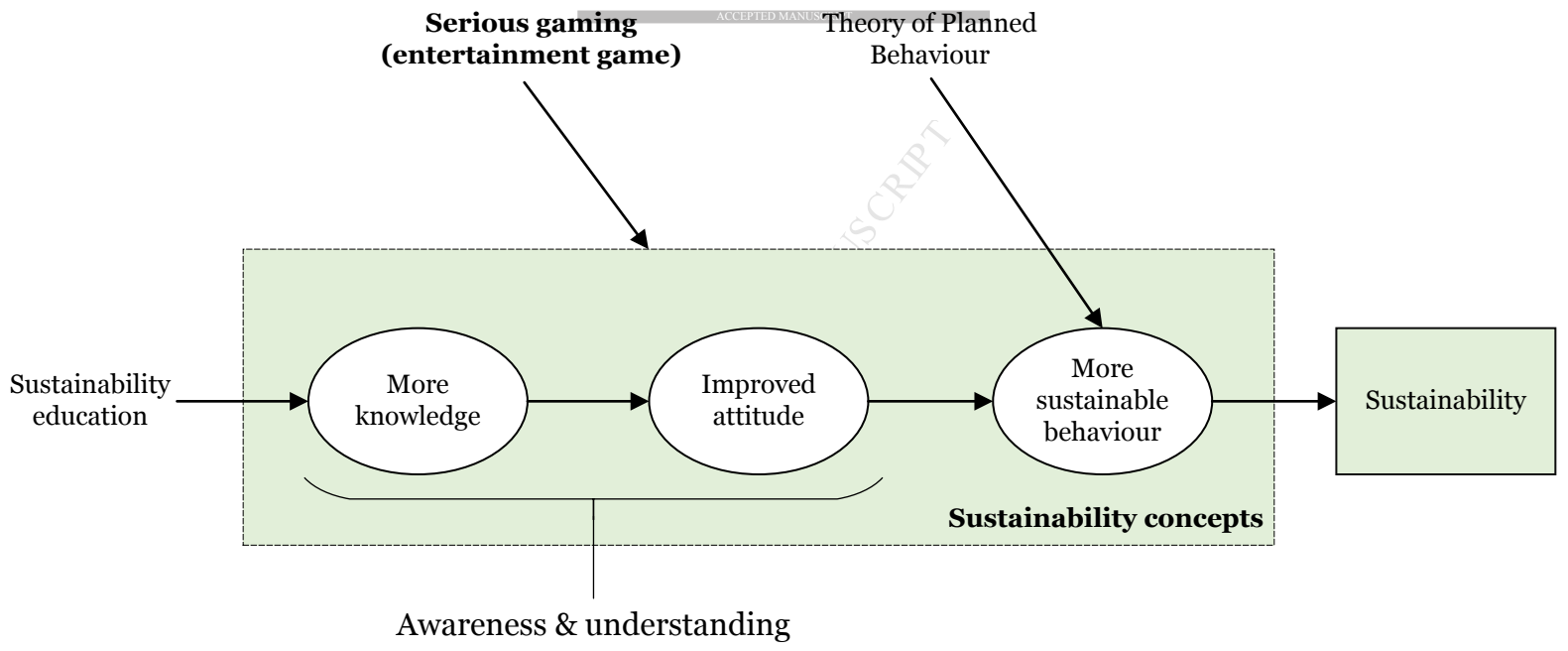
Variable	**Including outliers (*n*=35)**				**Excluding outliers (*n*=32)**			
	Difference to mean control group		Paired *t*-value	*p*-value	Difference to mean control group		Paired *t*-value	*p*-value
	Pre	Post			Pre	Post		
Knowledge	-1,3527	-1,3188	0.049	0.961	-0.1426	-0.5234	-0.576	0.569
Attitude	-2,6098	-2,0357	0.668	0.509	-2.1670	-1.5488	0.712	0.482
Behaviour	-3,6831	-2,3411	1.284	0.208	-3.0957	-2.2022	0.830	0.413

As can be seen in the Table C1, all paired Student t-tests fail to reject their respective zero hypotheses, both before and after excluding outliers. This means that with these tests no significant effects can be measured of playing the game on knowledge, on attitude, nor on behaviour.

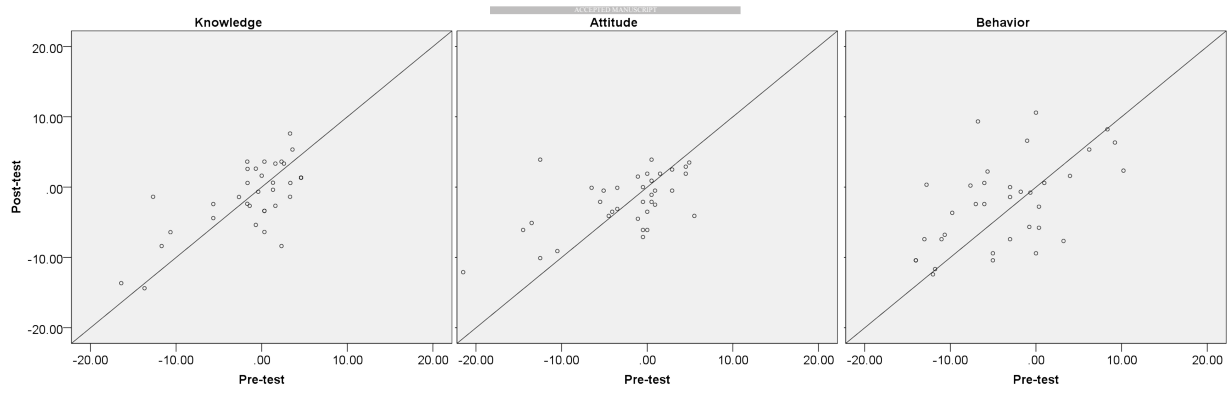
Despite the fact that the effects are not statistically significant, the small differences that are found are generally in the expected direction: the sustainable knowledge, attitude and behaviour all increase during the course of the game. The only exception is the effect on knowledge when outliers are excluded: a slight decrease is noted.

Despite the fact that these results are inconclusive, an interesting finding is in the size of the measured effects: the effect is smallest on knowledge, medium on attitude and largest on behaviour. The paired T-tests are insignificant but indicate that the effect can be mainly expected on behaviour, not on knowledge. This finding is consistent with the regression analysis (as documented in the main text).

ACCEPTED MANUSCRIPT



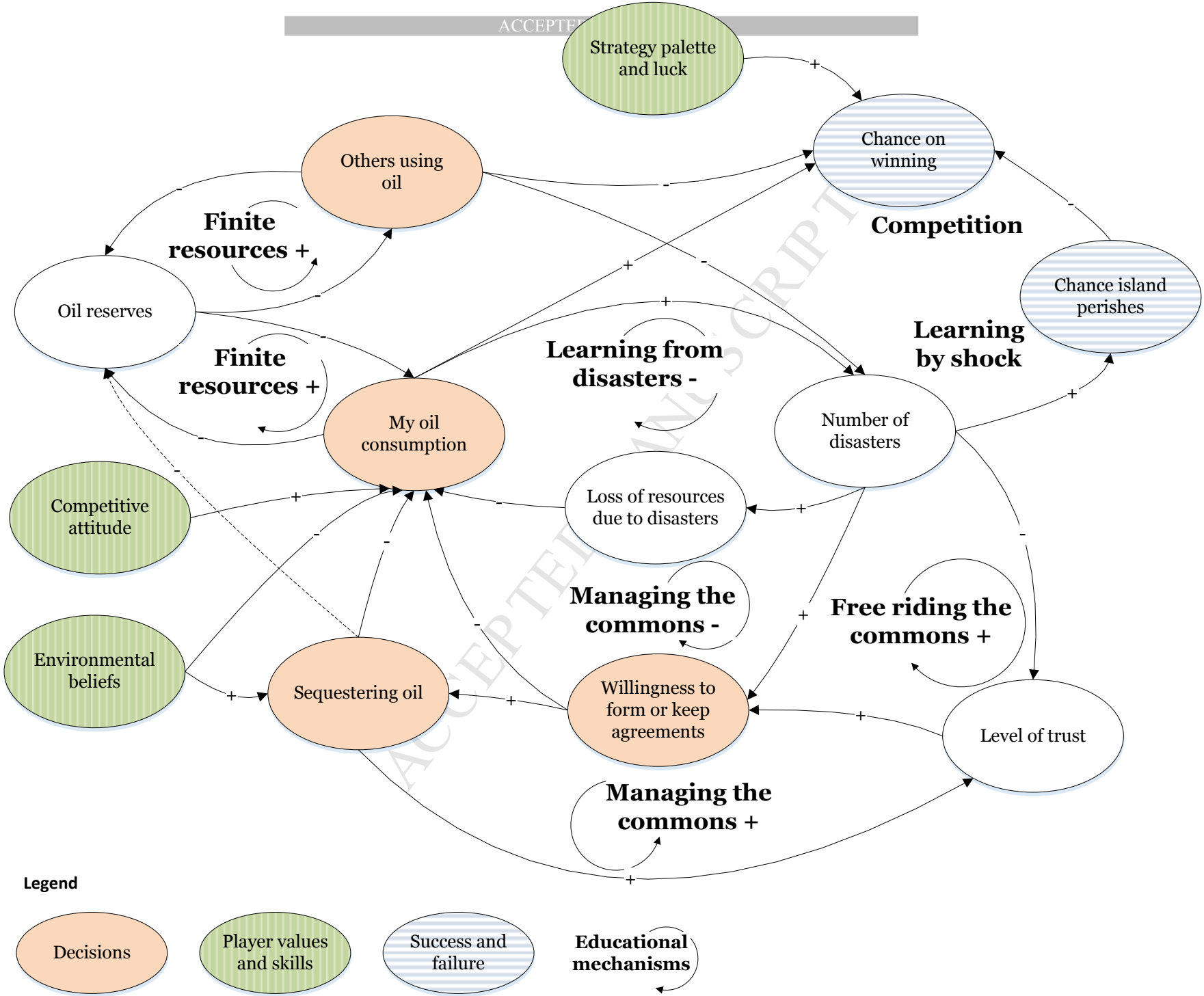
ACCEPTED MANUSCRIPT

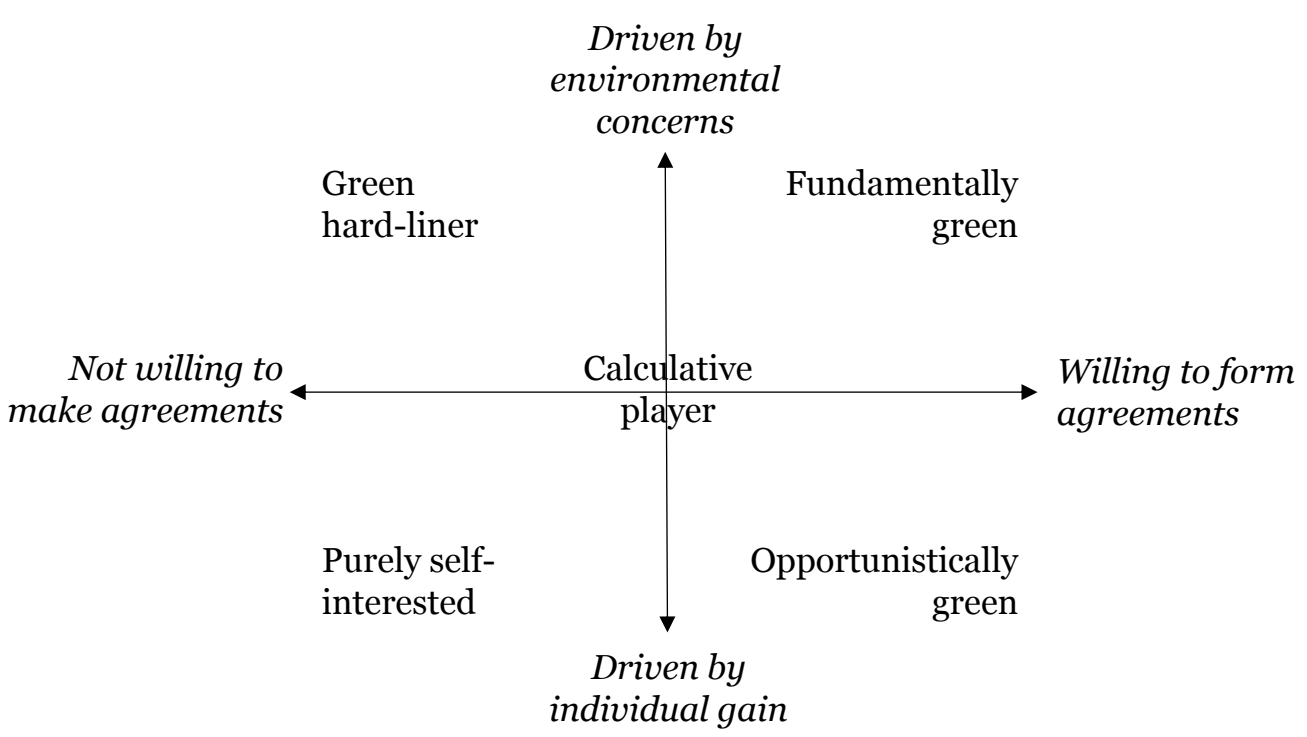


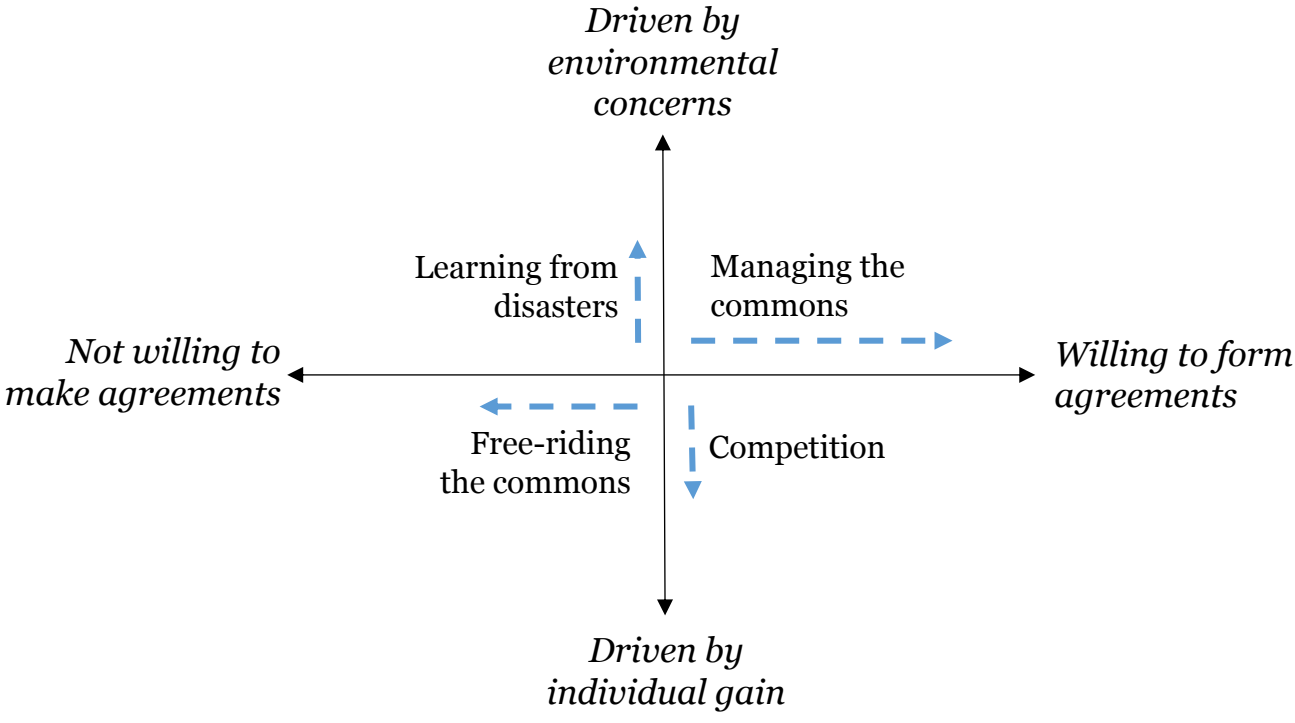
ACCEPTED MANUSCRIPT



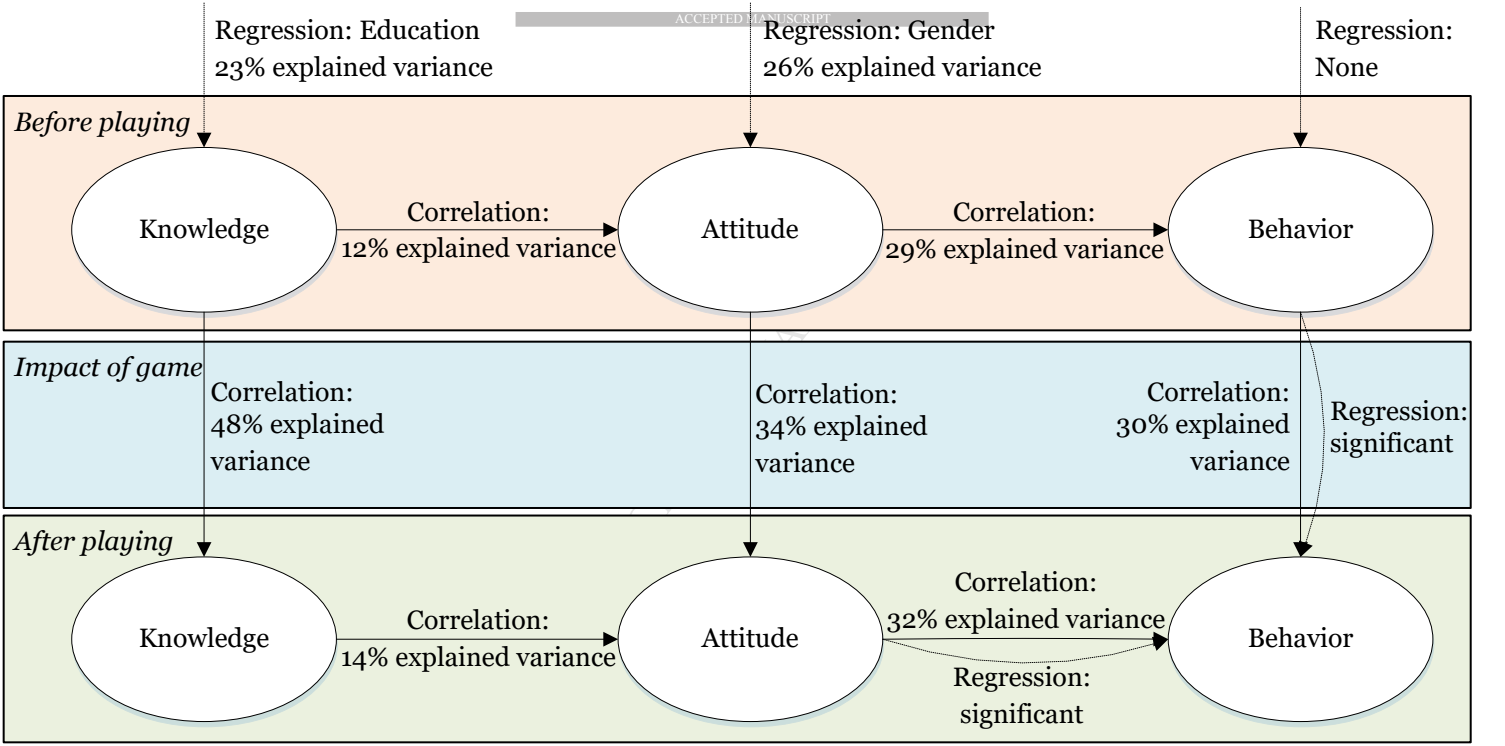
ACCEPTED MANUSCRIPT




Driven by environmental concerns
Green hard-liner
Fundamentally green
Not willing to make agreements
Calculative player
Willing to form agreements
Purely self-interested
Opportunistically green
Driven by individual gain


Driven by environmental concerns
Learning from disasters
Managing the commons
Not willing to make agreements
Willing to form agreements
Free-riding the commons
Competition
Driven by individual gain

ACCEPTED MANUSCRIPT



ACCEPTED MANUSCRIPT

Highlights:

- We present a novel form of sustainability education with a potentially wide reach
- The Catan: Oil Springs scenario provides for experiencing sustainability issues
- Competition, free-riders and the tragedy of the commons drive the educational effects
- The game appears to affect the players' behaviour towards sustainability issues

ACCEPTED MANUSCRIPT