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A SURVEY OF SERIOUS GAMES ON SUSTAINABLE DEVELOPMENT

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ABSTRACT

The continuing depletion of natural resources has become a major focus for the society at large. There is an increasing recognition of the need to sustain an ecologically-balanced environment, while, at the same time, exploring and exploiting the natural resources to satisfy the ever-increasing demands of the human race. A profound solution to this is the adoption of sustainable development practices. Increasing the awareness towards a more sustainable future is thus critical, and one way to achieve this is through the use of decision games called "serious games". Serious games are gaining in popularity as tools that add entertainment to teaching and training. In this paper we undertake a review of serious games on sustainable development with a view to facilitate the understanding of the issues around sustainability, to identify opportunities towards improving the feature-set of these games, and for enhancing knowledge around sustainable development strategies.

1 INTRODUCTION

The concept of sustainable development, in broad terms, is an attempt to combine growing concerns about a range of environmental issues together with socio-economic issues (Hopwood, Mellor, and O'Brien 2005). Sustainable development is defined as meeting "the needs of the present without compromising the ability of future generations to meet their needs" (Brundtland 1987). The depletion of natural resource has become a major focus of governments, organizations and citizens all over the world. The constant resource exploitation and depletion poses us with a twofold challenge - (a) to sustain an ecologically balanced environment, and (b) to generate sufficient energy to cater to our present needs, while, at the same time, making sure that our future demands can be satisfied. A profound solution to this can be the adoption of sustainable development practices to counteract the mounting problems that are intrinsic with the current policies of most businesses and governments and trends within the society; this may necessitate new governmental legislation and introduction of major reforms (e.g., those encouraging the investment, development and the increasing adoption of technologies for sustainable development) , a considerable shift from existing policies (e.g., modifications to the market), and radical changes to be made in lifestyle choices. There is widespread support for a dramatic increase in energy efficiency and change in energy use from fossil fuels to renewable sources (Flavin and Lenssen 1994). It is argued that these changes will offer market opportunities for businesses and they should grasp the changes, both for the environment and for the realization of increasing profits (Hawken, Lovins, and Lovins 1999). Moreover, government action is required to change the balance of tax and subsidies to favor employment and environment rather than energy consumption and to encourage business to change production technology (Roodman 1996; Roodman 1997; Hawken, Lovins, and Lovins 1999). Furthermore, in terms of personal change for a sustainable lifestyle, "light green" actions addressing responsibility as consumers such as changing purchasing habits, recycling, and saving energy and/or water need to be pursued (Kagawa

2007). These realizations have made the need for reforms very apparent, and consequently the issues around sustainability constitute an important part of the everyday agenda for many governments, organizations and educational institutions.

The focus of this paper is on learning and teaching sustainable development in an educational context. Many books have been written on this subject, e.g., *Higher Education and Sustainable Development: Paradox and Possibility* (Gough and Scott 2008), *Global Learning and Sustainable Development* (Gadsby and Bullivant 2011), and one journal is devoted to this particular topic –*Journal of Education for Sustainable Development* (Sage Journal). Modules on Sustainable Development are increasingly being integrated into the higher education curriculum with the objective of informing and training students and future professionals on the importance of the issue and on potential solutions. Furthermore, degrees programs on this subject are also being made available for students perusing higher education, particularly those studying management and engineering, e.g., *M.Sc. in Management for Sustainable Development* (Dublin City University, Ireland), *MPhil in Engineering for Sustainable Development* (University of Cambridge, UK). A complementary training method and a successful way of increasing the awareness towards a more sustainable development is the use of decision games or what is called "serious games".

In this paper we present a survey of serious games dealing with sustainable development issues. This is achieved through a methodological review and categorization of the games found in literature. The review also includes the online games on sustainable development that are available in the Internet and are accessible through the web browser. The review aims at providing insights into the development and use of such games in sustainable development and it presents, amongst others, the purpose, the application areas, the playing mode, the target age, the game complexity and the learning outcomes of these games. Moreover, analysis performed in this study facilitates the understanding of the issues around sustainable development and identifies educational opportunities and research potentials for enhancing not only the applications and features of the games but also the knowledge around sustainable development strategies.

The remainder of the paper is organized as follows. Section 2 reviews literature in serious games with the objective of ascertaining its suitability as an effective teaching and training tool. Section 3 describes the research methodology and enumerates the selection method used for the identification of the relevant games for the purposes of our study. Furthermore, it describes the parameters of the analyses that we perform. The findings are described in section 4. Section 5 describes the potential for future work and draws the paper to a close.

2 SERIOUS GAMES

Serious games are computer games and simulation approaches and/or technologies, which cover just about any non-game industry and therefore are used for applications unrelated to mere entertainment or traditional games (Blackman 2005, Michael and Chen 2005). Nonetheless, a Commercial Off-The-Shelf (COTS) game, used for non-entertainment purposes, may be considered a serious game (Susi, Johannesson, and Backlund 2007). Serious games include all aspects of education – teaching, training, and informing – and at all ages (Michael and Chen 2005). They can be applied to a broad spectrum of application areas, e.g. public policy, defense, corporate management, healthcare, training, and education (Zyda 2005). Their obvious advantage stems from the fact that, (a) they allow learners to experience situations that are impossible in the real world for reasons of safety, cost, time, etc. (Squire 2002, Corti 2006), (b) they engage the user in the pedagogical journey and can have a positive impact on the players' development of a number of different skills, such as analytical and spatial skills, strategic skills and insight, learning and recollection capabilities, psychomotor skills, visual selective attention, etc. (Mitchell and Savill-Smith 2004), and (c) they enable improved self-monitoring, problem recognition and problem solving, decision making, better short-term and long-term memory, and increased social skills such as collaboration, negotiation, and shared decision-making (Mitchell and Savill-Smith 2004). Serious games have become increasingly popular as an educational tool in schools, as a training device for professionals and as a means which may add entertainment to teaching and training, making the learning experience

more fun and motivating. A number of studies confirm that simulation games help students increase their awareness of real world issues and comprehension of course subjects (Hirose, Sugiura, and Shimomoto 2004; Philpot et al. 2005). Thus it is apparent that serious games tackling sustainable development issues can be an effective teaching and training tool to all the stakeholders directly affected by the phenomenon, which we can claim to be everybody and in particular those who are called to seek and exercise solutions to the problem, such as governments, academics, organizations, students and professionals. In the remainder of the paper, the acronym SD will be used to refer to Sustainable Development.

3 RESEARCH METHODOLOGY

3.1 Selection Method

The research methodology concerns with the identification of relevant games on SD by conducting a search on the following two sources – a search of scholarly literature, and a search for online games on SD that are accessible through the World Wide Web. Irrespective of the source of our search, the underlying methodology consisted of the following two stages, (a) the "Selection Criteria" stage that used a set of keywords with the purpose of collating papers (games) for subsequent filtration, and (b) the "Screening" stage that identified the final set of papers (games) for inclusion in this study (the final set is a sub-set of the papers/games identified in the "Selection Criterion" stage). Both stages of our methodology are further described in the subsequent paragraphs.

The academic papers selected for this study were identified from the *Web of Science*® (http://www.wokinfo.com) and the *SciVerse Scopus* (http://www.info.sciverse.com/scopus) journal databases. The Web of Science® is one of the largest databases of quality academic journals (impact research journals) and provides access to bibliographic information pertaining to research articles published mainly from 1980 onwards. Scopus offers about 20% more coverage than Web of Science in articles published from 1996. The Web of Science® and Scopus databases have user friendly search engines that assist in the refinement of a search by allowing the user to incorporate specific search conditions. To identify articles which would be incorporated in our initial dataset the following criterion were used: inclusion of the words, "game" AND "player" AND "sustainable" AND ("development" OR "environment") in the title, abstract or keywords of the published papers. We also performed a second search with slightly different set of keywords to identify further papers. The words "game" AND "player" AND "green" were used in the same logic as above. We also allowed for the inclusion of all keywords' derivatives in these search options. Aggregated results from these search strategies returned 132 different papers in total. This concluded the first stage of our selection methodology, namely, the "Selection Criterion" stage.

The second step ("Screening" stage) involved the screening of this initial set of 132 papers by reading the abstract (and when necessary, the full text) of each paper. At this stage we also took note of the references included in the paper so as to identify additional relevant papers. The screening stage involved two screening processes. The first screening process excluded articles that did not describe SD games in full but rather used them as a reference or as an example. This process identified 32 relevant papers. A second screening process identified that 19 out of these 32 papers related to *Game Theory*; these papers studied mathematical models of conflict and cooperation between intelligent rational decision-makers in sustainable development issues. A couple of other papers were also excluded by the authors (although the papers were on serious games/interactive games and related to sustainability) since, having read the papers, it was agreed that the focus of the research was not on sustainable development but on sustainable counter-insurgent operations and on motivating changes in a person's lifestyle . This left us with 11 academic papers from literature that described game-based learning of SD.

Our second search source acknowledged the existence (and contribution) of the online SD games for learning and teaching. For the purpose of identifying these games we used the same keywords (as used for our *Web of Science*® and *Scopus* searches) for conducting a Google web search. The hits were in millions and only the first 30 hits were pursued in order to identify relevant sites describing the SD games. This

endeavor identified a total of 24 SD games. Many of the game descriptions were included in the *Games in Education* website (http://www.gamesined.wikispaces.com).

3.2 Dataset

Following the paper/game selection and screening process described earlier, we were left with a total of 35 SD games for subsequent analysis. Information pertaining to these games is presented in Table 1.

Table 1: Games Dataset

Year	Game name	Source/Reference of the Game
1990	SimEarth	www.abandonia.com/en/games/185
1999	Build a Prairie	www.bellmuseum.umn.edu/games/prairie/build/sb1.html#
2000	Learning Sustainable Development (LSD)	Torres and Macedo (2006)
2004	Balance of the Planet	www.cdosabandonware.com/std_games_details.php?gameid=1639
2005	AtollGame	Dray et al. (2005)
	MHP	Guizol and Purnomo (2005)
2006	SHRUB BATTLE	Michelin (2006)
	3rd World Farmer	www.3rdworldfarmer.com/
	Climate Challenge	www.bbc.co.uk/sn/hottopics/climatechange/climate_challenge/
2007	Stop Disasters!	www.stopdisastersgame.org
	Energyville	www.energyville.com/energyville/
	EnCon CITY	www.enconcity.com/
2008	World Without Oil	Rusnak, Dobson, and Boskic (2008); www.worldwithoutoil.org/
	Environment Game	www.mysusthouse.org
	Building Game	www.mysusthouse.org
	ElectroCity	www.electrocity.co.nz/
	The Great Green Web	http://go.ucsusa.org/game/
	SymbioCity	www.symbiocity.org
	LogiCity	www.logicity.co.uk/
	Catchment Detox	www.catchmentdetox.net.au/
	Millennium Village	http://mvsim.ccnmtl.columbia.edu/accounts/login/
	Oiligarchy	www.molleindustria.org/en/oiligarchy
	Clim'way	http://climway.cap-sciences.net/us/index.php
2009	THE SIMS adapted	Tragazikis and Meimaris (2009)
	Shortfall	Isaacs et al. (2009); www.coe.neu.edu/Groups/shortfall/
	Green City	Shivshankar and Thirumavalavan (2009)
	Power explorer	Gustafsson, Bång, and Svahn (2009)
	PowerUp	www.poweruptheGame.org/
2010	EnerCities	www.enercities.eu/
	Fate of the World: Tipping Point	www.fateoftheworld.net/
	Precipice	www.precipice.altereddreams.net/
	CityOne	www-01.ibm.com/software/solutions/soa/innov8/cityone/

Year	Game name	Source/Reference of the Game
2011	SOS 21	Cahier et al. (2011); www.sos-21.com/Enter-the-game.html
	EnergyLife	Gamberini et al. (2011)
	Ludwig	www.playludwig.com/en/

From column 1 (the year that the game was launched/published in an academic paper) we recognize that although the first game dates back to 1990, most of the games have been developed in the first decade of 2000 and in particular after 2005. We would like to make two observations here, one, the *Kyoto Protocol to the United Nations Framework Convention on Climate Change* (United Nations, 1998) aimed at fighting global warming entered into force in 2005, and, two, it may be considered note worthy that 11 out of the 35 games (31%) were launched in 2008. The second column refers to the name of the game. The third column lists the web source of the game (for online games identified through web search – refer to section 3.1) or the reference of the academic paper in which the game is described. Some games have both a web source and an accompanying academic paper.

3.3 Variables for Analysis

With the purpose of analyzing and classifying the 35 SD games in meaningful categories we sought to capture specific information. This was made possible by reading related information from the websites hosting the online SD games and by playing the games, and by reading the full-text of the academic papers in our dataset. Overall, we captured the 12 variables noted below:

1. *Type of game*: gives information about the tools or techniques used to play the game; whether the game is a simulation game, a board game, a quiz game, a Role Playing Game (RPG) using Multi-Agent Based Simulations (MABS), a pervasive game (a location-based game in which the game play progresses by means of players' location using localization technology), whether the game is played online, or whether it is a sandbox game (a game wherein a player can roam freely through a virtual world having autonomy with regard to when and how game objectives are to be realized).
2. *Theme:* states the main focus of the SD game; whether it is on energy, on water management, on climate change, etc.
3. *Purpose:* describes the main aspect of the game
4. *How the game is played:* describes the actions the player needs to take to play the game.
5. *Player's objective:* reports the target the player needs to fulfill to reach the goal of the game.
6. *Player's role:* identifies the character that the player assumes while playing the game, e.g., in the Blood Supply Game the player takes the role of a distributor (Mustafee and Katsaliaki 2010).
7. *Number of players:* identifies how many players can participate in the game.
8. *Target Age:* identifies the age range (pupils, students, all ages, etc.) for whom the game is primarily targeted.
9. *Game evaluation:* reports on whether there was an assessment of the game's principles from its users. Usually the assessment takes place through questionnaires or interviews.
10. *Debriefing:* identifies whether there was a report that reflects on the experience of playing the game.
11. *Game Availability:* reports on the accessibility of the game for online use, or download or cd load (i.e., installing the game from compact disk) and whether the game is offered for free or has to be purchased.
12. *Graphics:* identifies the dimensions of the game illustrations and visuals (2D or 3D).

Unfortunately, we could not collect data on the modeling and simulation aspects of these games as the source codes were not available in most of the games in our dataset and especially in the commercial ones.

4 FINDINGS

Table 2 reports the following variables as identified in the previous section: *theme* (column 2), *player's role* (column 3), and *purpose*, player's *objective* and *how the game is played* (column 3; the new variable *game objective* encompasses information pertaining to the three variables). The data presented in Table 2 indicates that the majority of the games are on climate change management (9 games), 6 of which deal with global issues and 3 with local/regional issues; this is closely followed by energy management (7 games); sustainable urban development (4); ecosystem management (3), 2 of which have local focus and 1 with global perspective; we have two games each in water management, sustainable family and farm management in developing countries; environmental consumer choices; sustainable development learning; finally, we have one game in each of the following categories - petroleum business, forest plantation, sustainable house building and green automobile supply chain. The data presented in column two shows that the players can take on various roles, for example, the role of a president, the mayor or governor, a citizen, an engineer, a farmer, an energy advisor, a household manager, a CEO, etc. Mainly the roles vary from being somebody in authority that can take or advice on regulatory actions or development activities with an important effect on citizens' lives, to being an average civilian who, by making every day choices, can potentially affect the development of a region. In column 3 we note that a good proportion of the games (14 games, 40%) deal with making choices of "green" activities while keeping in mind their financial impact.

Table 2: Game description

Game name	Theme	Player's Roles	Game objective
SimEarth	Global climate change management	World eco-advisor	Control a planet's atmosphere, temperature, landmass, etc., then place various forms of life on the planet and watch them evolve aiming to be an advanced civilization.
Build a Prairie	Ecosystem management	Farmer	Choose the best combination of plants or animals to preserve and restore a particular shortgrass or longgrass prairie.
LSD	Learning SD	Concerned individuals	Choose, from a range of suggested practices, those the players believe will best suit a given scenario and will steer their communities toward sustainable practices.
Balance of the Planet	Global climate change management	World President	Tackle ecosystem issues to make the world a better place by influencing nature's mechanisms by taxing, granting subsidies and funding projects.
Atoll-Game	Water management	Institutional and local community representatives	Provide sufficient and safe water to the families in order to minimize the number of angry or sick people in each scenario by creating scenario-flowcharts and transforming them into viable roadmaps for the Government.
MHP	Forest plantation	Villagers with/without land	Communicate ideas of institutional arrangement to facilitate, maintain and enforce collective actions with regard to forest management and stay within budget.
SHRUB BATTLE	Ecosystem management	Plants and farmers	Colonize the board, which represent spread types and germination capacities and build graphs by recording parameters such as number of plants, events, farmers' practices, etc. to compare results and understand the different methods of livestock farming management or land management and sustainable farming.
3rd World Farmer	Sustainable family &	Farmer	Grow your African family and keep a stable income by managing your farm entities, crops and livestock through

Game name	Theme	Player's Roles	Game objective
	farm mgmt. in developing countries		difficult choices such as corruption, trade barriers, armed conflict, lack of education, sanitation, infrastructure and economic stability.
Climate Challenge	Global climate change management	President of the European Nations	Tackle climate change by lowering carbon dioxide emissions and maintaining vital resources. Choose policies of national, imports and exports, industry and household aspects and negotiate with other nation's presidents for global targets. Stay popular with your voters.
Stop Disasters!	Global climate change management	Energy advisor	Reduce human, physical and financial cost of disasters by providing defences and upgraded housing to prepare for the inevitable disaster.
Energyville	Energy management	Energy advisor	Power homes, offices, factories and vehicles of a virtual city and keep economic, environmental & security impacts low.
EnCon CITY	Energy management	Gas Engineer	Identify homes where energy is being wasted and give energy conservation advice to householders within budget.
World Without Oil	Energy management	Citizens	Imagine a progressively worsening of oil stock and describe what personal affect the fictional crisis would have. Learn ecological values and issues of sustainability and responsible citizenship and take real actions with the online community to preserve earth's resources.
Environment Game	Learnign SD	Citizen	Listen to the informative videos about sustainable development issues and answer the multiple choice questions.
Building Game	Sustainable house building	Civil Engineer	Choose the right materials to build a sustainable house within budget.
ElectroCity	Energy management	Mayor	Citizens need electricity and jobs, but they also love their clean green image. Therefore, balance the city's growth with its environmental impact.
The Great Green Web game	Environmental choices	Consumer	Answer questions and 'shop green' by ensuring good impact on air quality, water quality, natural habitats, and the sustainability of our climate.
SymbioCity	Sustainable urban development	Mayor	Create an attractive city for citizens and businesses alike by improving health, comfort, safety and QoL for your and future generations by balancing the economic, social and environmental effect of your decisions.
LogiCity	Climate change management	Citizen	Take individual actions to reduce the carbon footprint of an average resident and travel to the future to see the direct results of your actions to the planet.
Catchment Detox	Water management	Mayor	Manage a river catchment (plant crops, log forests, build factories or set up national parks) within budget and provide food and wealth for the population
Millennium Village	Sustainable family and farm management in	Helper	Help a family of two and a village survive and prosper over extreme poverty, disease, and environmental variability by making decisions regarding the family's allocation of time and financial resources, taking into consideration issues of

Game name	Theme	Player's Roles	Game objective
	developing countries		agronomy, nutrition, economics, epidemiology, public health and development management.
Oiligarchy	Petroleum business	CEO of Oil company	Explore and drill around the world and make profit by corrupting politicians, stopping alternative energies and increasing the oil addiction so you are not fired by the company's stakeholders.
Clim'way	Climate change management	Territory eco-advisor	Devise the city's climate plan aiming at reducing greenhouse gas emissions, balancing energy consumption and adapting to climate change by choosing actions available in the items of a typical western industrialised landscape
THE SIMS adapted	Environmental consumer choices	Manager, secretary, player, and translator	Manage a family's purchases and try to reduce their environmental impact by calculating the energy consumption and the emissions caused.
Shortfall	Green automobile supply chain	CEO, Environmental, R&D, or Production Manager	Minimize environmental impact while maximizing profit by making trade-offs from your position in the company and taking into consideration environmental, economic, and technological issues in the auto industry.
Green City	Sustainable urban development	Urban designer	Develop a city within budget by making sustainable or conventional choices and by considering the trade-offs between initial and running costs of each choice and the impact on the city's natural resources and power.
Power explorer	Energy management	Household manager	Use a real-time sensing system providing instant feedback on the mobile phone of the electrical appliances' energy consumption. The energy consumption is represented by a fun monster blob. Use the electrical appliances sensible to keep the monster healthy.
PowerUp	Global climate change management	Engineer	Design and build energy solutions in the mission to save the planet from extreme weather conditions caused from human pollution.
EnerCities	Sustainable urban development	Mayor	Build a metropolis and manage the energy balance, cash reserve, natural resources and population. Try to increase the scores in economy, environment and well-being from the impact of your actions.
Fate of the World: Tipping Point	Global climate change management	Governor	Solve the crisis by working through natural disasters, foreign diplomacy, clandestine operations, technological breakthroughs, and satisfy the food and energy needs of a growing world population.
Precipice	Climate change management	Activist	Convince through dialog and certain decisions the game characters to be more aware of the environment and create a positive change in the future.
CityOne	Sustainable urban development	Governor	Guide the city through a series of missions involving the energy, water, banking and retail industries and find the best way to invest to meet the financial, environmental and sociological goals of these industries while balancing their

Game name	Theme	Player's Roles	Game objective
			budgets and the needs of the citizenry.
SOS 21	Global eco-system management	Citizens and administrators	Be part of an on-line community to tackle global and local sustainable issues (i.e. find all places where there is an Aeolian, or particular waste have to be collected, etc.) and through competition and cooperation acquire experience to change role and become part of the governance of the system as a driving force within the virtual world.
EnergyLife	Energy management	Household manager	Use a real-time sensing system providing feedback of the electrical appliances' energy consumption and receive tips and quiz to minimize energy consumption while meeting your needs. Take part of the game's community to share experience among EnergyLife users.
Ludwig	Energy management	Physician	Physics game on the topic of renewable energies.

Table 3 presents data related to the following three variables – *type of game*, *graphics* and *game availability*. The numbers preceding the table shows the number of games that fall in each category. We identify that 43% of the games (15 games) are online sandbox simulation game with 3D graphics and are available free for online play. In terms of the number of SD games as per *type of game*, the sandbox simulation games (irrespective of whether they are available online or not) come first with 20 games (57%), followed by simple simulation games (5 games) and by quiz games (4). The vast majority of the games (24 games – 69%) have 3D graphics and only 11 have been developed to support 2D graphics. This shows that the game industry/authors have invested in the visuals which are a main pole of attraction for the players. Finally the last column gives information about the availability of the game. It shows that the bulk of these games (25 out of 35) are available online for free, 6 come with a fee for buying the game or buying the mechanism to participate in the game (i.e. pervasive games), and 3 games (all of which are identified from the literature) do not mention their availability.

Table 3 : Game Type and Display

	Game name	Type of Game	Graphics	Availability
1	SHRUB BATTLE	Board game	2D	Free, online play
1	LSD	Card game	2D	Not mentioned
4	Build a Prairie, Environment Game, Building Game, the Great Green Web game	Computer quiz game	2D	Free, online play
2	AtollGame, MHP	Computer RPG MABS	2D	Not mentioned
2	Power explorer, EnergyLife	Pervasive game	2D	Not for free, needs devise
1	World Without Oil	Online alternate reality game	2D	Free, online play
1	3rd World Farmer	Online sandbox Simulation game	2D	Free, online play
15	ElectroCity, Stop Disasters!, EnCon CITY, SymbioCity, LogiCity, Catchment Detox, Oiligarchy, Clim'way, EnerCities, Fate of the World: Tipping Point, Precipice,	Online sandbox simulation game	3D	Free, online play

	Game name	Type of Game	Graphics	Availability
	SOS 21, CityOne, Climate Challenge, Energyville			
1	CityOne	Online sandbox simulation game	3D	Not for free, online play
3	Millennium Village, Short-fall, Balance of the Planet	Online simulation game	2D	Free, online play
1	Ludwig	Online simulation game	3D	Not for Free, in German
1	PowerUp	Sandbox simulation game	3D	Free download
2	SimEarth, The SIMS adapted	Sandbox simulation video game	3D	Not for free, cd load
1	Green City	Simulation game	3D	Not for free, cd load

Table 4 presents variables pertaining to the *number of players*, *target age*, *game evaluation* and *debriefing*. The data in column 2 (*number of players*) shows that a total of 24 games were for individual play. With regard to the variable *target age* (column 3), most of the games refer to pupils, students and youngsters which also incorporate the teenagers' category (it is to be noted here that we followed the categories that were defined in the papers/online games; it is our understanding that the term *pupil* was mostly used to refer to children attending elementary or secondary school; the category *student* was used in the context of those who required subject-specific knowledge to play the serious games; finally, *youngsters* referred to all young people). It is however true that a game can be played by all ages. Column 4 presents data on *game evaluation*, and it shows that 10 of the games have been evaluated, mainly through questionnaires. For the remaining games no information pertaining to assessment could be gathered. Data associated with the variable *debriefing* (column 5) points to the fact that in a total of 12 SD games there is a debriefing component. It is apparent that most of the games that have been evaluated (8 out of 10) there is also a debriefing element; the majority of these games (i.e., those consisting of both game evaluation and debriefing elements) have been identified from the literature. This should come as no surprise since this information is more likely to come across a section for game evaluation and debriefing in a published paper rather than from the official web page of a game.

Table 4: Game play and evaluation

Game name	# Players	Target Age	Evaluation	Debriefing
SimEarth	1	Pupils	N/A	N/A
Build a Prairie	1	Students	N/A	N/A
LSD	4 - 6	Students and Professionals	N/A	Yes
Balance of the Planet	1	Youngsters	N/A	N/A
AtollGame	8	Adults	N/A	Yes
MHP	10	Adults	N/A	N/A
SHRUB BATTLE	multiple	First year Students	Yes	Yes
3rd World Farmer	1	Pupils	Yes	Yes
Climate Challenge	1	Youngsters	N/A	N/A
Stop Disasters!	1	Pupils	N/A	N/A
energyville	1	students	N/A	N/A
EnCon CITY	1	Youngsters	Yes	Yes
World Without Oil	multiple	All ages	Yes	Yes
Environment Game	1	Pupils	N/A	N/A

Game name	# Players	Target Age	Evaluation	Debriefing
Building Game	1	Pupils	N/A	N/A
ElectroCity	1	Students	N/A	N/A
the Great Green Web	1	Pupils	N/A	N/A
SymbioCity	1	Professional	N/A	N/A
LogiCity	1	Youngsters	N/A	N/A
Catchment Detox	1	Pupils	N/A	N/A
Millennium Village	1	Students	N/A	N/A
Oiligarchy	1	Teenagers	N/A	N/A
Clim'way	1	Youngsters	N/A	N/A
THE SIMS adapted	4 teams of 4	Pupils	Yes	Yes
Shortfall	3	Students	Yes	Yes
Green City	1	All ages	N/A	N/A
Power explorer	1	Teenagers	Yes	Yes
PowerUp	multiple	Students	N/A	Yes
EnerCities	1	Pupils	Yes	Yes
Fate of the World:	1	Youngsters	Yes	N/A
precipice	1	Youngsters	N/A	N/A
CityOne	1	Adults	N/A	N/A
SOS 21	multiple	All ages	N/A	N/A
EnergyLife	1	Adults	Yes	N/A
Ludwig	1	Youngsters	N/A	Yes

5 CONCLUSIONS AND FUTURE WORK

This paper has presented a survey of serious games for SD. It has adopted a methodological approach to identify SD games both from scholarly sources and those available online. The identified SD games have been briefly described and a number of their parameters were further analyzed. The findings suggest that a number of games are being developed which tackle the issues of sustainable development. Our survey has highlighted that the most popular profile of serious games for SD is as follows: they are available free of cost and thus makes it easier for someone to decide to play them; they are accessible online meaning that are easily accessible to a large audience as home broadband connections constantly increase; they are sandbox simulation games with 3D graphics (3D graphics usually require graphics cards and these have become commodity hardware today); they are played by an individual making it easier for anybody to play without the requirement of forming teams; they are targeted at youngsters who undertake the role of a decision maker who aims at solving environmental problems by using alternative "technologies" considering also the economic consequences. Youngsters of today will be the decision makers of tomorrow, and educating this particular group of people in SD is expected to have a direct impact on the future of the environment.

Serious games offer great opportunities in education because of positive effects on learning outcomes (Cohen and Rhenman 1961; Stapleton 2004; Westera et al. 2008) and therefore it is arguable that SD games will potentially play an increasing role in the school curriculum. Although some of these games already include resources for the game facilitator, further teaching and learning resources are expected to be developed in the future to accompany such serious games in order for them to be used as a tool for successful pedagogical intervention. This would also ensure that serious games are easily adopted in the existing SD modules to complement the more traditional teaching strategies. One direction towards improving the feature-set of these games is to acquire or enhance the mobile 3D graphics of sandbox style

simulations which have a great impact in youngsters (Sweetser and Wyeth 2005). Games should entice the player to linger and become immersed in the experience by affecting their senses through elements such as audio and narrative (Sweetser and Wyeth 2005). Moreover, in the present day and age of social networks, serious SD games ought to support and create opportunities for social interaction, for example, through the development of SD games for *Facebook*.

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