Managing Resources and Reducing Greenhouse Gas Emissions Through Game-Based Learning to Achieve Zero Emission Farms

Sobah Abbas Petersen, Andreas Hæstad, Kay Lyngdal and Thomas Evja Thingsaker
Dept. of Computer Science, Norwegian University of Science and Technology, Trondheim, Norway

sap@ntnu.no
andrhae@stud.ntnu.no
kayly@stud.ntnu.no
thomaset@stud.ntnu.no

Abstract: Farming and agriculture have been identified as a major contributor to greenhouse gas emissions. Climate calculators have been developed to help farmers assess the amount of greenhouse gas emissions for specific activities. Despite the possibilities to calculate emissions and concerns about climate change and reduction of emissions, there is a knowledge gap in understanding the trade-offs related to specific resources and taking specific actions. More importantly, there is a need to understand the impacts of taking a specific action, resource use and how to manage emissions over time to achieve zero emission farming. In this paper, we describe two game concepts based on a climate calculator that is used to teach students in an agriculture school. The aim of the games is to engage students and to enhance the understanding of the consequences of actions in farming and agriculture, and to manage the resources to achieve zero emission farms efficiently. The learning goal for the first game is to understand the greenhouse gas emissions and the consequences of taking an action or a combination of actions. The learning goal of the second game is to manage the greenhouse gas emissions in a farm over time through the use of available resources. The game mechanic virtual currency is used as points that the player has to manage, and it aims to encourage players to learn trade-offs in managing a farm and the available resources. Both game concepts use cards to represent actions and the consequences of actions are calculated as greenhouse gas emissions using a climate calculator. Both games are designed as digital games, in collaboration with an expert and a teacher from an agriculture school. The game concepts have been evaluated by the expert.

Keywords: Zero emission farm, Climate calculator, Simulation games, Game-Based learning, Expert evaluation

1. Introduction

The drive to create zero emission farms is important as farming contributes to 11% of global Green House Gas (GHG) emissions (Food and Agriculture Organization of the United Nations (FAO), 2020). Reducing the emissions in agriculture with integrating new technologies through carbon sequestration, renewable energy sources, smart grids and heat recovery along with new farming methods such as agrivoltaics, precision livestock farming and manure gasification can be used to reduce emissions. Design thinking, innovation and digital technologies are used to create innovative solutions and improve production (Berntzen and Florea, 2022 , Florea et al., 2023). Furthermore, climate calculators have been developed to help the agricultural services to evolve to a more sustainable future (Colomb et al., 2012).

Educational games have become an important part of adult education and games are perceived as more engaging and effective than traditional coursework. Games also provide a safe environment to fail and develop both critical thinking and gain a diverse set of experiences (Oliveira et al., 2013, Petersen and Ekambaram, 2012). Educational theories argue that people learn better when placed in authentic contexts and are given the opportunity to make decisions and interact in the virtual world within the game.

Farming games engage several adults as it promotes a certain culture that goes beyond farming skills (Sutherland, 2020). Digital farming games shape public perceptions of agriculture by offering both educational and recreational experiences. Educational games can promote the understanding of sustainable farming practices and long-term decision making. Most games that focus on agriculture focus on the crop farming aspect of agriculture and many focus on a limited version of livestock. Many farming games lack the educational aspect and focus on reducing GHG and zero emission technologies and creating a more sustainable agricultural sector. Even fewer of them focus on agricultural students and how they can be motivated and engaged in using Game-based Learning to learn the relevant concepts. Our work therefore seeks to fill the gap in knowledge by creating digital games for learning about farming, and investigates how these impact agriculture students' learning abilities, motivation and engagement with regard to sustainability and zero emission technologies.

Despite the possibilities to calculate emissions and concerns about climate change and reduction of emissions, there is a knowledge gap in understanding the trade-offs related to specific resources and taking specific actions. More importantly, there is a need to understand the impacts of taking a specific action, resource use

and how to manage emissions over time to achieve zero emission farming. One of the main challenges in learning about farming is that, in real life, actions and measures taken on a farm take time before their consequences could be determined. This can make it hard for students to understand the knowledge. Financial resources also play a factor in achieving change in a farm. There is a growing need for future farmers to deal with these challenges. In this paper, we describe two game concepts based on a climate calculator that is used to teach students in an agriculture school. The aim of the games is to engage students and to enhance the understanding of the consequences of actions in farming and agriculture, and to manage the resources to achieve zero emission farms.

This work is based on two Masters students' projects and the main aim is to obtain a proof of concept for games to implement the knowledge captured in a climate calculator and convey that to students studying agriculture and farming. The basic game concepts and game mechanics have been designed and implemented for both games to obtain a proof of concept. This paper describes the overall game concepts and their design process. An expert evaluation confirms that the games are aligned with the learning goals for the students, and they have the potential to engage and support learning.

2. Farming Games for Learning

Simulation games on farming are designed for entertainment and education purposes. "Stardew Valley" is a computer game for simulating farm life. Players take the role of a character who inherits their grandfather's farm. It is an open-ended game where players manage a farm by clearing land, growing seasonal crops and raising animals (2025). It can be played as a single or an online multiplayer game and includes several achievements to enhance engagement (Sijabat and Grahita, 2021). Another simulation game is "Farm Together" that allows the player to create a farm by selecting the plot of land to start the farm, select crops, plant and harvest them. This is a multiplayer game aimed to promote fellowship. It incorporates the aspect of real time by making the players wait for some time before their plants grow. Another game that supports farming is "Plant Tycoon", and engages players through achievements from caring for their plants (Sijabat and Grahita, 2021). These video games lack the complete picture of farming, the pedagogical aspects and they do not address sustainability issues such as GHG emissions.

A suite of interactive farm simulation computer-aided games that is used in the education of farming systems is "Risky Business" (Stewart et al., 2000). An issue, such as a farm affected by salinisation, is presented to the players and they have to solve them. While there are several entertainment games that are based on farms and agriculture, e.g., Farmville, the game "Roots of Tomorrow" appears to be the only one that addresses sustainable farming. It is an educational game to raise awareness and teach the general public about the strategic management of farms and about sustainable agriculture (Botadkar, 2022). The objective of the game is to transform the farm within ten years by upgrading and balancing the farmland's economic, environmental and social scores, and this is done by the players conducting farm related activities.

3. Method

The overall approach for designing the two games have been exploratory, iterative and using expert guidance. Both the games used the "gameplay loop" system, which builds upon the idea that a game has a series of loops that can be repeated and this idea was used for incorporating several rounds in the game. One of the games used the LEAGUÊ game design framework (Tahir and Wang, 2020a, Tahir and Wang, 2020b) more explicitly in the design of the learning goals and the cards used in the game. LEAGUÊ is a method of using ideation cards to design and identify elements of a learning game. The framework is split into different activities, which supply cards with suggestions on how to define different aspects of the game. The LEAGUÊ framework provides a means to analyse, design and evaluate the game.

An expert has been consulted throughout the design and implementation phases. The role of the expert is invaluable as the game designers are not knowledgeable about the domain of application, i.e. zero emission farming. At the beginning of the projects, advice was sought to help us understand the domain of application. Then, a consultation was done to ensure that the design concepts made sense and that the climate calculator, on which the games are based, has been interpreted correctly. Altogether three meetings were conducted with the expert, two of which were face to face meetings. These meetings followed the pattern of asking the expert questions that had come up while working on the games for clarifications, showing the game design ideas and getting feedback and sometimes suggesting alternatives and asking advice as well as alternative approaches that may be relevant.

An expert evaluation has been conducted for both the games to obtain feedback on the knowledge content and to improve the design (Klas, 2012). The expert is also the designer of the climate calculator and the climate game and is also a teacher at the Agriculture School. The evaluation was conducted by presenting the game to the expert, followed by a discussion. The game was presented using a shared screen. A white board and large sheets of paper were used to support the discussions and ideas for new ways to visualise the content. The discussions were captured as notes during the evaluation and processed to identify recommendations for future improvements of the games.

3.1 Climate Calculator

The climate calculator is central to our game as it is the basis for the numbers and calculations used to show how measures and practices impact agriculture within the game. Hence, the climate calculator that is used by the agriculture school, that is designed for the relevant climate zone, was selected (Grønt kompetansesenter Mære og Skjetlein). When the users select an action in the game, the consequence of the action in terms of productivity or Carbon Dioxide equivalent (CO2e) emissions are calculated using the climate calculator. Thus, both the games include a component within the game that reflects the climate calculator; see Figure 1. The interface component of the game submits values to the climate calculator component, which provides the new values for the next state of the game. The interface component then structures the quantitative data and visualises it to the player in a manner that is easily understood by the player.

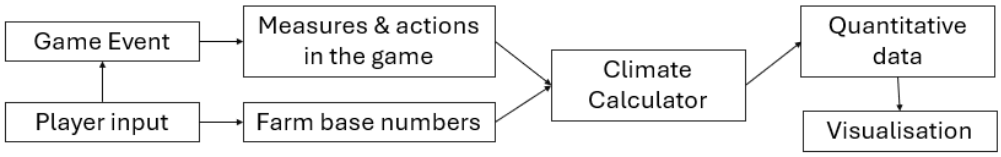

Figure 1: Climate calculator in the game

The current versions of the games do not use the full capabilities of the climate calculator as only a limited number of measures have been implemented in these prototypes. Emissions are calculated as CO2e rather than specific GHG as this is simpler.

4. Game Design

The main learning goal for both the games is to enhance the understanding of the consequences of actions in farming and agriculture, and to manage the resources to achieve zero emission farms. Hence, both games aim to support learning of actions or measures that could be taken on a farm that would help to reduce emissions and achieve a sustainable farm. Action cards have been used to support this learning goal, and these are designed from real life measures, and the players can see the consequences of individual actions instantaneously through a simulation based on the climate calculator. The target user group is the students of the agriculture school. The game is intended as a learning resource that could complement currently available resources and activities.

Both games are designed as single player games and are based on the climate calculator that has been developed by the Agriculture School, which calculates the emissions (Grønt kompetansesenter Mære og Skjetlein). The current versions of the games support the Norwegian language.

4.1 Game Concept 1 – Actions to Reduce GHG

The learning goal for this game is to learn about the different real-life measures, or actions, that could be taken on a farm to reduce the amount of GHG emissions and to understand the consequences of each action. In real life, many of the measures that could be taken would take time before their consequences are noticeable. Experimenting with the different measures and the possibility to see the consequences immediately within a game could enhance the learning possibilities. The goal of the game is to select actions representing real-life measures on a farm, in order to make the farm as environmentally friendly as possible.

A core pillar of the game concept is the “gameplay loop” system, which builds upon the idea that a game has a series of loops that can be repeated, typically with a reward towards the end of the repetitions. This game utilises cards to create a gameplay loop of “analysing cards, choosing a card, witnessing the effects of the action represented in the chosen card and repeating the process. Cards get shuffled and redrawn between

each loop; see Figure 2. A significant aim for making the loop system function properly is making sure it engages the player to continue playing.

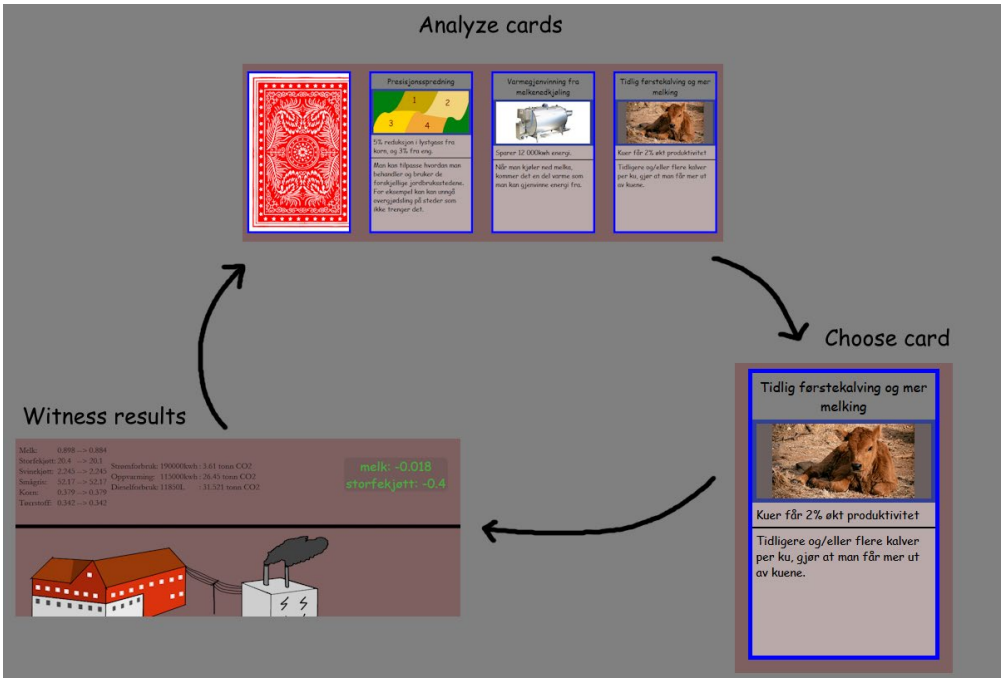

Figure 2: Core idea of Game 1

The game is played by selecting an action card which starts a loop, or a game round. Currently, a maximum of ten rounds are available in each game session, and each round includes a selection of a single action. This is intended to reflect that measures in real life are not free and implementing several or everything is difficult. Cards can primarily be picked to enhance the farm and make it more efficient. Secondly, they can affect the game loop itself by altering one of the loop areas. Players are able to see how many rounds and actions they have used and are remaining within each game round. Throughout this process, by utilising the loop system and encouraging multiple attempts at the game, the intention is that the player will retain the knowledge after playing.

Each action is represented as a card, which is divided into sections which provide different information about the specific action: a title, an image, a gameplay description and a description of what the action does in practice; see Figure 3.

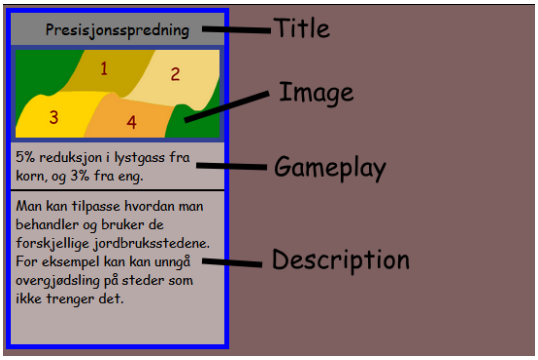

Figure 3: Design of an action card

As shown in Figure 2, a player gets three action cards to select from, referred to as “analyze cards”. A player could select 10 cards in each game. Once the player selects an action card, e.g., early first calving and more milking, the consequences of the action are shown as “Witness results”, which consists of two parts: a visual indication and quantitative data to indicate production and emissions; see Figure 4. The quantitative data, shown on the left hand side of Figure 4, indicates the change due to the action using an arrow, e.g., the top value shows that the milk (“Melk”) production has dropped from 0.898 to 0.884. The data shown in the middle

column shows emissions from energy consumption (“Strømforbruk”), heating (“Oppvarming”) and diesel consumption (“Dieselforbruk”), in tons of Carbon Dioxide Equivalent (CO2e).

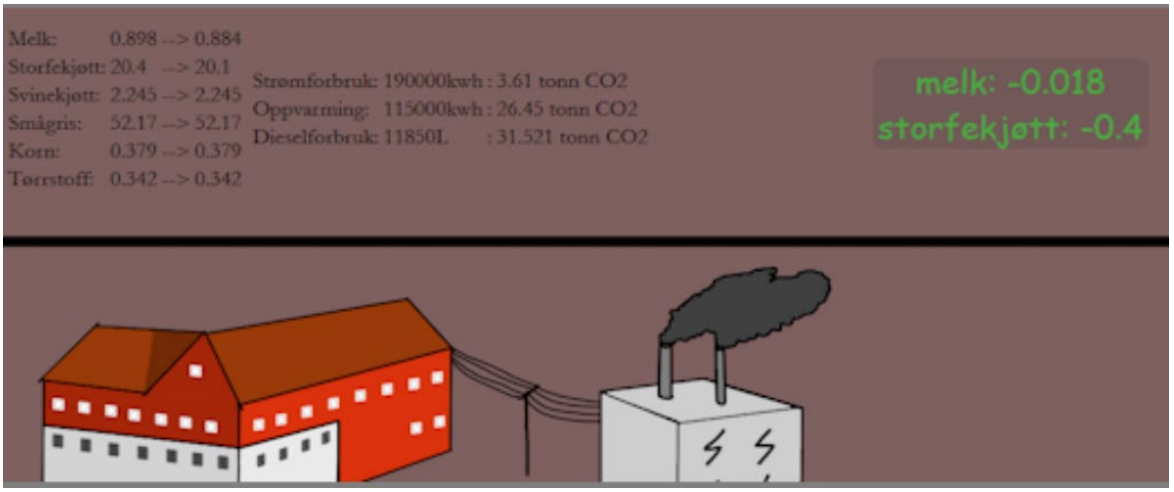

Figure 4: Consequences of an action shown as quantitative data and graphics

The current state of the game does not include scoring and one of the challenges in designing the scoring for the game is to value each action and determine which actions are better than others and how.

4.2 Game Concept 2 – Managing a Farm

The learning goal for this game is for agriculture school students to learn about zero emission technologies and practices in the agricultural landscape. The goal of the game is to reduce emissions while increasing production, creating a balance where the player must both increase their farm’s production and decrease emissions. The core idea in this game is on managing the available resources, depicted in the game as points, to find a balance between investing in increasing production, e.g., more cattle, and decreasing emissions, e.g., through new technologies such as renewable energies. The points represent a farm’s economic resources, and hence, they are used in the game to implement changes on the farm and are a representation of the monetary budget a farm could have to implement technologies or practices in the real world. This allows the player to purchase either an expansion to their farm, in the form of more cattle, land or other. Or they could use the points to invest in measures such as new technologies or practices that help create a more sustainable farm and farming practice.

The points are also used to unlock the different measures and expansions in the game. Because the player has a limited number of points, it is up to the player to decide how best to spend them. The points are based on the production of the farm and active measures from grants or other avenues. Hence, they consist of points that come from the economy of the farm and extra points that could be, e.g., a governmental grant or a bonus.

At the start of the game, the player is allocated some points. Each game has ten rounds, where each round represents a year. For each round, the player can take two types of actions which are to implement an enhancement measure to increase production, or take an action to reduce emissions, both of which are represented in the game by Action Cards. Each action card has a cost associated with it as in real life, and this means that the player will have to use one or more points. Hence, the player has to manage the points during the game. The aim for the player is to balance the farm’s production and emission over ten years. The player can also choose to view the status of the farm on the “My Farm” page.

At the beginning of the game, the player is provided an overview of the status of the farm and allocated points. The player is then presented the possibility to plan for the next year with the options to take an action, enhance or view the status of the farm. A part of the screen that shows some of the actions is shown in Figure 5. Depending on the choice, the player is then given an overview of the possible actions, or enhancements or the current status of the farm. The list of actions or enhancements are given as a set of cards where each card shows the name of the action or enhancement, a picture, results achieved during the year by taking this action and the value for many years and the number of points it costs. By clicking on the picture on the card, a detailed explanation of the action and consequences are available. Examples of the action cards are shown in Figure 5.

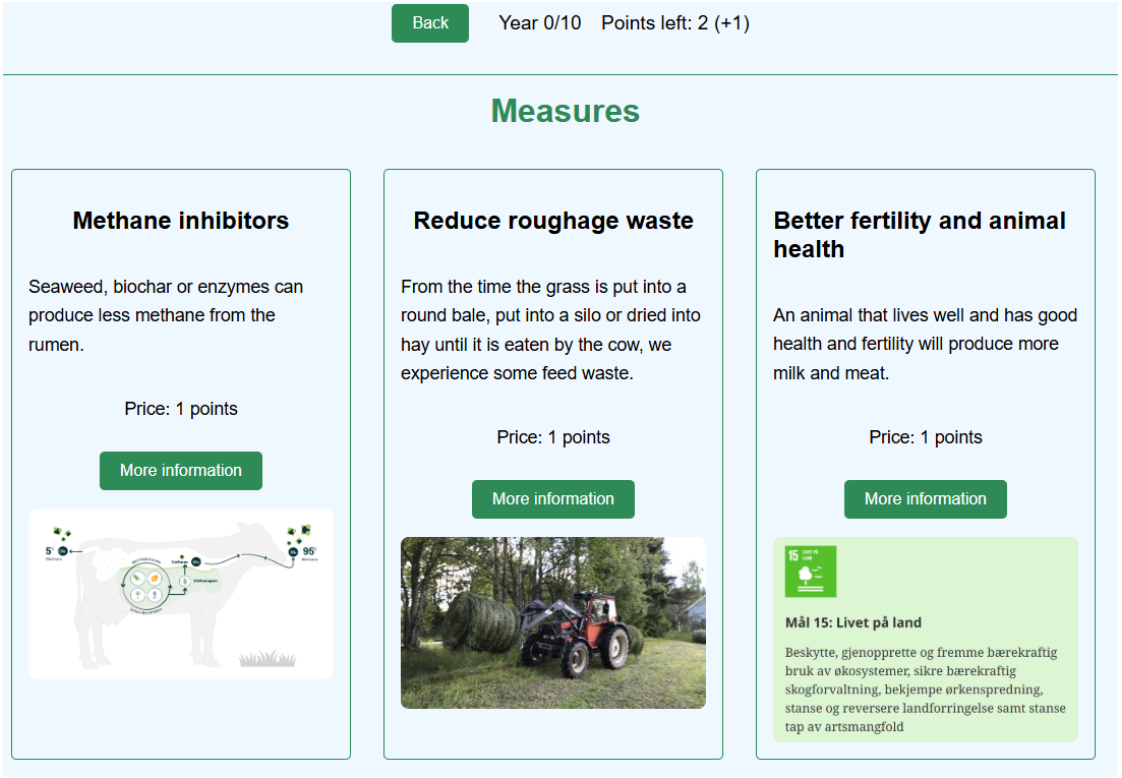

Figure 5: Main Page of Game 2

The consequences of the selected action or the enhancement are calculated using the climate calculator to determine the new state for each round, which is shown on the "My Farm" page; Figure 6. This page includes information about the area of the farm used and the quantity of products (e.g., no. of cows), total amount of emissions in tons of CO2e, production (e.g., kg of milk,) and emission per product (e.g., how much of the emissions come from milk). In addition, the breakdown of production and emissions are also shown as pie charts on the same screen. The no. of the round and the points that the player has remaining are shown on the top of the screen.

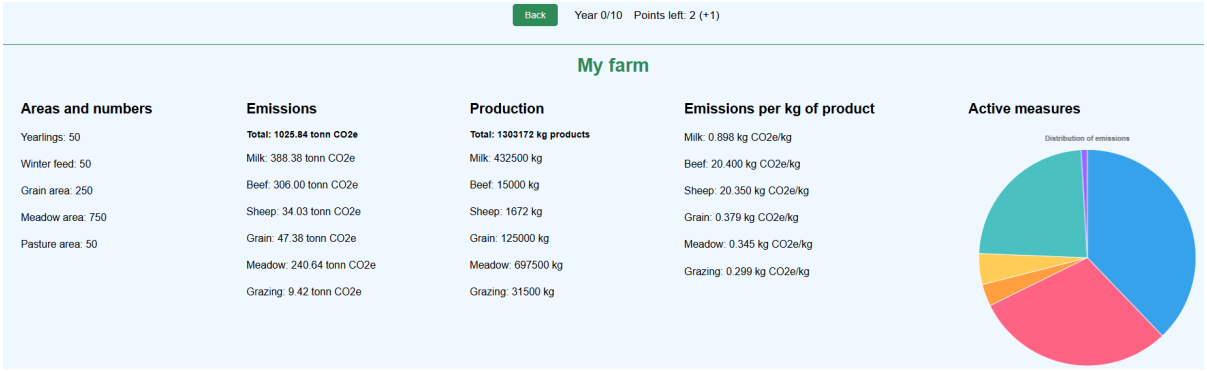

Figure 6: Consequence of an action or enhancement

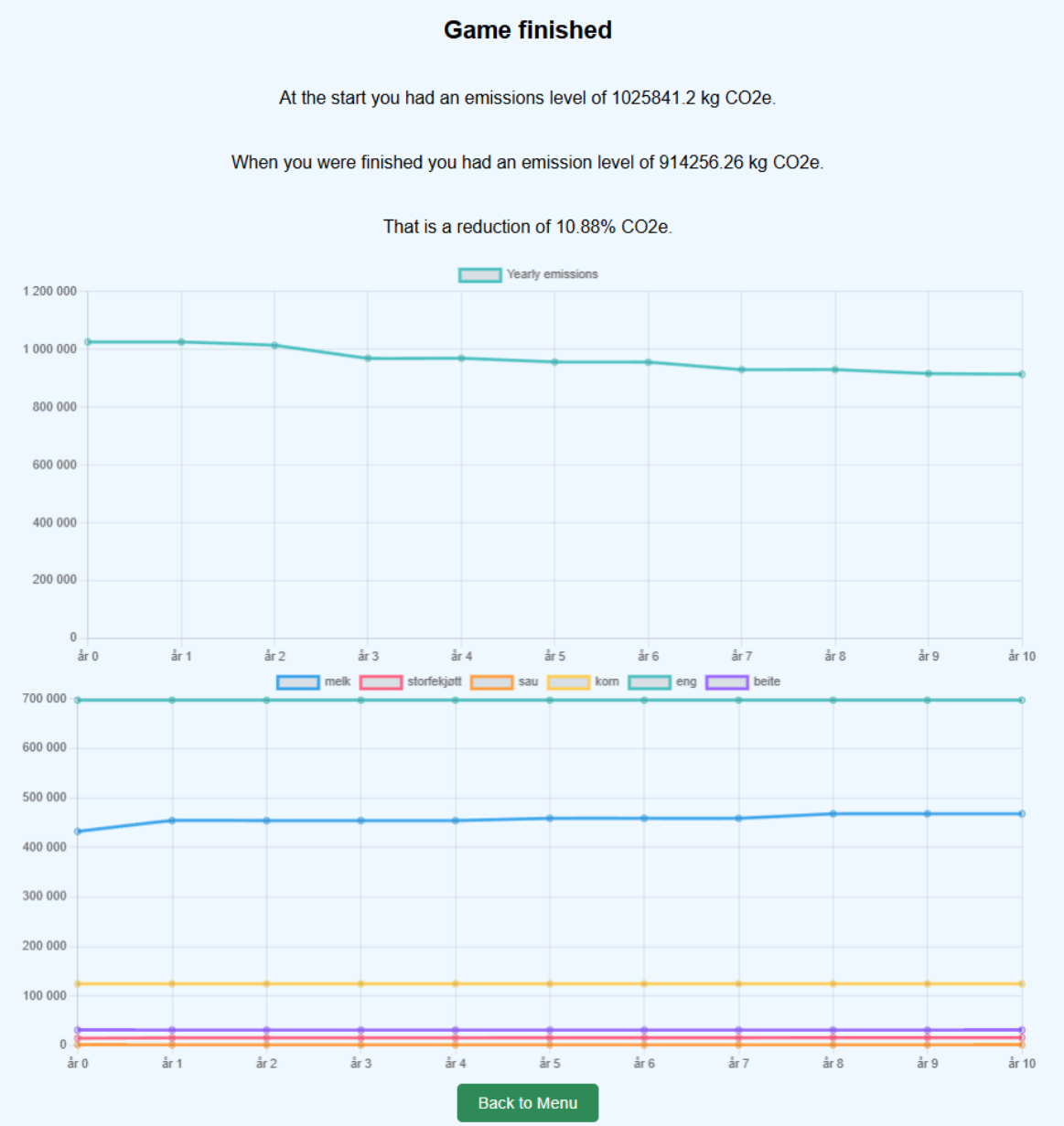

Figure 7: End state of the game after ten rounds showing CO2e emissions each year. Top graph shows the total amount of CO2e emissions; bottom graph shows a breakdown of emissions

After ten rounds, the player can view the actions and enhancements that have been applied and see their progression. This is shown in the two graphs in Figure 7 where the vertical axes show the emissions in tons of CO2e and the horizontal axes show the game rounds (or years). Information about the emissions at the beginning and the end of the game are shown; in this case 1,025,841.2 kg CO2e at the beginning, and 914,256.26 kg CO2e at the end of the 10 rounds, showing a 10.88% reduction of CO2e.

The quantitative values and the graphs are designed to give an indication of a score. In particular, if several individual players play the game, they could compare their quantitative values and the graphs at the end of the game, after ten rounds.

5. Expert Evaluation

Both the game concepts have been evaluated by the expert who had also been consulted during the design phase of the games. The expert evaluation was conducted to obtain feedback on the knowledge content and to improve the design, and to confirm that the game concepts have potential to support the learning goal. As a first step, the actions or measures and the consequences of the actions that were used in both game concepts

meet the learning goals for the students in the agriculture school. Beyond that, a challenge still remains on how to balance the different actions.

It was also clear that the motivation of the player is important for games such as these, and that making something engaging can be challenging. It was recommended to keep the idea of displaying both quantitative data and visual changes to the farm (e.g., see Figure 4), but also with the caveat that it can be difficult to convey certain concepts through that alone; e.g., what makes a cow more environmentally friendly, visually speaking? The feedback is summarised as a set of recommendations for improving the game:

- User Interface:
- *Provide clearer visual cues or warnings when the player has no more points to purchase a measure on their farm (in game 2). This would help the player understand that they have used their resources and prompt them to go to the next round.*
- *The game was easy to manage in the early stages. However, some areas were hard to identify, such as the limitations of undoing actions and where to proceed to the next turn.*
- Feedback mechanisms:
- *Feedback to the user and communicating the state of the farm through qualitative data such as progress in the game should be distinguished. (The current game versions do not include explicit feedback, hints or help to the player.)*
- *A graph could help players identify when they invested in a measure and how it impacted the farm, in such a way that a player could more intuitively understand what their choices mean.*
- *A representation of the state of the farm, e.g., a visual metaphor, could be helpful.*
- Game design and game mechanics:
- *Clearer distinction between farm expansions and other measures, and explanations of these are recommended. One suggestion was to increase the number of points per round so that there would be more to do during the first round and enable strategic decision making.*
- *Scoring design: points could be given separately for production and climate improvement. Bonus points could be given if player does/doesn't look up theory and hints.*
- Educational aspects and theoretical integration:
- *Connect domain knowledge and theory at possible places in the game, e.g., in game 2, the graph displaying emissions per round could have the specific action or enhancement, economy and relevant theory made available to the player on each value displayed on the graph.*
- *The player could be asked a random question or recommended to read theory after a set no. of actions and the player can only proceed after fulfilling this (e.g., for game 1).*
- *Including subsidies, carbon credit and economy was suggested.*
- *A leader board that shows different production and the reduction in emissions to create competition, to engage students.*
- *The division between information given and discovering solutions was commented on. One suggestion was to start with less information on the card, then present theory. Hints or help could be made available for the player as needed.*
- *Need careful consideration of actions that need to be done continuously, e.g., fodder, or sequence of actions that need to be carried out for effective results, and other similar domain related specific knowledge.*
- Motivation and user engagement:
- *Possibility for students to question and critique.*
- *Clear learning objectives that show how these things from the game work in the real world and what challenges there are in agriculture.*
- *Use of a reputation system which could affect how competitive the environment is and how much subsidies are given to a farm.*

6. Conclusion and Future Work

In this paper, we describe two game concepts based on a climate calculator that is used to teach students in an agriculture school. The aim of the games is to engage students and to enhance the understanding of the consequences of actions in farming and agriculture, and to manage the resources to achieve zero emission farms efficiently. The learning goal for the first game is to understand the greenhouse gas emissions and the consequences of taking an action or a combination of actions. The learning goal of the second game is to manage the greenhouse gas emissions in a farm over time through the use of available resources. Both game

concepts use cards to represent actions, and the consequences of actions are calculated as CO2e emissions using a climate calculator. Both games are designed as digital games, in collaboration with an expert and a teacher from an agriculture school. An expert evaluation of both games confirmed that the game concepts had potential and the knowledge contents in the game, presented as action cards and consequences of taking an action, were aligned with the learning goal for the target audience, who are the students in Agriculture schools. The expert evaluation also confirmed that the knowledge in the climate calculator was used correctly and the game had the potential to increase awareness about actions and their consequences to production and CO2e emissions. The feedback and recommendations from the evaluation are currently being reviewed.

Currently only emission reduction is considered for the games. Ideas for future developments include supporting multiple languages, stimulating multiple senses and using multiple media (e.g., movement, colour and text simultaneously) to increase the likelihood that a user retains information. For both games, the scoring needs to be designed and motivational aspects such as leaderboards will be considered. We also plan to evaluate the game with the target player group to see how the game could affect their learning capabilities and to identify how the game could be used both in and outside the classroom, and a design workshop is planned to identify potential improvements in the game designs and user interfaces.

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Ethics declaration: Ethical clearance was not required for this work.

AI declaration: No AI was used in this paper.

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