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Development of Massive Online Open Course 'Energy Transition and Climate Change'

Elina CERVINSKA[1*], Andra BLUMBERGA[2], Antra KALNBAĻĶITE[3], Jelena PUBULE[4]

[1–4]*Institute of Energy Systems and Environment, Riga Technical University, Azenes st. 12/1, Riga, LV-1048, Latvia*

Abstract – This study focuses on designing a massive open online course (MOOC) to enhance students learning about the energy transition process and its connection to climate change in theory and complex dynamic systems. The course 'Energy transition and climate change' covers one of the United Nations' 'Sustainable development goals' and is one of twelve MOOCs that will enable a comprehensive education in system thinking and its applications. It shows how system thinking methods and tools can be applied to tackle current and future energy and climate problems. The goal of the MOOC is to introduce users to the internal dynamics of modern energy systems and energy transition toward CO_2-neutral energy systems. The target audience of the course is students who study Environmental Engineering, Energy, Systems, or similar program and anyone else interested in insights into the topic. The course builds on previous energy supply and demand models by updating and adapting them to the existing situation. MOOC is designed by the Competency-Based Education (CBE) approach, and a literature review is used in the study to cover theoretical parts of the course. Technology Readiness Level (TRL) methodology describes the main steps of the course model development progress, and testing of MOOCs pilot version on five students is included in the final stage of the study.

Keywords **– Competency-based education; energy efficiency; renewable energy sources; system dynamics**

Nomenclature		
MOOC	Massive Online Open Course	–
TRL	Technology Readiness Level	–
CBE	Competency Based Education	–

1. INTRODUCTION

The educational model that focuses on the learning course outcome and is reached by changing from knowledge-based pedagogy to a skill-based pedagogy is called 'Competency-Based Education' [1]. Competency-based education is primarily focused on defining what the student should be able to achieve at the end of the program. Then the specific course is being modelled, moving backward to each activity to ensure that each objective is achieved. This form of education contributes to skill and competency development with student–centered and self–directed methods. According to the definition, competence is 'a combination of cognitive and metacognitive skills, demonstration of knowledge and understanding, interpersonal, intellectual and practical skills and ethical values' [2]. Competencies offer the

* Corresponding author.
E-mail address: elina.cervinska@gmail.com

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knowledge necessary for successful problem-solving in different situations and encourage acting in the given context. These skills can't be taught only by theoretical lectures; those must evolve with gaining learners' experience during practical tasks [3]. Key competencies, also called core skills or essential skills, are flexible items used in education models that support learning by practical tasks in real-world situations to understand the most effective solution for solving the given problem. Focusing on achieving different competencies allows students to use their knowledge, skills, and past experiences while performing a task [1]. Integrated knowledge includes different concepts, theories and data complemented with skills and components which leads to better social and cultural influence [4]. According to the Sistermans' publication on integrating competency-based education in online health sciences, there are six steps in planning a competency-based curriculum. First, the compilers of the educational program need to understand and define abilities that students must develop at the end of their studies. Then it is possible to point out exact competencies and their components. After that, 'the route' for achieving those competencies needs to be designed with key turning points. When the bases of the program are defined, appropriate educational activities, experiences, and educational methods need to be chosen and the most suitable assessment tools. The last step is to evaluate results at the end of the curriculum [5].

Climate change is a major environmental, economic, and political threat. The international community has recognized that education, which is a direct way of spreading awareness at different levels, is an essential element in identifying and highlighting the problem and training and mobilizing young people to face the main challenges of climate change [6]. Study courses focused on topics related to climate change should be able to provide good content and concepts to understand its magnitude, causes, and consequences. It is essential to provide information on the impact of climate change, both domestically and globally. Students need to understand the consequences of not responding and avoiding action. Climate change is a complex issue requiring additional technical and scientific sources in the study process, but the preliminary information should be clear and simple [7]. Implementing new learning tools contributes to student productivity and overall academic performance achieved during the course. The time spent creating an online course is compensated by the possibility of using such a course on several occasions [8]. Interactive learning environment approaches developed to create education more convenient, accessible, and affordable to anyone interested are called massive open online courses (MOOC). Various studies on the effectiveness of MOOCs have shown that users are more successful in learning the course content through self-regulated learning (SRL) when they need to study and read the course materials on their own [9]–[11]. The MOOC's online environment is found in a wide variety of formats, with some common characteristics collected by [12]. MOOCs, thanks to their extensive capabilities in acquiring content, materials, and skills, represent changes in studying process that soon might be a fundamental part of education system [13]–[15]. There is a wide diversity of the categorization of massive open online courses [9]. xMOOCs: based on traditional pedagogy and certification, with lectures, practical tasks, and more commonly used study model [16]. Problems such as high number of dropout cases and low co-operation among users would need to be addressed [16]. However, although MOOCs open up extensive technological opportunities and use of different teaching methods, in practice it has often maintained a standard educational approach where teaching content is represented and evaluated on the part of the teacher and not by the interaction between users [17].

The study addresses two research questions regarding the production context of an online course designed to be taken without the direct involvement of a teacher:

- How to design an adaptive online interactive learning environment for users that effectively encourages studying in and about themes regarding energetics and its

binding topics?
- How interface tools can be used in education to describe complex dynamic systems of the energy sector and the energy transition process towards CO_2 neutral energy systems?

This study has three main objectives:
1. Design a pilot version of a free massive open online course suitable for the target audience with a means of obtaining adequate competencies to tackle current and future energy and climate problems through theory and prism of system thinking;
2. Analyse and integrate CLD models and stock and flow structures of supply and demand sides of the energy sector in the content of the course and supplementing those with appropriate interactive tasks;
3. Test the developed version of the course for five students with advanced knowledge of system dynamics and energy systems.

2. METHODS AND METHODOLOGY

Technology Readiness Level (TRL) is a method used to assess the maturity phase of a new idea and the necessary actions in its development process. TRL consists of 9 levels which can be seen as a measurement of such an assessment. The benefits of this method are a structured and comprehensive view of the status of the prototype in its research and production process [18]. The TRL method aims to develop and test prototypes in their real application environment and is divided into three phases:
- Research;
- Prototype development;
- Product implementation.

A summary of TRL methodology according to the study is provided in Table 1. Levels 1–7, which include research, prototype development, and testing, are discussed in the study. At the beginning of the study, the research is made, which is compared to TRL 1–2. It starts with an introduction to the project – the expected content of the course and its main outcomes, as well as definition of the research questions. Similar courses from the partner universities were found and studied to understand the structure of the massive open online courses. One of them was 'Natural Resources Management' which is developed by the System Dynamics groups at the Department of Geography at the Faculty of Social Sciences at University of Bergen. This MOOC provides learning to manage various natural resources like fisheries, animal herds, water reservoirs and climate while focusing on complex dynamic systems. An important step in the study was the understanding of the MOOC's digital building tools, which is why different sources of information on the technical side of development of such courses were included in the research process.

TABLE 1. SUMMARY OF TRL ACCORDING TO THE STUDY

TRL	Description	Goal	Product/Evaluation	Outputs
1	Introduction in the current situation and goals of the project	Research	Feasibility of concept	Set of similar MOOCs from the partner universities
2	Definition of research questions	Research	Feasibility of concept	Publications regarding to the development of MOOC
3	Analytical studies and literature review	Development	Prototype	Scientific research and publications relevant to the topics included in the MOOC

TRL	Description	Goal	Product/Evaluation	Outputs
4	The basic components are integrated to test the operational capability of the MOOC	Development	Prototype	CLD models designed in *Stella Architect* Tools of the practical tasks available in the Moodle platform
5	The basic components are integrated to test the performance of the MOOC	Development	Prototype	CLD models designed in *Stella Architect* integrated in the content of the MOOC Tools of the practical tasks available in the Moodle platform used for theoretical and practical task development
6	Shaping of representative prototype	Development	Prototype	Collection of theoretical information and tasks included in the content of the MOOC
7	Testing of the prototype	Implementation	Prototype	Results of the tests carried out in the relevant environment
8	Research project to finalize the project	Implementation	Certified product	Defined main enhancements of the MOOC
9	Launch of the MOOC	Implementation	Deployed product	Functional final product developed

The next phase includes a literature review to establish a theoretical justification for the course model, which would be implemented as readable material for users in the study process. It's defined as level 3 of the described TRL method used in the study. More than 60 scientific research, publications, and books relevant to the MOOC's topics were used in the literature review, which was the most time-consuming part of the course development. The available tools for supplementing the theoretical part with practical tasks were examined in the following course development phase (TRL 4), as well as given casual loop diagrams (CLD) which were designed in *Stella Architect 2.1.5* software. These two CLDs of the supply and demand sides of the energy sector were created during 'Deliberation platform for energy transition policies: how to make complex things simple' research made by the Institute of Energy Systems and Environment at Riga Technical University in which an internet-based interface tool for the national energy simulation model as a tool for 'hybrid forum' was made [19]. Given casual loop, diagrams were converted into the generic stock-and-flow structures and used as study tools to explain how multiple parties of energy supply and demand sides interact in the energy sector by updating and adapting it to the existing situation (see Fig. 1). By creating interactive stories which visualize how elements of stock-and-flow structures affect different indicators like energy tariff, installed capacity of technologies using different fuels, and probability of investments users learn through the system dynamics how barriers to energy transition process are caused.

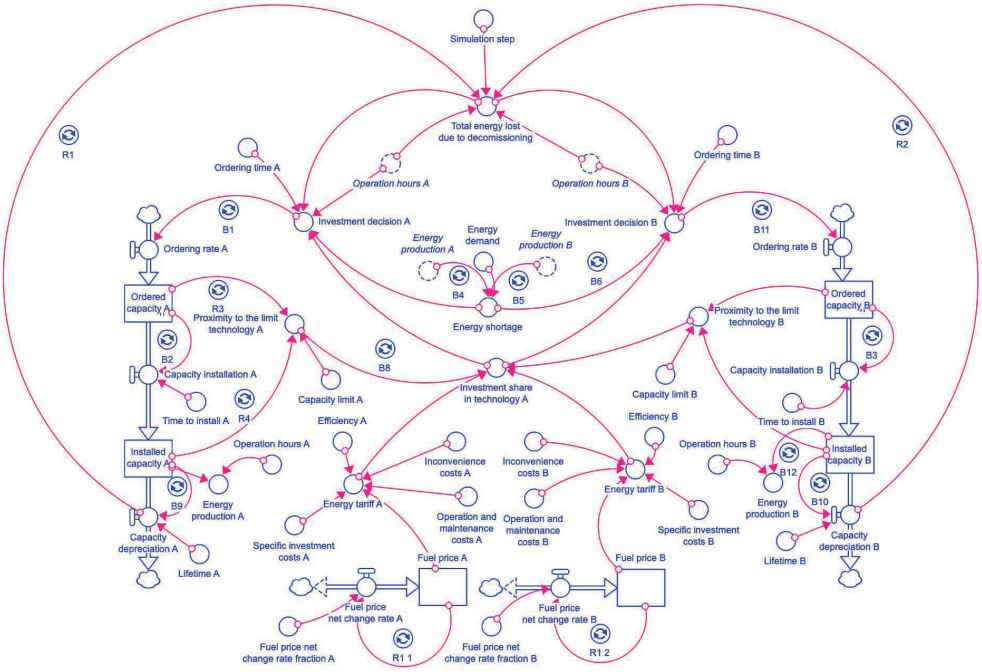


Fig. 1. Stock and flow structure for energy supply sector [12].

Reference [9] discusses that levels TRL 5 and TRL 6 include prototype validation in an environment like the actual environment, which in the case of this study was *Moodle* platform supported in the student course portal of the Riga Technical University called *ORTUS* [20]. A new course page was created which functions as the base of the developed prototype and includes all resources needed for both parts – theoretical and practical. *Moodle* platform allows building course structure by adding main sections of the topic and subsections, which include theory sheets and interactive content, such as interactive videos, question sets, 'drag and drop' questions, questions with answers, presentations, etc. Practical tasks used in the study course 'Energy transition and climate change' differ – some are made to aim student's knowledge of the described theory in the form of multiple-choice or 'true/false' questionnaires, but some involve practical work with interface after which user must answer quiz questions regarding the results reached by manipulating with different variables.

The final stage of the study was testing the pilot version on five students with advanced knowledge of system dynamics and energy systems after which the results were obtained through structured interviews (TRL 7). Students were chosen from Riga Technical University and the criteria was to have test users who had completed the System Dynamics course during their bachelor's studies. The following sections will set out the main points for the development of the MOOC 'Energy transition and climate change' with the Technology Readiness Level approach.

2.1. Research

In the first phases of course development research had to be made to evaluate the current stage of the MOOC, the goals of the content, and protentional outcomes of the user's knowledge and skills after studying. Useful research was made by completing one of the MOOCs that was published recently – 'Natural Resources Management' by the University of Bergen. It allowed an understanding of the basic structure and the most effective tools used to create an online course with a focus on the system dynamics approach.

The given MOOC 'Energy transition and climate change' which was one of the objectives of the study had almost no theoretical background and an important stage was to gather valid information for the content. That was done by selecting more than 60 resources relevant to the topics discussed in the course. Information had to be transformed in an educational manner to reach the target audience.

2.2. Prototype Development

Main structure of the created pilot course sections includes several steps, which contain practical tasks to determine the knowledge of users before, during, and after the studies. It contains the sections divided into chapters and subchapters (see Fig. 2). First, the student's knowledge of the following subject is tested through the training task. The results of these tasks are not included in the course final grade and are designed to give the student an idea of the content of the following topic. After completing students can look at the correct solution to the task. The 'Retry' function is provided for these tasks which allow the user to perform them multiple times. This structure is created to target the progress of the student and learning in practice. The basic section provides a theoretical insight into the subject. It is developed by literature review from publications and books that covers the main topics of interest. Some chapters also include additional training tasks, video materials, diagrams, interfaces, etc. for learning purposes. At the end of each chapter, the student must perform the practical assessment and the score of it forms part of the final rate of the course. Types of the tasks differ – there are multiple-choice, single choice, true/false questionnaires, as well as other interactive forms of tasks included. These tasks are designed to evaluate the user's understanding of the theory and behaviour of the system dynamics model (see Fig. 3). Practical assessments in the course can only be performed once. After completing the task, the student can look at the correct solution immediately and view a video that presents correct answers. For a positive rate, students must reach a minimum of 50 %.

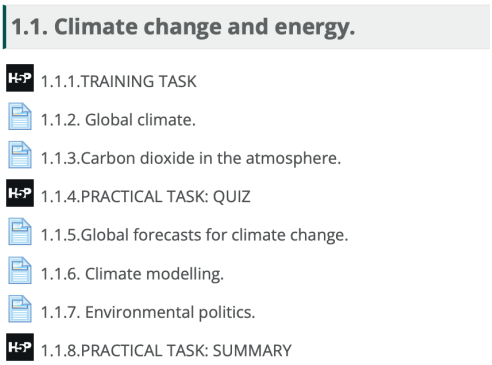
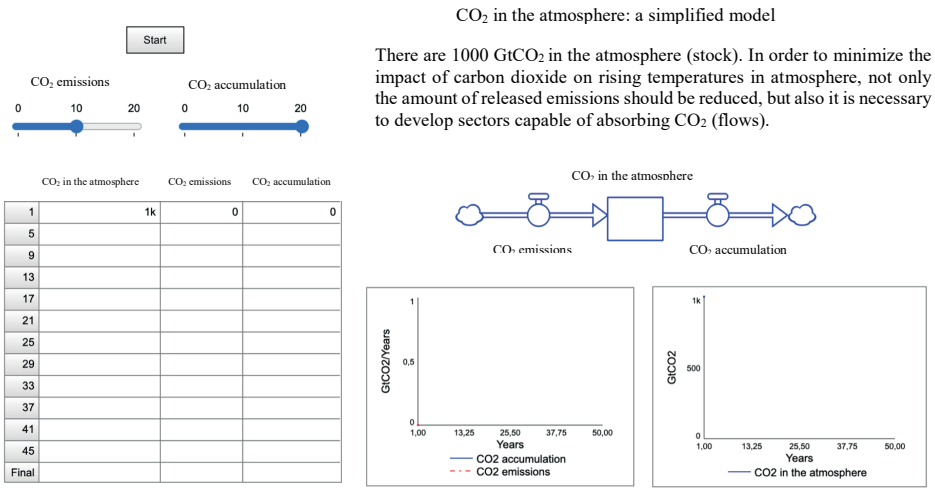


Fig. 2. Structure of the course chapter 'Climate change and energy' (icons represent various types of activities used in the MOOC).



Look at the photo of 'CO_2 in the atmosphere: a simplified model' interface, which was practically used in the introduction chapter. The flow of CO_2 emissions in the atmosphere develops during time period of 50 years. The settings show that each year CO_2 emissions increases by 10 $GtCO_2$ accumulation increases by 20 $GtCO_2$

How will the stock 'CO_2 in the atmosphere' develop during time period of 50 years?

You can click on the photo to increase its size.

- ○ CO2 in the atmosphere will increase linearly
- ○ CO2 in the atmosphere will stay constant
- ○ CO2 in the atmosphere will decrease linearly

Fig. 3. Single choice question regarding simplified model of CO_2 concentration on the atmosphere.

2.3. Product Implementation

After finalizing the pilot version of the course testing had to be made to get results from the target audience about the focus areas of the course development in the future. For this reason, five students at Riga Technical University were selected. All the students had advanced knowledge of system dynamics. Selected users had three days to complete the course and structured interviews regarding their experience took place afterward.

3. RESULTS

MOOC 'Energy transition and climate change' is developed in English and designed to be attended 100 % online. It allows students to learn at their own speed and deals with three important and interrelated aspects of modern energy policy: energy efficiency, renewable energy, and climate change. It describes the socio-technical transition of the current energy system, including innovative solutions in energy and climate technologies, discusses learning curves and economics, human behaviour as one of the main drivers of changes, as well as diffusion of different technologies to reach climate and energy policy goals. This knowledge is given to the user through the prism of system dynamics by explaining how the supply and

demand side of the energy sector works. The course consists of five sections of which three were included in the pilot version development. You can see the full course table of contents in Annex I. Each chapter includes practical tasks to test the knowledge of users before, during, and after the studies. The training task takes place at the beginning of each part of the course and the rate of it is not included in the final grade. Practical assignments are rated and included in the final note of the student.

The introduction part of the course explains what climate change is and how the energy sector relates to it. The outcomes of this part include knowledge about the main causes and impacts of climate change, dynamics of the carbon cycle in the atmosphere, and the basics of global policy measures for climate change. After finishing the first part of the course, students can distinguish the supply and demand sides and how they are interlinked, as well as name energy supply sources and differences in energy consumption tendencies in multiple sectors of the demand side. After the introduction course student can also describe the energy transition process, lock-in barriers, understands the dynamics of energy transition from fossil-based energy to renewables, and improved energy efficiency.

First, an introduction to Earth's climate and its natural and human-caused influencing factors is explained, focusing on greenhouse gas (GHG) emissions. The chapter includes material about the carbon cycle, which illustrates how the concentration of CO_2 in the atmosphere is constantly changing because of emissions and the accumulation process. Also, the influence of increasing concentration of GHG emissions on global warming is discussed, as well as policy tools for limiting it.

The second chapter dives deeper into the supply and demand sides of the energy sector. A short introduction in examples of different fuels used to produce energy is included, followed by the importance of energy efficiency and growing numbers of prosumers in the demand side of the energy sector. This part of the course includes an introduction to the supply and demand side relationship through the prism of system dynamics.

In the following chapter key features of the main sectors of energy users (residential, industrial, public, etc.) regarding the usage of electricity and heating/cooling systems are described. Finally, the last chapter of the introduction part of the course explains the importance, opportunities, and complications of the energy transition process [21]–[23]. It includes the transition theory, 'Shifting the burden' archetype, possible lock-ins in the energy transition process to more sustainable technologies, and how bridging fossil energy systems with renewable energy systems occurs. Decentralized energy management, which is the essential aspect of sharing economy as well as aggregators is also discussed.

Sections 'Supply-side' and 'Demand-side' are designed using a similar approach – information from publications that cover the main topics of interest are given first, following with the examples from the stock-and-flow structures of energy supply and demand sectors. Users can assess, describe, and evaluate the main driving forces of the energy transition on both sides from the system dynamics perspective. The Supply-side includes different current and future energy sources while the demand side sub-models include energy consumption sectors, such as households, tertiary, industry, public, and transport. Practical tasks using interfaces are included where users can plan different scenarios for the development of energy transition towards CO_2 neutral energy systems, major leverage points in energy systems, short- and long-term effects, as well as the impact of delays, non-linearities, and feedbacks in the process of the energy transition.

Topics discussed in the supply side section of the course include definitions of the main technologies used in energy production and their price range data followed by an interface explaining how the stock-and-flow structure of the energy supply sector is built (see Fig. 4). Users then have to design different scenarios to investigate which are the variables in the

structure that have the highest impact on energy tariff, the quantity of energy produced by fossil-fuel-based and renewable energy-based technologies, as well as installed capacity in power plants for different technologies. The chapter explaining how capacity is built between competing technologies using fossil-fuel and renewable energy sources (RES) with the theoretical examples from two power plants running on natural gas and wind energy is included. Factors like delays in capacity installation, public acceptance, and resource availability, explain how important land space is and how much land footprints are made by power plants using different types of fuels.

The demand-side section describes internal and external barriers to the implementation of energy efficiency measures, which often occur in terms of low-quality construction works during renovation projects [24], [25]. The behaviour of residents during the period of deciding whether to support or not to support the renovation of the building to increase its energy efficiency is also discussed and the effect of this decision is included in the stock-and-flow structure of the energy demand sector. While navigating through the interface, users are introduced to each element of the structure with theory and examples. Similarly, as it was in the supply side section, the interface includes a simulation model in which students build multiple scenarios and in the following chapter answer a quiz questionnaire about their experience. Energy efficiency in different end-use sectors (public, residential, industry, tertiary) is also discussed.

Each section of the course includes practical tasks to test the knowledge of users before, during, and after the studies. The training task takes place at the beginning of each part of the course and the rate of it is not included in the final grade. Practical assignments are rated and included in the final note of the student.

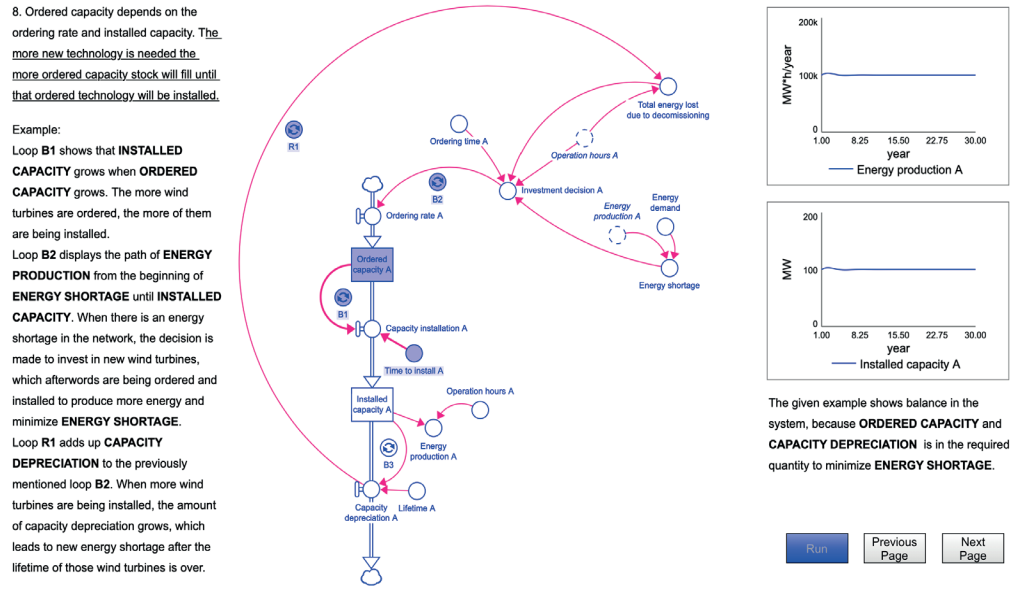


Fig. 4. Interface explaining how the stock-and-flow structure of the energy supply sector is built.

The Likert rating scale from 1 (Strongly Disagree) to 5 (Strongly Agree) was applied to evaluate the course in eight question groups. The average score for content was 3.65, learning and support 3.45, visual design 3.15, navigation 3.36, accessibility 3.27, interactivity 3.80, self-assessment and learnability 3.35, motivation to learn 3.71. The lowest rate (3.15) in

course evaluation has been given to the visual design of the MOOC. The MOOC prototype has not yet been developed to the stage where visual design for the course is being created. Users provided valuable comments and insights, which will be further used to improve the MOOC.

4. CONCLUSION

Study shows that Technology Readiness Level (TRL) method can be used to effectively measure the progress in the product development process, also it works as a useful guideline for understanding the following main steps in the building of the course. During the study, TRL approach proved to be a helpful tool to design an adaptive online interactive learning environment for users that effectively encourages studying in and about topics regarding energetics and its binding topics.

During the study a pilot version of a free massive open online course suitable for the target audience with a means of obtaining adequate competencies to tackle current and future energy and climate problems through theory and prism of system thinking was developed, which contains three from five sections intended in the project.

ACKNOWLEDGEMENT

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ANNEX

Massive open online course 'Energy transition and climate change' table of contents:

1. Introduction;

1.1. Climate change and energy;
- 1.1.1. Training task;
- 1.1.2. Global climate;
- 1.1.3. Carbon dioxide in the atmosphere;
- 1.1.4. Practical task: quiz;
- 1.1.5. Global forecasts for climate change;
- 1.1.6. Climate modelling;
- 1.1.7. Environmental politics;
- 1.1.8. Practical task: summary;

1.2. Supply and demand;
- 1.2.1. Training task;
- 1.2.2. Supply side;
- 1.2.3. Demand side;
- 1.2.4. How supply side and demand side interlink;
- 1.2.5. Prosumers;
- 1.2.6. Practical task: supply side, demand side or prosumer?;

1.3. Sector specifics;
- 1.3.1. Training task;
- 1.3.2. Introduction;
- 1.3.3. Residential sector;
- 1.3.4. Industry sector;

1.3.5. Tertiary sector;
1.3.6. Public sector;
1.3.7. Transport sector;
1.3.8. Practical task: quiz;
1.4. Energy transition;
1.4.1. Training task;
1.4.2. Energy transition;
1.4.3. Transition theory;
1.4.4. Shifting the burden;
1.4.5. Aggregators;
1.4.6. Energy accumulation;
1.4.7. Smart technologies;
1.4.8. Internet of things;
1.4.9. Practical task: summary of introduction chapter;
2. Supply side;
2.1. Training task;
2.2. Casual loop diagram: energy sector;
2.3. Technologies;
2.4. Stock and flow structure: single energy supply technology;
2.5. Practical task: quiz;
2.6. Capacity building;
2.7. Stock and flow structure: two competing technologies;
2.8. Practical task: quiz;
2.9. Delays;
2.10. Public acceptance;
2.11. Resource availability;
2.12. Practical task: summary of supply side chapter;
3. Demand side;
3.1. Training task;
3.2. Stock and flow structure: energy demand;
3.3. Practical task: quiz;
3.4. Barriers to energy efficiency;
3.5. Decision making and behavior;
3.6. Energy efficiency in different end use sectors;
3.7. Practical task: summary of demand side chapter.

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