Engineering a Sustainable Future with EPS@ISEP

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Abstract The challenge of engineering education is to transform engineering students into agents of innovation and well-being. In addition to solid scientific and technical knowledge, critical thinking, problem-solving and interpersonal competencies, it implies the ability to design and implement solutions supported by ethical and sustainability principles. With this goal in mind, the European Project Semester (EPS) provides a student-centred project-based learning framework. It is offered by a group of European higher education institutions, including the Instituto Superior de Engenharia do Porto (ISEP), the engineering school of the Polytechnic of Porto. Students work in teams of four to six, from different fields of study and nationalities, to design solutions to problems that affect individuals, society or the planet, taking into account the state of the art, the market and the ethical and sustainability implications of their decisions. These solutions are then implemented in a proof-of-concept prototype. Most of the projects address problems in education, the environment, food production and smart cities and have a strong educational, ethical and sustainability drive, encouraging students to develop sustainability competencies. This work analyses team papers of illustrative EPS@ISEP projects searching for evidences of the development of sustainability competencies. The proposed method maps keywords related to the sixteen United Nations Sustainable Development Goals to the contents of team papers by applying natural language processing and reusing the list of SDG keywords proposed by Auckland University. The results confirm EPS@ISEP fosters sustainability competencies in engineering undergraduates.

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1 Introduction

Engineering education for sustainable development (EESD) consists, according to UNESCO, in providing students with knowledge, abilities, and values to create, develop, implement, and run engineering systems that fulfil present needs without jeopardising the ability of future generations to satisfy their own (World Federation of Engineering Organizations et al, 2010). Education for sustainability, in addition to developing knowledge and understanding of environmental and social challenges, seeks to change attitudes, modify behaviour and promote the competencies needed to design a sustainable future (UNESCO, 2017). Although incorporating such skill building into core curricula can be difficult, it is especially relevant in the case of engineering education.

To better train future engineers to contribute to a more sustainable society, engineering curricula need to incorporate ethical considerations, environmental consciousness, and sustainable practices. This concern is visible in reference engineering learning frameworks such as the Conceiving, Designing, Implementing, and Operating (CDIO). It advocates the exposure of future engineers to CDIO real-world sustainable products in team-based engineering environments (Malmqvist et al, 2020a), and recommends integrating sustainability principles, cultivating entrepreneurial skills among engineering students and encouraging global perspectives and cross-cultural experiences through internationalisation and mobility (Malmqvist et al, 2020b).

In this context, capstone engineering programmes play an important role, as they usually take place in the final semester of the engineering course and allow participants to integrate, apply and expand their skills. This is the case with the European Project Semester (EPS), a 30-unit European Credit Transfer System (ECTS) programme created by Arvid Anderson in 1985 (Andersen, 2004). The EPS concept (European Project Semester, 2024a) combines multicultural and multidisciplinary teamwork with project-based learning to improve presentation, critical thinking and communication skills, expose students to a variety of fields of study and build a broader understanding of engineering by tackling real-world challenges. This teaching and learning practice promotes the development of technical and social competencies required by society, industry, universities, and students. Currently, the EPS network of providers comprises 20 European universities (European Project Semester, 2024b), including the Instituto Superior de Engenharia do Porto (ISEP), the engineering school of the Polytechnic of Porto, since the academic year of 2010-2011. EPS providers commit to following the 10 Golden Rules of EPS, the fundamentals of the programme (Budzinska et al, 2022).

To help foster sustainable development, the United Nations identified seventeen Sustainable Development Goals (SDG) and emphasised the value of gender parity, equal opportunities and the use of engineering to solve social problems (United Nations, 2018). This vital role of engineering has in addressing basic human needs, alleviating poverty, promoting secure and sustainable development, responding to emergency situations, reconstructing infrastructure, bridging the knowledge divide and promoting intercultural cooperation is reinstated in the last engineering report by UNESCO and International Centre for Engineering Education (2021). Future engineers need to develop core competencies for sustainability, as identified by UNESCO (2017) or Malheiro et al (2019), in order to meet the sixteen SDG. One way to determine whether students develop these competencies is through SDG mapping, a popular technique that establishes the frequency of specific SDG keywords in text documents. Thus, SDG mapping can be applied to the student textual deliverables to find evidence of the development of sustainability competencies.

This work explores the link between SDG and the development of sustainability competencies through means of SDG keyword mapping. Specifically, the proposed method analyses how EPS@ISEP, while an engineering capstone project programme, contributes to EESD, by analysing project papers in search of evidences related to the UN SDG. This is achieved by designing and applying natural language processing (NLP) together with the SDG-keyword search list from Auckland University, collected by Wang et al (2023), to map UN SDG to scholarly documents.

In terms of organisation, this document includes the following sections: Section 1 introduces the development of sustainability competencies in engineering undergraduates, contextualises the EPS programme and EPS@ISEP, and the structure of this document; Section 2 overviews related work on sustainability competencies and evidence-based analysis of EESD; Section 3 presents EPS@ISEP and summarises a set of illustrative projects; Section 4 describes the proposed method; Section 5 presents and discusses the experimental results obtained with the proposed method; Section 6 draws the conclusions.

2 Related Work

The current section overviews representative research on EESD, specifically on the desired sustainability competencies, as well as SDG mapping efforts, a popular technique that establishes the frequency of specific SDG keywords in a set of documents, to detect relevant evidences.

2.1 Sustainable Competencies

Engineering education for sustainable development builds upon undergraduate development of competencies for sustainability. Several research studies have addressed this topic.

Eight competencies for sustainability identified by UNESCO 2017 comprise systemic thinking, contextualisation and future vision, normative competency, strategic competency, ability to work in interdisciplinary groups, critical thinking, self-awareness and integrated problem-solving. In addition, Quelhas et al (2019) conclude that active learning, study visits, games, simulations or dramatisations are the most effective tools for integrating sustainability into the engineering curriculum and, thus, help foster these UNESCO competencies. EPS@ISEP implements active learning and contributes to the development of the eight competencies as reported in Malheiro et al (2019); Duarte et al (2020).

4C2S professional competencies analysis framework proposed by Malheiro et al (2019) assesses how engineering capstone programmes contribute to the development of critical professional competencies in engineering undergraduates (Malheiro et al, 2019). Specifically, it searches for evidences of the 4C competencies identified in 2012 by the American Management Association and of the 2S competencies proposed by these researchers as shown in Table 1. The

Table 1 4C2S Professional Competencies

Acronym	Competency
C	**C**ritical thinking and problem solving
C	effective **C**ommunication
C	**C**ollaboration and team building
C	**C**reativity and innovation
S	**S**ustainable development practices
S	**S**ocio-professional ethics

search considers the programme (syllabus, learning method, etc.), and the learning process (activities and deliverables) of the students. This work established that EPS@ISEP programme develops the 4C2S competencies. Specifically, it contributes to “the development of (*i*) critical thinking and problem solving by specifying open-ended project proposals and by promoting inner team brainstorms and weekly meetings with a group of multidisciplinary coaches; (*ii*) effective communication by fostering intercultural and professional communication skills by producing multiple textual and media deliverables during the semester and the definition of the agenda, leading, reporting the achievements, and writing the minutes of the weekly project meeting with the panel of advisers; (*iii*) collaboration and team building by working together in multicultural and multidisciplinary teams; (*iv*) creativity and innovation by being expose to ill-defined open-ended problems, i.e., with very general requirements such as the budget, the applicable European Union (EU) directives, and the adoption of the International System of Units; (v) socio-professional ethics by tackling the related aspects of the project within the ETHDO module, with the writing of a dedicated report chapter, and the PROJE module, with the establishment of associated project requirements; and (*vi*) sustainable development by addressing all aspects related within the ESUSD and PROJE modules, resulting in the writing of a dedicated report chapter and the identification of related project requirements, respectively". Given these established results, the current work focuses exclusively on mapping student technical papers to UN SDG, rather than on the analysis of the EPS@ISEP programme and learning method.

Semi-automatic search of sustainability evidences by Duarte et al. (2020) adopts natural language processing to analyse how sustainability is addressed in the three EPS programmes in the Iberian Peninsula (Duarte et al, 2020). The data, collected from repositories and institutional websites between 2011-2015, consists exclusively of staff inputs (study programmes, project summaries and report templates) and team outputs (reports). The semi-automatic data analysis adopted includes: (*i*) the pre-processing of reports to remove student names, numbers, captions, template headings and irrelevant sections such as acknowledgements and references; (*ii*) the automatic generation of the term frequency (TF) list of reports with a natural language toolkit (NLTK); (*iii*) manual identification of the sustainability-related term-frequency (SRTF) list; (*iv*) creation of the reports' word clouds from the SRTF lists using WordClouds (Zygomatic, 2024) ; and (*v*) the generation of the co-occurrence network between the TF list of chapter parts and the SRTF list using KH Coder. This research concluded that Iberian EPS programmes are oriented towards sustainability and empower students with a vision of socially responsible action. The current work also performs text mining with the help of KH Coder, but this time looks specifically for SDG-related evidences exclusively on the selected EPS@ISEP project papers based on the Auckland list of keywords (University of Auckland, 2021).

EESD and academic success by Malheiro et al. (2022) analyses how EPS@ISEP simultaneously addresses these two essential educational goals - learning and academic success - by challenging engineering students to find innovative and sustainable solutions in a student-centred context (Malheiro et al, 2022). The study shows that this learning framework promotes academic success among engineering students and prepares them to become future agents of ethical and sustainable development. The main factor contributing to academic success is an increase in student motivation. This stems from identification with the real problems addressed, the empowerment and autonomy given by teamwork and the adopted ethics and the sustainability driven decision-making. These conclusions show the importance of adopting EESD to motivate students and, ultimately, improve academic success.

2.2 SDG Mapping

Previous research has investigated how academia instils ethics and sustainability into university programmes, capstone projects, internships and unit modules. The case of engineering education is of particular interest, since engineers are called to solve individual, social and global challenges that affect people and the environment. As such, their decision-making must be guided by ethical and sustainability principles and sound technical and scientific knowledge in order to create and apply viable solutions. In this context, the search for SDG-related evidences in scholarly publications and other documents, mostly through bibliometric and NLP-based approaches, has gained prominence in recent years. Bibliometric queries rely on lists of relevant keywords to measure the extent to which research, student, staff and institutional publications are related to SDG. However, interpreting SDG, defining relevance, and building queries remain challenging.

SDG search keywords for mapping or querying documents have been proposed by several higher education institutions, namely the University of Auckland, University of Toronto and Monash University, as well as other organisations like the European Union (EU), the Institut Teknologi Sepuluh Nopember from Indonesia and SIRIS Academic, among others. The Auckland list comprises 2321 terms based on the SDG mapping work conducted by Elsevier, Sustainable Development Solutions Network (SDSN), and United Nations (UN) (Wang et al, 2023). The Toronto University list from 2022 (University of Toronto, 2022) holds 393 terms. It is an updated version of the list proposed and used by Brugmann et al (2019) to perform a sustainability course inventory at the University of Toronto, which in turn is based on the larger SDSN list. The Monash list, also known as the SDSN list, contains a total of 914 terms. This list, compiled by Kestin et al., was applied to the course portfolio of the Monash University (SDSN Australia/Pacific, 2017). The EU-mapper list holds 185 terms to map texts to SDG and SDG targets (KnowSDGs Platform, 2024). The Institut Teknologi Sepuluh Nopember list from 2023 is a compilation of 846 terms inspired on prior lists suggested by the UN and SDSN (Institut Teknologi Sepuluh Nopember, 2023). SIRIS academic proposes a list of 3445 controlled terms that define the scope and breadth of SDG to tag and index textual records accordingly (Duran-Silva et al, 2019). These lists of SDG-specific keywords can be used to search through large sets of text data, such as research publications, course listings or student deliverables, allowing some degree of automation and benchmarking. Consequently, the current method reuses a publicly available list of SDG-related keywords.

SDG query-based search initiatives, like those lead by Aurora and Elsevier, attempt to identify SDG-related research landscape. The Aurora university consortium developed an SDG classification model to search for research output related to each of the SDG targets. The Aurora model offers sixteen executable queries built from a comprehensive and peer-reviewed list of keywords that relate to the 169 SDG-Targets within the 17 SDG-Goals (Aurora European Universities, 2024). The queries use the ASCM Supply Chain Dictionary Query Language, comprising keywords and advanced Boolean operators. The results are summarised through contingency tables. The SDG Research Mapping Initiative lead by Elsevier includes the University of Southern Denmark, Aurora consortium, and the University of Auckland. Together, they generated SDG mappings, which are search queries designed to map publications to SDG. This method is currently used by the SciVal platform and Times Higher Education

Impact Rankings to track progress toward SDG targets. The SDG Research Mapping Initiative defines a set of SDG queries to map research documents to SDG (Bedard-Vallee et al, 2023).

The current method also builds sixteen dedicated SDG queries to detect and count the corresponding SDG keywords in the project documents. These queries, specified as KH Coder rules, link the relevant Auckland keywords using Boolean operators. Similarly, the results are presented through contingency tables.

Methods to map scientific publications with SDG have been analysed by Kashnitsky et al. (2024). The authors contribute with a new methodology to mapping scholarly records to SDG and compares it against other nine SDG-to-research mapping approaches, using five hand-labelled validation data sets (Kashnitsky et al, 2024). The proposed method implements SDG-keyword queries, applies machine learning models for SDG classification and, finally, integrates the results of the queries and the models. The benchmarking results show that there is no single approach that is best for all datasets, nor is there a preferred validation dataset. Moreover, each dataset suffers from intrinsic deficiencies and biases resulting from the interpretations of SDG made by query creators. Based on this outcome, the current method adopts a SDG-keyword query-based method with the SDG-keyword data set produced by the University of Auckland (Wang et al, 2023), one of the mapping approaches considered in this benchmarking study.

Methodology for mapping and monitoring ESD by Adam et al. (2023) consists of a keyword analysis tool for measuring the presence of SDG-related content in educational modules (Adams et al, 2023). The keyword list, derived from the Auckland, Elsevier, EU-mapper, Monash and SIRIS lists, was purged of duplicate words, words absent from curricular metadata and low frequency words, resulting in 156 supportive and 66 focused keywords. In addition, this list of keywords was enriched with contextually relevant synonyms with the help of ChatGPT, improving the accuracy of the measurement of SDG coverage. The method was successfully applied to the curricula of the curricular offer of the University of Galway. The current method also explores an existing SDG-keyword list.

Comparison of society and student views on sustainability by Urushima et al. (2021) also implements a natural language approach to evaluate the correspondence between sustainability topics of interest to society in general and first-year Kyoto University (KU) students in particular, using text mining techniques (Urushima et al, 2021). The data, consisting of two sets, was collected from articles in the Asahi Shimbun newspaper, representing the vision of society on sustainability, and from student reports on sustainability, written as part of interdisciplinary science courses offered by KU. The two textual data sets were processed with KH Coder (Higuchi, 2024), considering word frequency and correspondence analyses, to investigate the effects of sustainability courses on the students and the relationship between the interests of students and the sustainability topics of interest to society. The results, visualised according to the frequency and co-occurrence of the appearance of words, show that after university learning, students became aware of their own individual role in neighbouring spheres of action and the sustainability views of students and the society partially overlap with different degrees of intensity. The current method also performs text mining with the help of KH Coder, considering the compound word frequency of the adopted SDG keywords.

3 EPS@ISEP

The European Project Semester at Instituto Superior de Engenharia do Porto (EPS@ISEP) (ISEP, 2024) is a semester-long student-centred engineering capstone programme that combines challenge-based learning, ethics- and sustainability-driven problem-solving, and international multidisciplinary teamwork to prepare engineering undergraduates to become future agents of ethical and sustainable development (Duarte et al, 2020). The programme empowers students to become lifelong learners and agents of sustainable development by providing them with the opportunity to work on autonomous project teamwork guided by ethics and sustainability concerns.

3.1 Syllabus

The syllabus comprises one 20-ECTU core module – Project (PROJE) –, four 5-ECTU project supportive modules – Project Management and TeamWork (PRMTW), Marketing and Communication (MACOM), Energy and Sustainable Development (ESUSD), and Ethics and Deontology (ETHDO) – and one 5-ECTU Portuguese Language and Culture (PORTU) module. In addition, there are two workshops dedicated to Design Thinking (12 h) and Technology (16 h) which were introduced in 2017 and 2015, respectively, based on student feedback. These activities are distributed by the 15-week period of the programme as follows:

[**W1**] Team building, as part of PRMTW;
[**W2**] Design Thinking Workshop;
[**W2-W6**] Energy and Sustainable Development (ESUSD), Ethics and Deontology (ETHDO), Marketing, as part of MACOM, and the Technical Workshop;
[**W2-W15**] Communication, as part of MACOM, Project, Project Management and Portuguese Language and Culture.

3.2 Milestones

The teams have to fulfil a total of 16 milestones (EPS@ISEP, 2024). The five main milestones correspond to the submission of the: (*i*) top-3 problems the team wishes to address from the list of open-ended problems on offer [end of W1]; (*ii*) team agreement with the top-3 conflict resolution strategies [end of W2]; (*iii*) submission of the mid-term report and presentation [end of W6]; (*iv*) hand-in of the final report and presentation, technical-scientific paper, leaflet, brochure, poster, video, and proof-of-concept prototype with a user manual [end of W13]; and (*v*) prototype demonstration [mid of W15].

The plenary events comprise the welcome session [W1], project presentation [W1], mid-term presentation and discussion [W7], final presentation, discussion and individual evaluation [W14], and closing session [W15] with prototype demonstration and certificate awarding.

3.3 Teams

The teams, composed of four to six students, are assembled in advance with diversity in mind. To do this, the staff considers the field of study, nationality, gender and team role of the participants.

The team role, defined by Belbin and Brown (2022) as "a tendency to behave, contribute and interrelate with others in a particular way" , is essential for understanding team dynamics and individual contributions within a team. They identified action-, thought- and people-oriented individuals and organised them into the nine profiles that underlie team success: monitor evaluator (thought-oriented), specialist (thought-oriented), plant (thought-oriented), shaper (action-oriented), implementer (action-oriented), completer/finisher (action-oriented), coordinator (people-oriented), team worker (people-oriented) and resource investigator (people-oriented). Moreover, they designed a tool – the Belbin test – to determine individual team roles.

The EPS@ISEP staff sends, before the start of the semester, the Belbin test to the accepted students and then forms the teams, ensuring that each team includes as many different skills, cultures, perspectives and team role behaviours as possible.

3.4 Learning Process

The team and project work are at the centre of the learning process. In this context, the project support modules contribute in various ways. Marketing and Communication, Energy and Sustainable Development and Ethics and Deontology force teams to consider ethical, market and sustainability implications in the ideation, requirements specification, design and development phases. Project Management and Teamwork helps teams implement Scrum, an agile project management framework, as a means of structuring and managing their work, while initial team building acts as an ice-breaking integration activity. In addition, the process and results of these project support modules are reported in specific chapters of the project report.

A panel of multidisciplinary coaches from the Chemical, Electrical, Informatics, Mathematics, Mechanics, Physics departments meets weekly with each team to discuss around a team-defined agenda for a team-led meeting. This coaching panel is essential to support the work of multidisciplinary teams as well as the development of multidisciplinary projects.

Project development has four main phases: (*i*) kick-off, with team formation, topic selection, ideation and initial design thinking; (*ii*) specification of requirements based on contextual analysis, including the state of the art, the market, sustainability and ethical dimensions; (*iii*) design of an innovative solution in line with the identified requirements; and (*iv*) creation of a proof-of-concept prototype, involving development, assembly and testing. Moreover, this approach is compliant with the CDIO framework as demonstrated in Malheiro et al (2015).

The learning process is fully documented. Throughout the semester, the teams maintain an online wiki, a collaborative tool that centralises, supports, presents the progress and, in the end, showcases the project work. The EPS@ISEP wiki is organised into six pages: Home, Milestones, Logbook, Deliverables, Report and About EPS. While the structure of the whole Wiki and Report page, as well as the contents of the Milestones and About EPS pages are defined in advance, the team has to add the agenda and minute of the weekly project meetings to the Logbook page, upload the finalised deliverables to the Deliverables page, and detail the project work in the Report page. The Report is organised into nine chapters: Introduction, State of the Art, Project Management, Marketing, Sustainability, Ethics and Deontology, Project Development, Conclusions and References.

3.5 Assessment

EPS assessment involves students, project coaches and module teachers. This means that, depending on the size of the team, an individual grade can have from 18 to 20 different contributors (4 to 6 students plus 14 staff).

The student self and peer assessment as well as detailed coach and teacher feedback occur at mid-term presentation [W7] and final presentation [W14]. The self and peer assessment questionnaire needs to be submitted by the eve of both presentations and comprises the following questions (Andersen, 2012):

Q1 What is your professional contribution to the work done?
Q2 What is your opinion of the group performance?
Q3 What is your contribution to the teamwork?
Q4 What is your opinion of the work done?

On the day of the final presentation, coaches also conduct interviews to fine tune individual Project grades. Other module teachers grade students based on their performance during the semester and on the quality of corresponding report chapters. The Portuguese language and culture grade is based on several small tests and deliverables.

3.6 Illustrative Projects

Most EPS projects display a strong pedagogical, ethical and sustainability orientation, promoting sustainable development skills among students and end users. Such projects fall under the scope of education, sustainable environment, food production and smart cities fields.

All projects include as mandatory requirements the need to reuse materials and components, adopt whenever possible open source solutions, comply with a predefined budget, the relevant EU directives and regulations on safety, electromagnetic compatibility, low voltage, radio equipment and hazardous substances. Many of the explored concepts involve the smartification, including web or mobile user interfaces, or automation of personal, household or public equipment.

Table 2 lists the selected illustrative projects, specifying their main field of application, their name and the SDG to which they contribute, as interpreted by the authors. This set of projects covers the period from 2012 to 2023.

3.6.1 Education

The following projects address mainly SDG 4 – Quality Education and comply with engineering, environmental, social and sales and marketing ethics.

Bro-Fish is a biologically inspired swimming robot as well as an educational toy for youngsters. The solution designed in 2014 adopts carangiform locomotion and controllable swimming, powered by an innovative tail mechanism that imitates the undulation of fish (Ishii et al, 2015). The tail is actuated by a motor connected to a low-cost microcontroller that regulates the motor's rotation speed via a motor driver. The robot allows children to experiment with the physics of floating objects by changing the shape and size of the fins and the tail. The children can also modify the speed of the tail motor.

Bubbles was designed in 2016 to introduce children to programming and robotics. The educational robotic platform has a cylindrical hull with a spherical transparent cap at the front and a flat tail at the back (Reinhardt et al, 2017). The body holds the electronics and a shaft connected to the tail via a crank mechanism, which converts rotational motion into oscillating motion.

The adopted programming language is based on Ardublock, a graphical block programming environment for Arduino that uses icons and colours to represent different commands and parameters. This simple and intuitive language allows children to: (*i*) control speed and direction; (*ii*) create loops and conditional statements; and (*iii*) obtain feedback on the overall status of the toy.

MATI is the Music and Technology Item, an interactive light and sound table for children that combines light and sound stimuli, controlled by hand movements over a table top (Reimus et al, 2013). The 2012 design comprises a control block, a sound block, and a table top with nine blocks, each with four LED and one infrared (IR) sensor to detect the hand position and distance.

Table 2 Main application field, project and addressed SDG categories.

Field	Project	Year	SDG
Education	Bro-Fish	2014	04 – Quality Education
	Bubbles	2016	04 – Quality Education
	MATI	2012	04 – Quality Education
Environment	Aquality	2018	03 – Good Health and Well-being 06 – Clean Water and Sanitation
	NAUTA	2013	13 – Climate Action
	Soasksy	2020	03 – Good Health and Well-being 13 – Climate Action
	Surf Logger	2014	13 – Climate Action
Food Production	EscarGO	2017	02 – Zero Hunger
	GREEN·flow	2022	02 – Zero Hunger
	INFAKIT	2022	02 – Zero Hunger
	Wormify	2021	02 – Zero Hunger 15 – Life on Land
Smart Cities	Billy	2018	03 – Good Health and Well-being 11 – Sustainable Cities and Communities 13 – Climate Action
	bin it.	2023	04 – Quality Education 11 – Sustainable Cities and Communities 12 – Responsible Consumption and Production
	GOairLight	2020	11 – Sustainable Cities and Communities 13 – Climate Action
	Suno	2017	07 – Affordable and Clean Energy 11 – Sustainable Cities and Communities

This 3D musical toy also selects different musical instruments and notes for each block using a music shield and a pair of speakers.

3.6.2 Environmental Monitoring

The following projects contribute to SDG 3 – Good Health and Well-being, SDG 6 – Clean Water and Sanitation, SDG 13 – Climate Action, and comply with ethical design and development practices.

Aquality is an intelligent solar-powered drifting buoy developed in 2018 by a five-student team to monitor the quality of the water in urban ponds and pools (Colen et al, 2019). The designed solution comprises the buoy, which collects and communicates via Wi-Fi the temperature and turbidity of the water to a cloud-based Internet of Things (IoT) platform, and the user mobile application, that displays the water temperature, air temperature, turbidity and water quality of the water body.

NAUTA is the Nautical and Telemetric Application Buoy designed in 2013 (Möller et al, 2013). It records, stores and broadcasts environmental data as well as beacon data for autonomous sailing platforms, both in real time. In environmental monitoring, the buoy gathers and stores data from underwater (conductivity, depth and temperature) and above water (temperature and wind) sensors and, in regatta mode, it becomes an active course mark for the autonomous sailing boats in the vicinity (Ferreira et al, 2015).

Soasksy is a floating trash collector for small water bodies that operates continuously and automatically (Serafia et al, 2022). Developed in 2020, it comprises two bins (external and internal) and three floaters, an ultrasonic sensor to measure the trash level, a water level sensor to measure the water level inside the bin and a temperature sensor that monitors the outlet of the pump. While floating on the surface of the water, the thin layer of water that slides into the inner container is pumped out through the bottom, retaining the rubbish in the inner container. The acquired data are processed, communicated and presented to the user on a website, constituting an educational and environmental tool.

Surf Logger is a low-cost, low-power, and waterproof solution created in 2014, comprising a device and a mobile application, that records, analyses and displays the surfing data. The cork-encapsulated device acquires and communicates via Bluetooth the speed, acceleration, orientation, and position of the surf board together with the internal temperature. Indirectly, it acts as a wave data probe. The mobile application displays in real time the surfing data, including map, historical and statistical data, and a 3D model of the surfboard's movement (Villota et al, 2014).

3.6.3 Food Production

The following projects support SDG 2 – Zero Hunger and SDG 15 – Life on Land and adopted ethical decision making.

EscarGO is a domestic smart snail farm for educational and food production purposes. Created in 2017, it includes as innovative features the use of curtains to increase the living space for the snails, the use of alginate microspheres to keep the soil moist and provide calcium, and the automatic control of the temperature, humidity and light inside the terrarium. The control system comprises a low-cost microcontroller, temperature, humidity, light and level sensors, a fan for air circulation, a heating device to warm the air, and water tank with a valve to moist the ground (Borghuis et al, 2018).

GREEN·flow is a smart home system designed to cultivate algae and fish based on algae-fish mutualism (Blomme et al, 2024), where the fish excrete nutrients into the water that the algae feed on and, in doing so, purify the water for the fish. Created in 2022, this app-controlled system features a modular structure with transparent tanks: one for the fish below and several illuminated tanks for the algae above. The water is periodically pumped from the fish to the algae tanks and returns back by gravity, passing through filters to remove debris. The mobile application allows the user to check the status (water level and temperature of the fish tank) and control (lighting of the algae tank and water pumping) GREEN·flow.

INFAKIT is a mealworm-farming kit to produce protein and fertiliser at home (Copinet et al, 2023). The kit, designed in 2022, is partly self-regulating, with sensors and microcontrollers to control the ideal conditions. It addresses the loss in soil quality, followed by the loss of biodiversity and depletion of water resources. Overall, the INFAKIT project aims to provide a sustainable food and soil enrichment solution based on insect farming, while adhering to ethical and sustainable practices.

Wormify is a web-monitored modular keyhole garden based on vermicomposting (Mendes et al, 2021). While vermicomposting, which is the process of using earthworms to convert organic waste into fertiliser, occurs in the central hole, the plants, which are fertilised with the compost, grow around it. Devised in 2021, it includes a structure, a control system and a website. The structure, made of wood, bamboo, and rope, has two concentric cylinders connected by tubes for the worms to move between the composting centre and the surrounding soil. Wormify communicates with a website that displays the data collected from the sensors and allows the user to remotely monitor the system.

3.6.4 Smart Cities

The following projects adopt a design and development practices guided by ethics concerns and fall into the scope of SDG 3 – Good Health and Well-being, SDG 4 – Quality Education, SDG 07 – Affordable and Clean Energy, SDG 11 – Sustainable Cities and Communities, SDG 12 – Responsible Consumption and Production, and SDG 13 – Climate Action.

bin it. is a waste management initiative that aims to address waste disposal and recycling issues across Europe (Bohon et al, 2024). The project aims to educate young adults about proper waste disposal and make waste management more attractive. It integrates a campaign, a web app and the Garbage Gladiator bin, a distinctive human-looking metal bin that attracts attention. The App comprises a map-based interface to add, confirm and search for bins, educational information about the type of bins available and recycling, and user functionalities like bin location validation, rank checking (points and badges) and user profile updating.

Billy is an urban sensing billboard created in 2018 that monitors and displays the air quality and other environmental parameters of public spaces. It comprises a renewable power source, environment and proximity sensors, Wi-Fi link to an IoT platform and provides map-based and screen interfaces to display local and remote air quality. As an educational tool, it provides useful information and advice on how to reduce carbon footprint and air pollution (Farrag et al, 2019).

GOairLight comprises a smart bicycle probe, powered by a dynamo, and a mobile app. Created in 2020, this bicycle handlebar probe collects and uploads urban air quality data to an IoT cloud platform. It is packed in a reusable waterproof bag and includes lighting, air and light sensors, a low-cost microcontroller, and rechargeable batteries. The mobile app downloads, stores, uploads and displays data collected by all probes as well as suggests less polluted routes to the user (Boularas et al, 2021). GOairLight raises awareness to the problem of air pollution and contributes to better health and environment.

Suno is a self-oriented solar mirror that tracks and reflects the Sun's radiation onto a predefined area (Simons et al, 2017). It was developed in 2017 for domestic lighting and heating. Suno features a square mirror attached to a frame supported by a central pole and base. The pole houses the electronics and holds the gearing system and azimuth shaft that automatically orientates the mirror frame. The user interface allows setting the position of the mirror, *i.e.* to focus of the reflected light onto the desired area.

Figure 1 uses logos to represent the selected projects (summarised above) together with the SDG categories addressed (according to the authors).

Fig. 1 Projects and addressed SDG categories.

4 Methods

This research builds upon the 4C2S analysis framework of Malheiro et al. (2019), which established that EPS@ISEP as a programme develops competencies related to sustainable development and socio-professional ethics, and the semi-automatic text mining method of Duarte et al. (2020).

The current method applies text mining to map EPS@ISEP team papers to the sixteen UN Sustainable Development Goals (SDG) using the list of SDG-related keywords proposed by the University of Auckland (University of Auckland, 2021). These keywords are grouped by SDG category to create sixteen SDG queries.

The mapping relies on SDG queries, contingency or co-occurrence analyses to characterise the links between SDG categories and the contents of project papers. This technique creates: (*i*) a contingency table, also called a cross-tabulation matrix, containing the observed counts of SDG categories within papers; and (*ii*) a co-occurrence network graphical representation of how frequently SDG categories appear in all papers based on the Jaccard coefficient. Figure 2 represents the proposed NLP-based processing pipeline, comprising data collection, pre-processing, processing and visualisation.

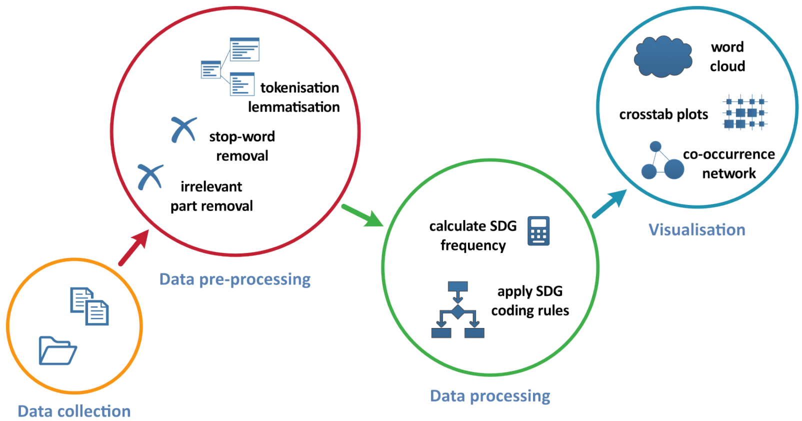

Fig. 2 NLP-based processing pipeline

Data collection from ISEP and Auckland University.

(*i*) Retrieves papers from the personal repository of the authors and extracts the text directly from the source files (Word files) or using the `detex` line command (LaTeX files).
(*ii*) Downloads the SDG-keyword list from the University of Auckland (2021).

Data pre-processing involves data filtering and cleansing.

(*i*) Removes irrelevant parts of each paper, such as author information, affiliation, figures, tables, acknowledgements and references, and stores the result in a text file (TXT).
(*ii*) Unifies the TXT files by field and globally, generating five data sets, with the help of KH Coder.
(*ii*) Applies traditional pre-processing steps, such as stop-word removal, tokenisation and lemmatisation, using KH Coder and reusing the default Stanford Part-of-Speech tagger.

Data processing relies on KH Coder[1] for text mining.

[1] KH Coder is a computer software package designed for quantitative content analysis and text mining. It is a versatile tool that allows researchers to explore and extract meaningful insights

(*i*) Calculates the frequency of occurrence of the SDG keywords in the data sets, taking into account the fact that most keywords are compound rather than single words. The results are exported as a CSV file for visualisation.
(*ii*) Applies the sixteen KH Coder coding rules to the different data sets, containing all, by field and individual papers, to generate the global, by field and individual results. These rules implement the SDG queries, connecting the SDG keywords of each SDG category with the appropriate Boolean operators. The coding rules map document contents to SDG, providing the input to create: (*i*) the contingency table known as frequency-based cross-tabulation matrix by KH Coder; and (*ii*) the semantic network referred to as co-occurrence network by KH Coder.

Visualisation of the SDG keywords and categories present in the analysed data sets:

(*i*) Word cloud of the SDG keywords found in the whole set of papers using an online generator.
(*ii*) KH Coder cross-tabulation bubble plots showing the relative frequency of SDG categories in individual papers as well as by project field.
(*iii*) KH Coder co-occurrence network graph displaying the coincidence of SDG categories in individual papers.

5 Results and Discussion

5.1 Results

The NLP-based pipeline applies the four stages of the method to project papers.

Data collection produces fifteen text files, one per project paper, and downloads the Auckland list of SDG keywords.
Data pre-processing generates the following text files:

(*i*) One file per paper (cleansing of irrelevant parts, like authors, affiliation, figures, tables, acknowledgements, and references). Figure 3 displays the relative size of the resulting files.
(*ii*) One global data set comprising the remaining parts of all papers.
(*ii*) One data set by field (education, environment, food production and smart cities).

Data processing performs the following analyses:

(*i*) Term frequency – calculates the frequency of occurrence of SDG keywords in the submitted data sets.

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from textual data, namely word clusters, descriptive statistics like term frequency, term frequency distribution (TF), document frequency distribution (DF), TF-DF plots, word association and co-occurrence network of words (Higuchi, 2024).

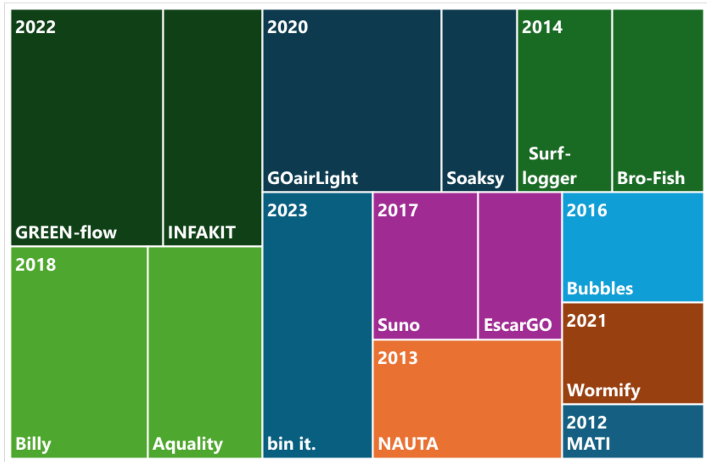

Fig. 3 Relative size of individual papers after cleansing.

(*ii*) SDG occurrence – calculates the relative frequency of SDG categories in the submitted data sets, using coding rules to group SDG keywords by category, and generates the corresponding contingency table and semantic network.

Result visualisation includes:

(*i*) Word cloud representing the SDG keyword frequency in the global data set (Figure 4).

Fig. 4 Word cloud of the SDG keywords found.

(*ii*) Number of SDG keywords discriminated per SDG category, paper, field and globally (Table 3) and the total number of SDG keywords per SDG category (Table 4).

Table 3 Cross-tabulation matrix of SDG categories by paper, field and globally.

Field	**Project**	**SDG**								**Sentences**
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
Education	Bro-Fish	0	0	1	3	0	4	0	2	261
	Bubbles	1	1	3	4	3	4	0	4	243
	MATI	0	0	0	1	0	2	0	0	118
Subtotal		1	1	4	8	3	10	0	6	622
Environment	Aquality	0	3	3	1	0	3	0	1	375
	NAUTA	0	0	1	0	3	4	1	0	346
	Soaksy	0	1	3	2	2	5	4	2	213
	Surf-logger	0	0	1	0	0	0	0	7	269
Subtotal		0	4	8	3	5	12	5	10	1203
Food Production	EscarGO	0	9	7	4	0	7	0	2	189
	GREEN-flow	0	15	2	3	2	13	1	10	559
	INFAKIT	0	15	6	2	3	7	2	7	366
	Wormify	0	44	8	6	0	7	0	12	224
Subtotal		0	83	23	15	5	34	3	31	1338
Smart Cities	Billy	2	1	5	0	0	2	3	2	447
	bin it.	0	0	3	12	4	12	1	3	453
	GOairLight	0	1	8	1	0	6	2	3	508
	Suno	0	8	1	0	4	6	4	8	240
Subtotal		2	10	17	13	8	26	10	16	1648
Total		3	98	52	39	21	82	18	63	4811

		9	**10**	**11**	**12**	**13**	**14**	**15**	**16**	
Education	Bro-Fish	7	0	1	2	4	0	9	0	261
	Bubbles	9	3	3	7	12	0	8	2	243
	MATI	4	0	0	5	1	0	4	0	118
Subtotal		20	3	4	14	17	0	21	2	622
Environment	Aquality	15	2	1	11	3	0	11	1	375
	NAUTA	8	0	0	1	0	2	11	4	346
	Soaksy	7	2	6	13	9	0	5	5	213
	Surf-logger	7	0	1	11	4	0	4	0	269
Subtotal		37	4	8	36	16	2	31	10	1203
Food Production	EscarGO	12	4	1	14	10	0	31	0	189
	GREEN-flow	16	4	4	18	15	0	8	5	559
	INFAKIT	13	4	5	16	13	0	9	2	366
	Wormify	23	5	20	32	15	0	13	5	224
Subtotal		64	17	30	80	53	0	61	12	1338
Smart Cities	Billy	10	2	11	22	9	0	3	1	447
	bin it.	14	5	37	17	31	0	7	3	453
	GOairLight	10	0	17	19	10	1	4	0	508
	Suno	11	0	4	19	14	0	8	5	240
Subtotal		45	7	69	77	64	1	22	9	1648
Total		166	31	111	207	150	3	135	33	4811

Table 4 SDG keywords per SDG category in the global data set.

Category	Keywords (#)	Description
SDG 12	207	Responsible consumption and production
SDG 9	166	Industry, innovation and infrastructure
SDG 13	150	Climate action
SDG 15	135	Life on land
SDG 11	111	Sustainable cities and communities
SDG 2	98	Zero hunger
SDG 6	82	Clean water and sanitation
SDG 8	62	Decent work and economic growth
SDG 3	52	Good health and well-being
SDG 4	39	Quality education
SDG 16	33	Peace, justice, and strong institutions
SDG 10	31	Reduced inequalities
SDG 5	20	Gender equality
SDG 7	18	Affordable and clean energy
SDG 1	3	No poverty
SDG 14	3	Life below water

(*ii*) Cross-tabulation plots of the SDG categories in the global data set. The colour of the ratio squares represents the Pearson relative standard deviation (RSD) and the area the relative size. Figure 5 presents the visual interpretation of the SDG contingency analysis by paper, and Figure 6 presents the

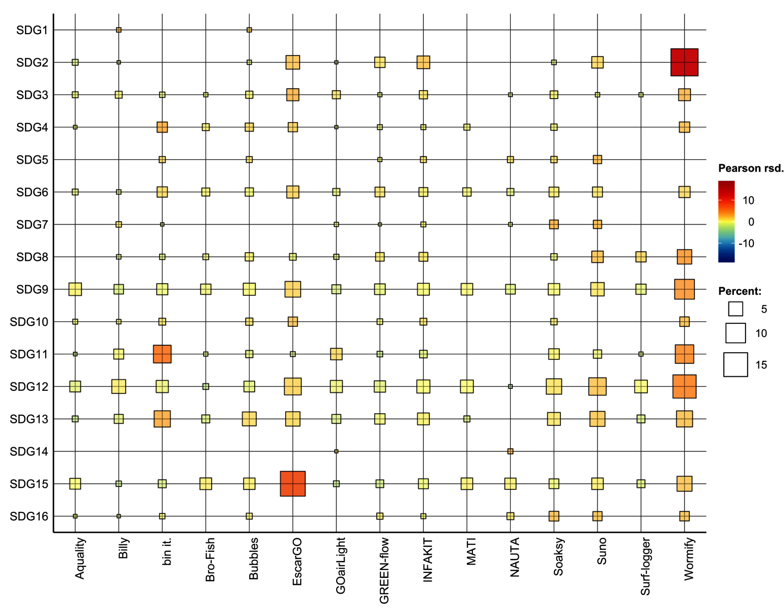

Fig. 5 Relative ratio of SDG categories by paper.

visual interpretation of the SDG contingency analysis by field.

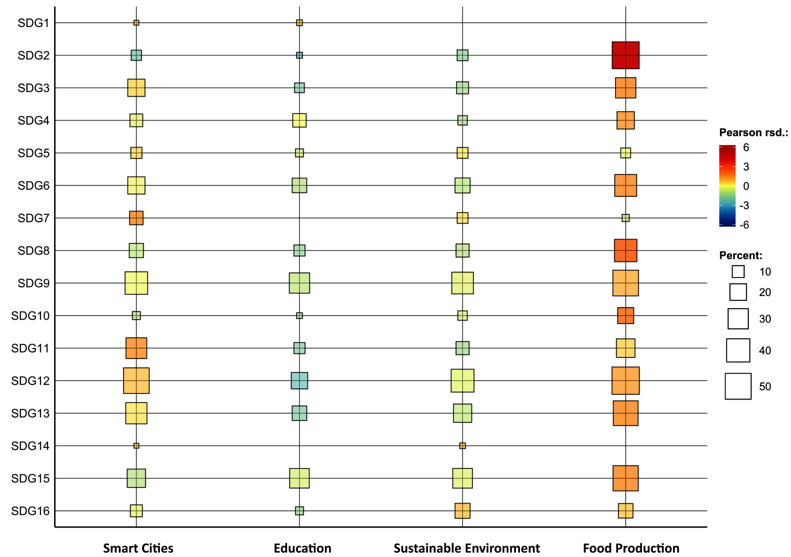

Fig. 6 Relative ratio of SDG categories by field.

(*iii*) Co-occurrence network graph between SDG categories and individual papers. The graph displays SDG categories as circular nodes, papers as rectangular nodes and the connections between categories and papers as edges. The circle area depicts the relative frequency of the SDG category within papers, whereas the colour codifies the number of connections between category and papers. Figure 7 presents the co-occurrence graph between SDG categories and papers.

5.2 Discussion

The proposed text mining method was applied to a data set made of the papers written by the EPS@ISEP teams. The decision to create SDG queries based on a keyword-based search designed for research documents was challenging. Not only these documents are more technical than scientific, but their size is typically smaller. Nonetheless, fourteen out of the fifteen papers analysed have been publish or accepted for publication in peer-reviewed conferences.

The results show that these documents contain evidence related to the SDG and therefore to the development of sustainability competencies. The word cloud in Figure 4 provides an overview of the keywords present in the global data set.

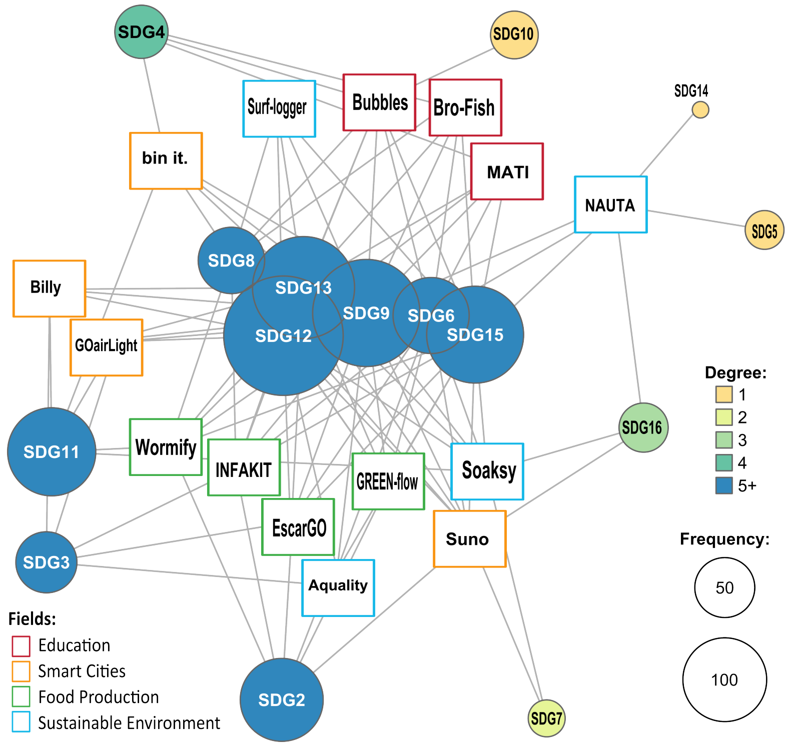

Fig. 7 Co-occurrence between SDG categories and individual papers.

The contingency analysis provides additional insights: (*i*) Table 3 quantifies the number of occurrences per SDG category by document, field and globally; (*ii*) Figure 5 shows the relative weight, considering all articles, of each SDG category by paper; and (*iii*) Figure 6 collates the same type of information by field. Both plots allow the comparison between the *a priori* SDG-interpretation of the authors in Table 2 and the text mining results based on the Auckland list of keywords. The main difference occurs in the consistent detection of SDG 9 – Industry, Innovation and Infrastructure in all projects and the faint presence of SDG 4 – Quality Education in the education field projects. In the latter case, the method detects instead a clear predominance of SDG 6 – Clean Water and Sanitation, since two of the projects are floating educational toys. The detection of SDG 9 in most papers can be explained by the fact that most EPS@ISEP projects, being engineering projects, have a strong technical component and attempt to apply technology in an innovative way.

The co-occurrence results in Figure 7 provide a global view of the communalities between SDG categories and EPS@ISEP papers. Most project papers address SDG 12 – Responsible consumption and production, SDG 9 – Industry, innovation and infrastructure, SDG 13 – Climate action, SDG 15 – Life on land, SDG 8 – Decent work and economic growth, and SDG 6 – Clean water and sanitation, indicating the development of comprehensive sustainability awareness and competencies.

6 Conclusions

This work succeeded in the mapping between the sixteen SDG categories and fifteen EPS@ISEP project papers, based on the University of Auckland's SDG-keyword list. The mapping results indicate the development of sustainability competencies and, ultimately, of EESD at the capstone level.

The proposed text mining method reuses the SDG-keyword list of the University of Auckland to perform an initial keyword frequency analysis as a way to verify the presence of SDG keywords in the data set, followed by a more sophisticated SDG category co-occurrence analysis. The latter executes SDG queries based on the keywords to identify the SDG categories within the documents analysed.

The contingency analysis confirms the *a priori* expected SDG categories by paper. The exceptions are the identification of SDG 9 in all documents and scant evidence of SDG 4 in the education field projects. This suggests that: (*i*) technology and innovation are pervasive in engineering projects; and (*ii*) the interpretations of the authors and the University of Auckland (2024) are misaligned regarding SDG 4. The method provided clear evidences that projects are aligned with UN SDG and, consequently, that participants developed sustainability competencies. The co-occurrence analysis captures student wide-ranging awareness of SDG, leading to the development of comprehensive sustainability competencies.

These findings reinforce the previous conclusions that EPS@ISEP implements EESD at the capstone level. Moreover, it indicates that this method can be applied to identify SDG evidences in syllabi and project briefs from staff as well as reports or papers from students.

The method is yet to be applied to publicly available annotated datasets for evaluation and benchmarking. However, as the method devised is based on third-party work – the list of SDG keywords by the University of Auckland (2024) and the KH Coder text mining tool by Higuchi (2024) – it is expected to present results similar to those reported by Kashnitsky et al (2024) with the same list of keywords.

In the near future, the plan is to: (*i*) automate and refine the proposed text mining method; (*ii*) experiment with keyword lists and data sets publicly available for evaluation and benchmarking; and (*iii*) apply the revised and evaluated method to the complete set of sixty papers produced from 2010 to 2024, to fully map EPS@ISEP projects and the UN SDG.

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